Soil Quality Index for Different Cropping Systems in Northwestern Himalaya Region of India

ABSTRACT

Background: A study was conducted to examine the impact of soil quality under different cropping systems in Mid hill conditions of Himachal Pradesh". The study was carried out to ascertain the physical, chemical and biological properties of soils under prevalent cropping systems maize- wheat, rice- wheat and vegetable based in different in mid hill conditions of northwestern Himachal Pradesh.

Method: On the basis of representative 90 soil samples from two depths i.e. 0-0.15 m and 0.15-0.30 m were collected. Soil samples were analyzed for their physical, chemical and biological properties and key indicators were identified using multivariate statistical analysis for computing the soil quality index. Wide variations in the soil health indicators were observed among different sites.

Results: Soil reaction across various sites under present study was 5.30-6.70. Higher salt accumulation (EC) was observed under vegetable based cropping systems as compared to those of cereal based. Organic carbon was medium to high and available N, P and K contents were in low to medium range. DTPA Fe, Mn, Zn and Cu were observed sufficient, whereas total Fe, Mn, Zn and Cu were recorded higher in cereal and vegetable based cropping system. Microbial biomass carbon, microbial biomass nitrogen, potentially mineralizable nitrogen and soil respiration were low to medium in all cropping systems.

Conclusion: Soil quality index was 1.00 under vegetable based cropping system as compared to the cereal based cropping systems

Keywords: *Assessment Soil quality, Cropping systems, Mid hill, India*

1. INTRODUCTION

Himachal Pradesh, is a mountainous region spread over an area of 55,673 km² with elevation ranging from 350 to 6,500 meters above mean sea level noticeably increased from west to east and south to north. The State categorized into four agro-climatic situations viz. low hills, mid hills sub humid, high hills temperate and high hills dry temperate. Mid hill zone extends from 65 to 1,800 meters above mean sea level. This zone occupies about 8% of the total geographical area and about 37% of the cultivated area of the state mainly having brown soils. (6).

In India, the rice – wheat is the most extensive and traditional cropping system which has become the mainstay of cereal production in the country. It occupies an area of about 737.91 lakh hectare (4). The prominent cropping systems of India are Rice - Wheat (11 m ha), (39), Maize - Wheat (1.86 m ha), (…), and Pearl millet -Wheat (2.26 m ha), (54). In India, maize is cultivated in an area of 8.69 million hectare having production of 21.81 million tonnes with a productivity of 2509 kg ha^{-1}. Maize is the major crop of Himachal Pradesh. The production of maize, which was cultivated on an area 0.30 million hectare having production 0.67 million tonnes with a productivity of 2270 kg ha^{-1}. Wheat is an important post monsoon crop of the country as India is ranking second in wheat production with an area of 30.2 million hectare having production of 93.5 million tonnes along with productivity of 3093 kg ha^{-1}.

Soil quality has been defined as “the capacity of specific kind of soil to function within ecosystem and land use boundaries to sustain biological productivity, maintain environmental quality and sustain plant, animal and human health” (15). To assess the soil quality have to consider various physical, chemical and biological attributes referred to as indicators. Soil quality indicators can also be used to evaluate sustainability of particular land-use and soil management practice in agro-ecosystems (56). Therefore, to assess management-induced changes in soil quality over time, a minimum number of soil quality indicators (minimum data set, MDS) need to be identified from a large data set. Further, combining these indicators in a meaningful way into a single index may help assess soil quality more precisely (26 and 9). A valid SQI would also help in interpretation of data from different soil measurements and show whether management and land use are having desired results for productivity, environmental protection and health.

2. MATERIALS AND METHODS

The study fields were located in Mandi District, Himachal State, India. The study site is situated at 31043’19 N latitude and 76058’31” E longitude at an elevation of 880-950 m above mean sea level of Mandi District of Himachal Pradesh. The region receives on an average 1239.98 mm rainfall. Soil sampling was done up to a depth of 0-0.15m to 0.15 – 0.30m. A total of 90 representative surface (0-0.15 m) and subsurface (0.15-0.30 m) soil samples were collected randomly from different cropping systems falling under different agro-climatic zones of the state from 45 sites (15 samples from each cropping system). Soil samples were air dried and ground to pass through a 2-mm sieve. Soil texture was determined by International pipette (44), while WHC, bulk density and Aggregate analysis were determined by Yoder apparatus (42). 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 in the supernatant liquid of soil/water suspension (1:2) with conductivity bridge (25). Soil organic carbon (OC) was determined using the wet digestion method 20ml (98 % concentrate H_2SO_4) (68). Available nitrogen (N) was measured by the alkaline permanganate method as described (62). Available phosphorus (P) was determined by the Bray II method (43). Available potassium of soil was determined as per the procedure outlined (25). Whereas total Nitrogen and Phosphrous determined by wet and digestion method (13). Available micronutrient content copper (Cu),manganese (Mn), iron (Fe), and zinc (Zn) were determined by diethylenetriaminepentaacetic acid (DTPA) extraction (36), followed by atomicabsorption spectrophotometry. Total micronutrients determined by triacid method (25). Microbial biomass carbon (MBC) determinations were made by using chloroform fumigation method (65). Microbial biomass nitrogen (MBN) determination was made by using the Chloroform fumigation method (28). The Potential minealizable nitrogen (PNM) was determined by anaerobic incubation method (32) and soils respiration determined by chloroform fumigation ad incubation. (27).

