Agric Res J **60** (5) : 665-673, *October* 2023
DOI No. 10.5958/2395-146X.2023.00112.6

LONG TERM EFFECTS OF ORGANIC LAND USE SYSTEMS ON SOIL QUALITY IN A SEMI-ARID CLIMATE OF PUNJAB, INDIA

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ABSTRACT

The impact of five long term (10 years) organic land use systems viz. agroforestry (Poplar + turmeric (LS_1)), vegetables (bottle gourd – broccoli (LS_2)), basmati – wheat (LS_3), sugarcane fodder (LS_4) and maize + summer moong–wheat (LS_5) was studied on soil quality. Results showed that LS_1 has significantly higher soil organic carbon (SOC) content, mean weight diameter (MWD) of aggregates and soil moisture retention. Significantly higher soil pH, saturated hydraulic conductivity (Ks) and infiltration rate (IR) in LS_4, bulk density (BD) in LS_5 while significantly lower electrical conductivity (EC) in CS_3 were observed. The LS_1 has significantly better soil quality index (SQI) than all the other land use systems. The SQI was in the order of LS_1 > LS_2 > LS_3=LS_5> LS_4. The order of overall contribution of MWD, particle density, soil moisture retention, Ks and IR to SQI was 45.3, 29.3, 16.6, 6.4 and 2.5% respectively.

Keywords: Mean weight diameter, Particle density, Soil organic carbon, Soil moisture retention, Soil quality index

The increased food production worldwide has depleted the soil resources through intensive land use systems. Soil degradation (approximately 60%) due to increasingly intensive farming has been reported since the 1950s (Lal, 2015), with agricultural land use being one of the principal factors (Ray *et al.,* 2021). Over past few decades, intensive cultivation of rice-wheat system in Punjab to feed Indian population has led to soil degradation, which further declined the soil productivity (Aziz et al., 2013). Additionally, the viability of this agroecosystems greatly depends on soil quality (Raj *et al.,* 2023). Indiscriminate use of chemical fertilizers without additions of organic materials to soils leads to gradual decline in soil quality (Biswas *et al.,* 2014). Most research indicated that the application of organic manure in combination with inorganic fertilizers improve soil quality through linear increase in soil organic carbon (SOC) and improvement in soil physical properties (Brar *et al.,* 2015; Bassouny and Chen 2016). The decline in SOC in most of agricultural land use systems and the awareness towards the importance of global carbon budgets have boosted the interest in organic farming to enhance crop production and maintain soil quality under increasing world population and climate change conditions (Scialabba and Lindenlauf 2010; Williams *et al.,* 2017). The land use systems involving crop residue recycling (Blair *et al.,* 2006), manure application (Rudrappa *et al.,* 2005), conservation tillage (Six *et al.,* 2000) and mulching have been considered as an effective approach to increase storage of C in soil (Madari *et al.,* 2005). Soil organic carbon accumulation can improve soil quality by decreasing bulk density, surface sealing and crust formation, and by increasing aggregate stability and nutrient cycling (Karlen *et al.,* 2006). The labile or active pool of soil C has been shown to be more sensitive to soil management effects than total soil organic matter or organic C (Weil *et al*., 2003; Weil and Magdoff, 2004). Soil quality is inferred from changes in a number of soil quality indicators such as SOC level, aggregate stability, pH, electrical conductivity (EC), bulk density (BD), water holding capacity, saturated hydraulic conductivity and infiltration rate (Malik *et al.,* 2014; Williams *et al.,* 2017). There is thus a need to improve the understanding of how different organic land use systems contribute to changes in these soil properties. Land use systems that maintain and improve levels of SOC may also improve soil quality. One of the ways of assessment of soil quality is through soil quality index (SQI). The SQI is a measurable soil parameter that affects the capacity of a soil to perform a specific function (Karlen et al., 2006). Therefore, in the present study the long term effects of organic farming in different land use systems on changes in soil organic carbon and soil properties related to soil quality were studied.

MATERIALS AND METHODS

Description of the study area

The research work was conducted at *Bhagat* Puran Singh (BPS) Natural Agriculture Farm and Research

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Date of receipt: 09.01.2023, Date of acceptance: 18.07. 2023

Centre, Dherekot, Jandiala Guru, Amritsar (31^0 34' 24″ N, 75^0 03' 58″E) situated at an altitude of 236 m above mean sea level. The total area of the organic farm is 12 ha. The impact of long term five organic land use systems viz. agroforestry (15 year poplar + turmeric as intercrop (LS_1)), vegetables (15 years bottle gourd – broccoli (LS_2)), basmati – wheat (10 years, LS_3), sugarcane fodder (3 years, LS_4) and maize + summer moong (cover crop) – wheat (6 years, LS_5) was studied on soil physico-chemical properties and buildup of soil organic carbon.

The farm has a herd (20) of *Sahiwal* cows. In all these land use systems, none of chemical fertilizer, herbicide and pesticide was used. Instead, different crops were grown with the application of locally prepared compost, *jivamrita/jeevamrutha, bijamrita* prepared at the farm (Badwal *et al.,* 2019) and mulching of paddy straw (9 Mg ha^{-1}) to supply nutrients. Other important principles for crop growth were intercropping of legumes and use of local species of earthworms. The pest management was done through the use of *agniastra*, the *brahmastra* and the *neemastra* (Badwal *et al.,* 2019). Experiment was designed in CRD with four replications.

Description of major organic land use systems

Agroforestry (LS1)

The poplar (*Populus deltoides)* + turmeric as intercrop are being practiced in cycle since fifteen years on 0.4 ha. After every 5 years poplar plants are harvested. Every year turmeric was sown as inter crop in the poplar upto 4 years age during the month of April and harvested by the end of December (from 2003 to 2018). Before sowing of turmeric (*Curcuma longa*) two preparatory tillage operations with cultivators were done. Two rows of turmeric were sown on 37.5 cm wide beds with plant to plant spacing of 18 cm. Paddy straw mulch was applied at 9 Mg ha^{-1} after the first irrigation. No other chemical fertilizer was added. Irrigation was applied in the rows as and when required. Poplar was harvested after 5 years age and turmeric is grown as intercrop.

Vegetables (LS2)

Vegetables were grown since 15 years (from 2003 to 2018). Preparatory tillage with cultivator followed by rotavator was done before sowing of bottle guard *(Lagenaria siceraria)* and broccoli *(Brassica oleracea var. italica)* in the inter row spacing. Bottle gourd was sown during the month of March and harvested in September. Broccoli was transplanted in the month of October after bottle gourd and harvested in December to February. Only organic manures (added through compost @ 5 Mg ha^{-1} + *Jeeva Amrita*) were used to raise vegetables and sugarcane. Vegetables were grown as intercrops in 12' space between sugarcane rows.

Basmati rice – wheat (LS3)

Basmati rice (Pusa Basmati 1121 var.) was transplanted in the month of July and harvested in October on 1 ha. After incorporation of basmati straw with discing+ rotavator, wheat (Sona moti var) was sown in eight rows on 120 cm beds with 30 cm wide furrows for 10 years (from 2008 to 2018). Before sowing of basmati *Dhaincha* green manure was incorporated with rotavator during puddling and no any manure or fertilizer was added. Residue of basmati was incorporated before sowing of wheat and no any fertilizer was applied to wheat No any insecticide or weedicide was applied to basmati or wheat. Manual hoeings were done to control weeds.

Sugarcane fodder (LS4)

Sugarcane fodder (KRFo93-1 var.) was sown on 75 cm beds at 75 cm plant to plant spacing during 2016 (after preparatory tillage with cultivator) and it was a 3-year ratoon crop (2017-19) on 0.5 ha plot. During three years no any tillage operation was carried out in sugarcane fodder. Manures (compost @ 5 Mg ha^{-1}) were applied through irrigation water.

Maize+ summer moong – wheat (LS5)

After harvesting of wheat in the month of April, maize (var. local) was sown (after one preparatory tillage with rotavator) on 0.5 ha at a 60 cm row to row spacing and two rows of summer moong (SML 668 var.) were sown as inter/cover crop in maize every year. After maize, wheat was sown (after preparatory tillage of one discing+rotavator) in October as 8 rows on the beds (120 cm width and 30 cm furrow).