After selection of physical, chemical and biological indicators, each of parameters was scored on the basis of the performance of soil function, considering variation of values within variables. Each variable was transformed or standardized to a value between 0 (least favourable soil function) and 1 (most favourable soil function) scoring functions (2). Principal components (PCs) for a data set are defined as linear combinations of variables that account for maximum variance within the set by describing vectors of closet fit to the ‘n’ observation in p-dimensional space, subject to being orthogonal to one another. The principal components receiving high eigen values and variables with high factor loading were assumed as the variables that best represent system attributes(8). Therefore, only the PCs with eigen values 1 or greater, which explained at least 5% of the variation in the data were examined (Wander and Bollero 1999). Within each principal component only highly weighted factors (*i.e.*, those with absolute values within 10% of the highest factor loading or $r \geq 0.40$) were retained for the minimum data set (MDS). To reduce redundancy and to rule out spurious groupings among the highly weighted variables within PCs, multivariate correlation matrix were used to determine the strength of the relationships among variables (Andrews et al. 2002). If the highly weighted factors were not correlated (correlation coefficient <0.60), then each was considered important and thus retained in the MDS. As a check of how well the MDS represented the management system goals, multiple regressions were run by using the final MDS indicators as independent variables representing management goal as dependent variables.

Highly weighted variables which got higher factor loading under Principal component analysis (PCA) or minimum data set (MDS) for assessment of soil quality under cereal and vegetable based cropping systems. Whereas, other variables did not get enough loading to qualify for MDS. All the factor loadings under PCs discarded for MDS formation because eigen value was less than 1 and it is assumed that PCs receiving higher eigen value are only the best to represent the variation between the systems. Therefore, only the PCs with eigen values $\geq$ 1 were examined and considered for MDS (minimum data set) preparation. PCA was performed using XLSTAT (version 2018.6, Excel 12.0.4518 32 bit) for variables with significant differences. The main objective of PCA was to reduce the dimension of data while minimising the loss of information (5). Highly weighted variables under PC1 included available copper and available zinc, under PC2- EC and total Mn. Whereas, other variables did not get enough loading to qualify for MDS. The only variable which got higher factor loading under PC3 were available MWD and PMN and WHC and available nitrogen under PC4.

3. RESULTS AND DISCUSSION

Sand content of surface layer (0-0.15 m) under rice-wheat, maize-wheat and vegetable based systems varied from 57.10 to 67.10, 58.50 to 69.50 and 56.00 to 68.00 per cent with mean values of 63.09, 65.94 and 62.02 per cent, respectively. Whereas in sub-surface layer (0.15-0.30 m) of respective cropping systems in same zone, sand content varied from 58.30 to 66.00, 55.50 to 67.50 and 55.10 to 64.80 per cent with mean values of 61.98, 64.01 and 59.95 per cent, respectively. Sand contents were found a little higher in cereal based cropping systems than vegetable based cropping systems and lower in subsurface of all the three cropping systems of the zone. More content of coarse sand in all the soils under study could be explained due to presence of sandy type of rocks *viz.*, sand stones, silt stones, granites etc. prevailed in the area (37).

Silt content of surface layer (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems in mid hills humid zone ranged from 15.40 to 18.10, 15.50 to 25.00 and 16.00 to 26.00 per cent with mean values of 17.37, 18.20 and 21.40 per cent, respectively, whereas in subsurface (0.15-0.30 m) silt content varied from 16.20 to 18.80, 13.00 to 22.00 and 15.00 to 25.00 per cent with mean values of 17.50, 16.13 and 20.07 per cent, respectively. Data with respect to the depth and cropping systems revealed that silt content is high in surface under vegetable based cropping systems which might be due to the regularly frequent irrigations resulting in movement of clay to lower layers. The results are in accordance with the findings of Gupta et al. (20).