The cow dung and urine were collected every day to prepare compost (having nitrogen 0.8 percent) of the farm waste using natural water from an artificial wetland which contains natural microbes. Before applying irrigation tube well water was mixed with cow urine and wetland water (containing natural bacteria, fungi etc). Mostly sprinkler system was used for irrigation at different time intervals as and when required.

Soil sampling and analysis

The soil samples were collected from four sites and four depths (0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm) under each land use system after the harvest of *rabi* (2018-19) and *kharif* crops during 2019. The collected soil samples were dried, grounded and passed through 2-mm sieve for analysis. Particle size distribution at each soil depth was measured by International Pipette Method (Blake and Steinhardt, 2008). The soil pH was determined from 1:2 soil: water suspension with Elico-glass electrode pH meter (FAO, 2021). The electrical conductivity (EC) of 1:2 soil:water suspension of soil samples was recorded using conductivity meter (Richards 1954). The SOC was estimated by dichromate wet oxidation procedure (Walkley and Black 1934). Soil bulk density (Mg m^{-3}) was measured using metallic cores having inner diameter of 6.8 cm and height of 7.5 cm as per procedure described by Blake and Hartge (1986). Different size soil aggregates (percent) were determined using wet sieving method (Yoder 1936). The mean weight diameter (MWD) of the soil samples (Youker and McGuinness 1956) was computed as:

$$\text{MWD (mm)} = (\textstyle\sum^{n}_{i=1} d_i \times w_i) / (\sum^{n}_{i=1} w_i) \quad (1)$$

where, di, is mean diameter of i^{th} size fraction in mm, n is number of size ranges, w_i is the weight of aggregates of size fraction in g. The soil moisture characteristics curve was prepared for each sample collected from different depths and land use systems using pressure plate apparatus (Richards, 1949) with application of 10, 30, 50 100, 200, 300 and 1500 kPa pressure.Saturated hydraulic conductivity (Ks) of undisturbed soil cores taken from different land use systems and soil depths was calculated using Darcy's equation as given below and detailed by Reynolds *et al.,* (2002).

$$\text{Ks} = (\text{Q} \times \text{L}) / \text{At (H+L)} \quad (2)$$

where Q is the volume of water percolated in cm^3, A is the cross-sectional area of the core in cm^2, 't' is time of percolation in minutes, L is the length of core in cm, H is the height of water above soil surface in the core in cm. *In-situ* infiltration rate of the soil was measured, after the harvest of crops in the month of May 2019 and December 2019 in all land use systems using double ring infiltrometer (Reynolds *et al.,* 2002).

Selection of indicators

The selection of the soil quality indicators was made using principal component analysis (PCA). The PCA with varimax rotation was performed using SPSS 10 for soil properties and derived indices. Principal components (PC) with eigenvalues ≥1 were selected since PC with eigenvalue <1 account for less variation (Armenise *et al*., 2013). Under each PC, highly weighted variables were selected as soil quality indicators. Multivariate correlation coefficients were used to check for redundancy and correlation between the variables. If the variables were well-correlated (r > 0.70), then the variable with the highest factor loading (absolute value) was retained as an indicator. The soil quality index (SQI) was calculated as

$$\text{SQI} = (\textstyle\sum^{n}_{i=1} w_i S_i) \quad (3)$$

where Wi is the principal component analysis (PCA) weighing factor and Si is the indicator score.

Each PC explained a specified amount (%) of the variation in the total dataset. The percentage of variance from each PC was divided by the total cumulative variance percentage to derive the weightage factor. The derived weightage factor was used with selected variables (indicators) from respective PCs. When more than one variable was retained under a single PC, multivariate correlation was employed to determine if the variables could be considered redundant and, therefore, eliminated from the SQI (Andrews *et al*., 2004). If the highly loaded factors were not correlated then each was considered important, and thus, retained in the SQI. Among well-correlated variables, the variable with the highest factor loading (absolute value) was chosen for the SQI.

Scoring of indicators

Selected indicators in the minimum data set (MDS) were scored into dimensionless values ranging from 0 to 1 using the linear scoring method (Liebig *et al*., 2001). Indicators were ranked in ascending or descending order depending on whether a higher value was considered 'good' or 'bad' in terms of soil function. For 'higher is better' indicators, each value of indicator was divided by the highest value such that the highest value received a score of 1. For 'less is better' indicators, the lowest value was divided by each data value such that the lowest value received a score of 1. For indicators like hydraulic conductivity and infiltration rate 'optimum' threshold value was considered. They were scored as 'higher is better' up to a threshold value then scored as 'lower is better' above the threshold. The numerical data of the selected indicators were normalized from 0.1 to 1.0 using equation 4 for 'more is better' indicators, and equation 5 for the 'less is better' indictors.

Linear scoring function

Because of different indicator units, scoring functions (eq. 4 and 5) were used to score soil indicators. The linear scoring functions are widely used for scoring the data of selected indicators (Liebig et al., 2001) as explained above. These functions are explained as:

$$Y = (x-s)/(t-s) \quad (4)$$

$$Y=1- (x-s)/(t-s) \quad (5)$$

where Y is the linear score, x the soil indicator value, s and t are the lower and upper threshold soil indicator values. Equation (4) is used for 'More is better' scoring function, Equation (5) for 'Less is better' and a combination of both for 'Optimum' scoring function. If the calculated score is >1.0, it was considered as 1.00.

Statistical analysis

Data were all analysed using analysis of variance at a 0.05 level, with SPSS10.0 for Windows (SPSS Inc., Chicago, USA). One-way analysis of variance (ANOVA) procedures was used to test for significant differences in variables among treatments.

RESULTS AND DISCUSSION

Soil properties

Soil particle size analysis (Table 1) of the experimental area revealed that soils were sandy loam in texture. However sand content was significantly higher in LS_4 and LS_5 compared to LS_1, LS_2 and LS_3 while LS_4 and LS_5 were at par. There was no significant difference in silt content among cropping systems. Clay content was significantly higher in LS_1 and LS_2 compared to other land use systems while these both were at par.

The data of SOC (Table 1) of both the seasons was pooled and found that LS_1 has significantly higher values than LS_2, LS_3, LS_4 and LS_5. However no significant differences in SOC were observed in LS_2, LS_3 and LS_5 but these have significantly higher SOC than LS_4. Higher SOC in LS_1 could be due to the higher biomass addition by mulching with paddy straw in turmeric and addition of leaf litter of poplar during winter months particularly in the surface soil layers and higher clay content. Similar results have been reported by Barreto *et al.,* (2011) and Benbi *et al.,* (2012) where total organic carbon (TOC) was higher in soils under agroforestry systems. The lower SOC in LS_4 may be due to less addition of organic manures in *ratoon* sugarcane fodder compared to other land use systems having greater number of crops per season which can add more carbon in the top 30 cm soil (West and Post 2002). Significantly higher pH was observed in LS_4 than LS_1, LS_2, LS_3 and LS_5 may be due to calcareous nature of the soil (Taalab *et al.,* 2019). No any significant difference in pH was observed between LS_1 and LS_5. Soil pH of LS_3 was significantly lower than all other land use systems. Lowering of soil pH of alkaline soil in basmati-wheat land use system may be attributed to effect of puddling (Fageria *et al.,* 2011) and submergence (Sharma *et al.,* 2015) compared to poplar-based land use system. Significantly lower EC was observed in LS_3 than LS_1, LS_2, LS_4 and LS_5 (Table 1). No any significant difference in EC was observed among LS_1, LS_2, LS_4 and LS_5. The increase in soil EC as impacted by manure addition might be due to the high amount of dissolved salts in the manures (Ozlu and Kumar 2018). The decrease in EC in LS_3 may correspond to leaching of soluble salts in basmati. Among land use systems, LS_3 has significantly higher bulk density than LS_1, LS_2 and LS_5. However, no significant difference in BD was observed in LS_3 and LS_4 land use systems. Higher bulk density in LS_3 may be attributed to compaction during puddling (Singh *et al.,* 2009). Lower bulk density in LS_1 may be attributed to addition of more organic carbon (Table 1). Similarly, Ramanandan and Jogan (2019) observed lower BD in organic farming compared to conventional farming. LS_3 has significantly higher particle density than LS_1, LS_4 and LS_5. The particle density was correlated negatively with soil organic carbon (Blanco-Canqui *et al.,* 2006). Higher particle density in LS_3 may be due to more churning of soil during tillage. However no significant difference in PD was observed in LS_2 and LS_3. Significantly higher MWD of soil aggregates was observed in LS_1 has than LS_2, LS_3, LS_4 and LS_5 (Table 1). However no significant difference in MWD was observed in LS_3 and LS_5 but MWD in these cropping systems was significantly higher than LS_4. The order of decrease in MWD with