Clay content of surface layer (0-0.15 m) in mid hills humid zone under rice-wheat, maize-wheat and vegetable based cropping system ranged from 15.00 to 18.50, 15.80 to 17.50 and 16.00 to 19.20 per cent, with mean values of 16. 53, 16.77 and 17.32 per cent, respectively, whereas in subsurface (0.15 – 0.30 m) clay content varied from 16.10 to 22.20, 17.10 to 20.15 and 16.40 to 20.20 per cent with mean values of 18.93, 18.49 and 18.44 per cent, respectively. Clay content, in general, increased in the sub-surface in comparison to surface layer which may have resulted due to movement of clay from upper to lower horizon. Minhas et al. (41). Soil texture under different sites varied from sandy loam to clay loam.

Bulk density (Table 2) of surface soil (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems ranged from 1.22 to 1.37, 1.14 to 1.28 and 1.20 to 1.27 Mg m^{-3} with mean value of 1.27, 1.22 and 1.21 Mg m^{-3} respectively, whereas in sub-surface (0.15-0.30 m) bulk density values varied from 1.26 to 1.39, 1.19 to 1.31 and 1.21 to 1.29 Mg m^{-3} with mean value of 1.30, 1.25 and 1.24 Mg m^{-3}, respectively. Bulk density generally increased with depths which were obvious because of decreasing trend of organic carbon (38). The result indicated that as BD increases, OC decreases, and vice-versa.

MWD values under rice-wheat, maize-wheat and vegetable based cropping systems surface layer (0-0.15 m) ranged from 2.03 to 2.86, 2.03 to 2.88 and 2.03 to 2.88 mm with mean values of 2.45, 2.43 and

2.43, respectively, whereas in subsurface layer (0.15 to 0.30 m), it varied from 2.02 to 2.85, 1.07 to 2.71 and 1.02 to 2.79 mm with mean values of 2.43, 1.78 and 1.82 mm, respectively. Irrespective of the depth, higher values of MWD were observed in vegetable based cropping systems than cereal based which decreased in subsurface soil depth. The slightly higher values of MWD in vegetable based cropping systems soils may be attributed to high amount of organic matter responsible for more aggregation in soils. (50). Soil aggregate are consequently stabilized naturally by the accumulation of organic matter produced by microorganisms such as fungi, whose hyphae hold soil particles together and generate a glycoprotein (glomalin) cementing agents that helps bound primary soil particles.

Water holding capacity in surface soils (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping system ranged from 38.10 to 53.30, 38.10 to 51.40 and 40.30 to 55.20 per cent, with mean value of 47.41, 44.17 and 50.82 per cent whereas, in subsurface (0.15-0.30 m) water holding capacity varied from 40.10 to 58.30, 40.30 to 52.40 and 50.40 to 58.30 per cent with a mean value of 50.81, 46.84 and 54.55 per cent, respectively. Higher WHC of subsurface and surface soil in vegetable based cropping systems as compared to that of cereal based cropping system may be due to less bulk density and more organic matter content coupled with higher percentage of clay in subsoil and vegetable based cropping system which enhanced the available water (33).

A perusal of data in Table 3 soil pH in the surface (0-0.15 m) layer ranged from 5.30 to 6.70, 5.40 to 6.60 and 5.90 to 6.70 with mean values of 5.80, 6.11 and 6.51 under rice-wheat, maize-wheat and vegetable based cropping system, respectively, whereas in subsurface layer (0.15 -0.30 m), it varied from 5.20 to 6.60, 5.10 to 6.50 and 5.70 to 6.60 with mean values of 5.70, 5.87 and 6.38 respectively.The soil pH was found to decrease in the sub soil depth and higher pH values were observed in vegetable based cropping systems. This might be due to reduction in leaching of bases and moderating effect of organic matter as it decreases the activity of exchangeable Al^{3+} ions in soil solution due to chelation effect of organic molecules and formation of alumino-phosphate complexes, respectively (10).

Electrical conductivity for surface soils (0–0.15 m) of rice-wheat, maize-wheat and vegetable based cropping systems ranged from 0.14 to 0.49, 0.22 to 0.44 and 0.32 to 0.44 dS m^{-1} with mean values of 0.31, 0.36 and 0.39 dS m^{-1}, respectively. Likewise, for sub-surface soil (0.15-0.30 m), EC varied from 0.14 to 0.47, 0.21 to 0.43 and 0.31 to 0.42 dS $m^{-1}$with mean value of 0.30, 0.34 and 0.37 dS m^{-1}, respectively. Comparatively a little higher salt accumulation, as evidenced by EC values, under vegetable based cropping system was observed, might be the consequence of frequent applications of fertilizers, composted animal manures and high evaporation conditions coupled with restricted leaching (55).