Table 1. Soil quality indicators under different cropping systems

Soil properties	Cropping systems					LSD (0.05)
	LS_1	LS_2	LS_3	LS_4	LS_5	
Sand	54.7	56.4	56.8	61.2	59.1	2.8
Silt	27.6	26.7	28.8	28.6	27.6	NS
Clay	17.7	17.0	14.5	10.2	13.1	2.3
Organic carbon (g kg^{-1} soil)	8.8	7.3	6.3	4.9	6.8	1.1
pH	7.77	7.92	7.51	8.13	7.75	0.18
Electrical conductivity (dS m^{-1})	0.1676	0.1703	0.1214	0.1562	0.1554	0.031
Bulk density of soil (Mg m^{-3})	1.64	1.68	1.75	1.71	1.66	0.06
Particle density (Mg m^{-3})	2.69	2.74	2.80	2.72	2.67	0.07
Mean weight diameter of soil aggregates (mm)	0.412	0.337	0.247	0.202	0.269	0.041
Saturated hydraulic conductivity of soil (mm h^{-1})	2.8	1.9	1.0	61.3	8.5	1.67
Soil porosity (%)	38.8	38.5	36.9	36.8	37.8	NS

Table 2. Effect of different land use systems on soil water retention (percent v/v) at different soil moisture potentials

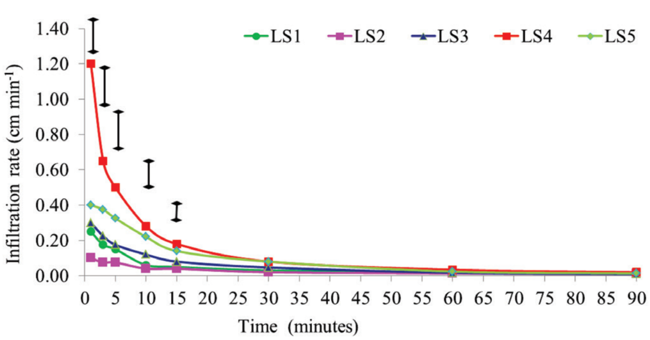
Soil moisture potential (-kPa)	Cropping systems					LSD (0.05)
	LS_1	LS_2	LS_3	LS_4	LS_5	
10	26.9	26.1	20.8	19.9	22.9	1.98
30	20.3	20.1	16.0	15.5	18.3	1.47
50	17.6	17.7	14.4	13.7	16.1	1.44
100	14.5	14.9	13.1	11.7	14.1	1.32
200	12.5	12.6	11.7	10.2	11.6	1.33
300	10.7	10.7	10.3	9.2	9.5	NS

different cropping systems is LS_1>LS_2>LS_5>LS_3>LS_4.

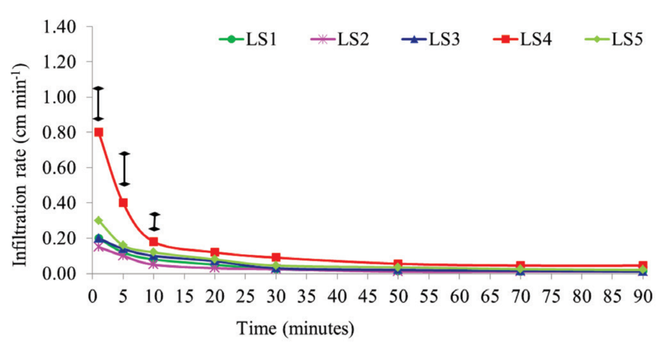
The order of decrease in saturated hydraulic conductivity (Ks) with different land use systems is LS_4 > LS_5 > LS_1 > LS_2 > LS_3 (Table 1). The Ks differed significantly among land use systems. LS_4 has significantly higher Ks than LS_1, LS_2, LS_3 and LS_5. Higher Ks in LS_4 may be due to more macropores in light textures due to decay of roots during ratooning. Similarly, Singh *et al.,* (2009) also reported higher Ks in soils having more sand content. LS_3 has significantly lower Ks than LS_1 and LS_4. This may be due to more micropores due to puddling. Similarly Singh (2011) reported significantly lower Ks in puddled soils compared to unpuddled soils. The Ks was at par in LS_1 and LS_2 but these land use systems have significantly lower Ks than LS_4 and LS_5. No significant difference in total soil porosity was observed among land use systems.

The pooled data of two seasons pertaining to soil moisture characteristics in different land use systems is presented in Table 2. Pooled data of cropping systems showed that LS_4 has significantly lower soil moisture at 10, 30, 50, 100 and 200 kPa compared to LS_1, LS_2 and LS_5. The lower soil moisture at different soil matric potentials (SMP) in LS_4 may be due to lighter soil texture and less organic carbon. Similar results have been reported by Nath (2014) and Singh et al., (2009). At 10, 30 and 50 SMP matric potential LS_1 and LS_2 has significantly higher soil moisture compared to LS_3 and LS_5 land use systems. This may be due to more aggregation in LS_1 and LS_2 which favours moisture retention at lower suctions. Similar results were reported by Guber *et al*., (2004) where soil water retention can be predicted from soil aggregation.

The data pertaining to infiltration rate (IR) in different land use systems in two seasons is presented in Fig 1. Generally, IR was more after *rabi* than *kharif* season. This may be due to lower initial moisture after *rabi* than *kharif* season. After *rabi* season the initial infiltration rate was 1.2, 0.4, 0.3, 0.25 and 0.1 cm min^{-1} in LS_4, LS_5, LS_3, LS_1 and LS_2, respectively. After 1, 3, 5, 10 and 15 minutes IR was significantly higher in LS_4 compared to all other land use systems. Significantly higher infiltration rate in LS_4 may be due to bypass flow of water in decaying root channels of ratoon sugarcane fodder crop and lighter soil texture having more macropores. Increase in IR with inclusion of perennial crops in rotation has also been reported by Basche and DeLonge (2019). Infiltration rate was also significantly higher in LS_5 compared to LS_2. The higher infiltration in LS_5 may be due to more proliferation of roots of intercropped summer moong in surface soil. The lowest IR in LS_2 may be attributed to higher initial moisture content due to more organic carbon compared to LS_4 and LS_5. Afterwards no significant difference in



(a)



(b)

Fig. 1. Effect of long-term organic farming in different cropping systems on infiltration rate of soil after a) *rabi* (2018-19) and b) *kharif* (2019) seasons

IR among different cropping systems was observed. After *kharif* season the initial infiltration rate was 0.8, 0.3, 0.2, 0.2 and 0.15 cm min^{-1} in LS_4, LS_5, LS_3, LS_1 and LS_2, respectively. After 1, 5 and 10 minutes, IR was significantly higher in LS_4 compared to all other land use systems. Afterwards no significant difference in IR among different land use systems was observed.