Organic carbon contents for surface soils (0–0.15 m) under rice-wheat, maize-wheat and vegetable based cropping system ranged from 6.0 to 10.8, 6.0 to 14.0 and 6.5 to 13.0 g kg^{-1} with mean values of 8.3, 8.3 and 10.1g kg^{-1}, respectively, whereas, in subsurface layer (0.15-0.30 m), organic carbon varied from 6.0 to 10.7, 6.0 to 14.0 and 6.1 to 12.9 g kg^{-1} with mean values of 7.6, 8.1 and 9.3g kg^{-1}, respectively. Organic carbon contents were decreased in the subsurface, irrespective of the cropping systems though the organic carbon contents were higher under the vegetable based cropping systems under study. Accumulation of organic matter in the surface layers might be due to incorporation of FYM, leaf litter and addition of decayed roots in the upper layers and their further decomposition might have resulted in accumulation of organic carbon in the surface layers (34).

Available nitrogen (Table 4) of surface soils (0–0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems ranged from 205 to 347, 201 to 379 and 238 to 467 $kgha^{-1}$ with mean values of 258.80, 279.87 and 332.87 $kgha^{-1}$, respectively, whereas in subsurface layer (0.15-0.30 m), it varied from 204 to 346, 198 to 369 and 219 to 457 $kgha^{-1}$ with mean values of 257.27, 270.40 and 319.93 $kgha^{-1}$, respectively. Low to medium available nitrogen was observed in all the cropping system. Available nitrogen decreased in sub-soil depth and higher nitrogen content were observed in vegetable based cropping systems as compared to cereals based systems which might be due to addition of organic matter and frequent application of nitrogenous fertilizers. Content of available phosphorus in surface layer (0-0.15 m) varied between 15.30 to 26.40, 17.60 to 29.50 and 17.40 to 38.30 $kgha^{-1}$ with mean values of 20.20, 23.97 and 29.90 $kgha^{-1}$, whereas in subsurface layer (0.15-0.30 m), it varied from 13.60 to 25.40, 16.60 and 27.50 and 17.10 to 37.30 $kgha^{-1}$ with mean values of 18.93, 22.31 and 28.68 $kgha^{-1}$, respectively. Irrespective of the depth, available P content in soils of vegetable based cropping systems was higher in comparison to that of cereals and its values decreased in the subsurface, irrespective of the cropping systems. Higher P content in the surface horizons of cultivated soils might be due to the confinement of crop cultivation to this layer and supplementation of the depleted phosphorus through additional phosphatic fertilizers (14).

The content available potassium under rice-wheat, maize-wheat and vegetable based cropping systems, available potassium in surface layer (0-0.15 m) varied between 124 to 201, 145 to 223 and 158 to 243

$kgha^{-1}$ with mean values of 154.87, 165.27 and 196.00 $kgha^{-1}$, whereas in subsurface layer (0.15-0.30 m) varied from 114 to 199, 136 to 221 and 154 to 241 $kgha^{-1}$with mean values of 145.67, 160.60 and 191.67 $kgha^{-1}$, respectively. The overall status of available potassium was found to be high in the vegetable based cropping systems, irrespective of the depth of soil (64).

Available Fe of surface layer (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping system ranged from 10.30 to 19.40, 10.40 to 19.40 and 13.40 to 24.20 mg kg^{-1} with the mean values of 14.72, 14.40 and 17.89 mg kg^{-1}, respectively. Whereas in subsurface layer (0.15-0.30 m), varied between 9.30 to 18.40, 9.40 to 18.40 and 12.40 to 21.20 mg kg^{-1} with mean values of 13.59, 12.67 and 16.15 mg kg^{-1}, respectively. Available Fe was found decreased in subsurface in all the cropping systems. Among different cropping systems, the higher mean extractable Fe was recorded under vegetable cropping systems, might be due to higher organic carbon content under vegetable based cropping systems. Iron oxide minerals play an important role in the preservation of OC by binding mechanisms involving adsorption, co-precipitation, aggregate formation, and occlusion. Similar results were also observed by Sidhu and Shrama (57) for the soils of Himachal Pradesh.