Principal Component Analysis

The results obtained from PCA indicated five PCs with eigenvalues >1 (Table 3) and soil variables from each PC were considered for MDS. The soil parameters selected from PC1 were MWD, OC, BD, EC and pH. However, multivariate correlation between these parameters indicated high correlation (Table 4) and only MWD which has the highest factor loading (0.927) was retained in the MDS. Soil HC, pH, EC and infiltration rate were chosen from PC2 and after correlation results (Table 4) only HC was included in MDS having highest factor loading of 0.841. In PC3, only particle density was selected having factor loading of 0.849. Soil moisture retention at 10 to 300 kPa and IR were selected as indicators from PC4 and PC5, respectively since they were highly weighed parameters. Among the selected parameters MWD is independent of particle density and hydraulic conductivity but has a positive relation with water retention and infiltration rate. Hydraulic conductivity is independent of particle density but has positive relation with IR and negative relation with soil water retention. Particle density is independent of soil moisture retention and infiltration rate. The amount of variability explained by PC1 was 34.98%, with an eigenvalue of 3.499, which includes the MWD with the highest positive factor loading value (Table 3). The second component (PC2) explained about 17.23% of variance, with an eigenvalue of 1.723 and the highest positive loading value for Ks with positive factor loading. The third component explained about 11.91 % of variance with eigenvalue of 1.191 and the highest value for particle density. The fourth (PC 4) and fifth component (PC 5) explained variance of 11.04 and 10.98 % with eigenvalues of 1.104 and 1.098 respectively. The cumulative variance explained by the selected PCs was 86.14.

Soil quality index

The calculated soil quality under different organic cropping systems was compared using SPSS 10. The higher index values implied that soil quality under that cropping system is better as compared to other cropping systems. The SQI representing the overall state or condition of the soils under different land uses varied from 0.372 to 0.575 (Fig. 2). The results indicated that LS_1 has significantly better soil quality index (SQI) than all other land use systems. Soil quality of LS_2 was also significantly higher than LS_3, LS_4 and LS_5. SQI of LS_3 and LS_5 was at par but significantly higher than LS_4. So the SQI of LS_4 was significantly poor than all other land use systems. Soils under agro-forestry land use had the highest SQI value of 0.575, followed by vegetables (0.517), maize+legumes-wheat (0.451), basmati-wheat (0.431) and sugarcane fodder (0.372). This indicated that paddy straw mulching coupled with leaf litter improved soil properties. The order of overall

Table 3. Component matrix of soil quality determinant for organic cropping system

Parameter	PC1	PC2	PC3	PC4	PC5
Eigenvalue	3.499	1.723	1.191	1.104	1.098
Variability (%)	34.98	17.23	11.91	11.04	10.98
Cumulative %	34.98	52.21	64.12	75.16	86.14
Weight	0.42	0.21	0.16	0.13	0.11
Variable			Factor loading		
Saturated hydraulic conductivity	-0.065	<u>0.841</u>	0.144	-0.030	0.034
Organic carbon	0.768	-0.175	-0.283	0.069	0.227
Bulk density	-0.863	-0.341	-0.062	0.049	-0.074
Electrical Conductivity	0.667	0.363	-0.011	0.040	-0.328
pH	-0.456	0.502	0.080	0.417	-0.387
Mean weight diameter (MWD)	<u>0.927</u>	-0.011	-0.125	-0.033	0.042
Soil porosity	0.667	0.161	0.568	-0.077	-0.038
Soil water retention	0.328	-0.304	0.092	<u>0.844</u>	0.059
Particle density	-0.127	-0.274	<u>0.849</u>	-0.030	0.215
Infiltration rate	-0.280	0.539	-0.112	0.167	<u>0.708</u>

Underlined factors loading consider highly weighted, PC = principal component

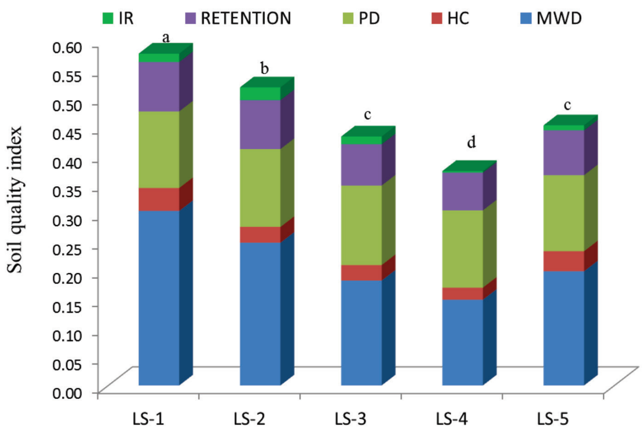


Fig. 2. Soil quality index based on principal component analysis under different land use systems

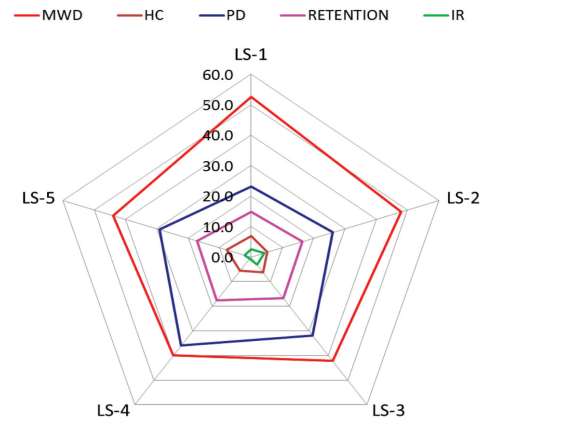


Fig. 3. Radar graph depicting the percent contribution of selected key indicators to soil quality as influenced by land use systems

Table 4. Correlation matrix of soil quality parameters (n = 160)

Variable	HC	OC	BD	EC	pH	MWD	Porosity	Retention	Particle density	Infiltration rate
HC	1									
OC	-0.198	1								
BD	-0.217	-0.540	1							
EC	0.164	0.363	-0.583	1						
pH	0.308	-0.386	0.258	-0.031	1					
MWD	-0.101	0.751	-0.774	0.579	-0.402	1				
Porosity	0.109	0.270	-0.671	0.390	-0.181	0.504	1			
Retention	-0.193	0.269	-0.161	0.098	-0.084	0.238	0.161	1		
Particle density	-0.099	-0.146	0.169	-0.151	-0.044	-0.164	0.205	0.051	1	
Infiltration rate	0.336	-0.139	0.039	-0.117	0.227	-0.218	-0.179	-0.126	-0.047	1

Values in bold indicate significance at the P <0.05 level

Saturated hydraulic conductivity (HC), organic carbon (OC), bulk density (BD), electrical conductivity (EC) and mean weight diameter (MWD)

contribution of the selected indicators to the SQI was 45.3, 29.3, 16.6, 6.4 and 2.5% by MWD, particle density, soil moisture retention, saturated hydraulic conductivity and infiltration rate respectively (Fig. 3). The highest contribution of MWD to SQI was 52.6, 47.9, 42.1, 40.0 and 43.9 % in LS_1, LS_2, LS_3, LS_4 and LS_5 respectively. Particle density contributed to SQI by 23.1, 26.1, 31.9, 36.0 and 29.2 per cent in LS_1, LS_2, LS_3, LS_4 and LS_5 indicating more contribution of particle density in LS_4. Saturated hydraulic conductivity and infiltration rate contributed almost same in all land use system.

In conclusion, maximum carbon sequestration was observed in land use systems having paddy straw mulch and leaf litter recycling during every year which further resulted improvement in mean weight diameter, bulk density, pH, electrical conductivity and moisture retention of soil. The improvement in soil physical properties was maximum in poplar + turmeric followed by vegetables (bottle gourd – broccoli), maize + summer moong – wheat, basmati – wheat and sugarcane fodder land use systems. Soil structural stability indicator MWD tended to decrease with increase in sand (%), silt (%) and bulk density and increased with the increase in clay (%), organic carbon and EC. The cropping system of sugarcane fodder has higher saturated and unsaturated hydraulic conductivity due to development more number of root channels due to decay of roots. SQI was significantly higher in LS1 than other land use systems. Maximum contribution to SQI was by MWD indicating a good quality indicator for assessment of soil quality.

Authors' contribution

Conceptualization of research work and designing of experiments (JK, DS); Execution of field/lab experiments and data collection (JK); Analysis of data and interpretation (JK); Preparation of manuscript (JK, DS)

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