Available Mn of surface layer (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems varied between 8.20 to 12.10, 8.40 to 12.30 and 10.30 to 14.50 mg kg^{-1} with mean values of 9.70, 10.37 and 12.70 mg kg^{-1}, respectively. Whereas in subsurface layer (0.15-0.30 m), it varied from 7.40 to 11.10, 7.40 to 11.30 and 9.20 to 13.50 mg kg^{-1} with mean values of 8.89, 9.33 and 11.62 mg kg^{-1}, respectively. Among different cropping systems, higher Mn contents were observed in vegetable based cropping systems which found decreased in subsurface, irrespective of the cropping systems. These results are in conformity with the findings of Gupta et al. (21).

Available Zn in surface layer (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems varied from 1.5 to 4.1, 1.4 to 4.1 and 1.5 to 5.2 mg kg^{-1} with mean values of 2.51, 2.39 and 3.02 mg kg^{-1}, respectively, whereas in subsurface layer (0.15-0.30 m), it ranged from 1.2 to 3.7, 1.2 to 4.7 and 1.4 to 5.1 mg kg^{-1} with mean values of 2.18, 2.29 and 2.79 mg kg^{-1}, respectively. Irrespective of cropping systems, available Zn was found decreased in sub surface soil depth, though recorded higher in vegetable based cropping systems when compared to cereal based cropping systems. High content of available Zn in surface layers might be due to variable intensity of pedogenic processes and more complexing with organic matter that provides chelating agents for complexation of added or soluble Zn and reduces adsorption and precipitation. These results are in conformity with the findings of Mahajan (37).

Content of available Cu of surface layer (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems varied from 0.11to 0.24, 0.18 to 0.26 and 0.28 to 0.34 mg kg^{-1} with mean values of 0.19, 0.24 and 0.30 mg kg^{-1}, respectively. Likewise in subsurface layer (0.15-0.30 m), it ranged from 0.11 to 0.21, 0.12 to 0.26 and 0.18 to 0.31 mg kg^{-1} with mean values of 0.17, 0.19 and 0.25 mg kg^{-1}, respectively. Cu decreased with the increase in depth and higher contents were observed in vegetable based cropping systems. The results are in conformity with the earlier findings of Dhale and Prasad (14).

Microbial biomass carbon in surface soil (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems varied from 145.40 to 352.10, 234.50 to 342.20 and 309.40 to 432.20 µg g^{-1} with mean values of 251.52, 271.73 and 365.45 µg g^{-1}, whereas in sub surface layer (0.15-0.30 m), it ranged between 135.40 to 342.10, 215.20 to 322.20 and 307.40 to 431.20µg g^{-1} with mean values of 239.45, 257.47 and 352.65 µg g^{-1}, respectively. Higher microbial biomass carbon contents were observed in vegetable based cropping than cereal based cropping systems. Higher microbial biomass carbon in vegetable based cropping systems may be due to production of more leaf litter and more root volume allowing more microbial activities. Similar findings were reported by Sharma et al. (53).

Microbial biomass of nitrogen (0-0.15 m) surface layer under rice-wheat, maize-wheat and vegetable based cropping systems ranged from 9.40 to 20.20, 11.40 to 23.70 and 14.20 to 26.30 µg g^{-1} with mean values of 15.15, 17.56 and 20.30 µg g^{-1}, whereas in subsurface layer (0.15-0.30 m), it varied from 9.30 to 19.20, 10.40 to 22.70 and 12.20 to 24.30 µg g^{-1} with mean values of 14.77, 16.23 and 18.43 µg g^{-1}, respectively. Higher microbial biomass nitrogen was recorded under vegetable based cropping systems as compared to the cereal based cropping systems. This might be attributed to the high soil organic carbon content, more root proliferation and additional supply of N by FYM along with fertilizers. These results are in agreement with the findings of Mishra et al. (41).

Potential mineralizable nitrogen (PMN) surface layer (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems ranged from 10.40 to 20.40, 10.40 to 23.30 and 11.40 to 22.90 µg g^{-1} with the mean values of 15.03, 16.18 and 17.02 µg g^{-1}, respectively. Likewise in subsurface layer (0.15-0.30 m) under respective cropping systems, it varied from 10.20 to 20.10, 10.20 to 21.30 and 10.40 to 21.90 µg g^{-1}, with mean values of14.61, 14.63 and 15.95 µg g^{-1}, respectively. Potentially mineralizable nitrogen relates to organic carbon content. Therefore, under vegetable based cropping system, higher organic carbon owing to more production as well comparatively higher additions of organics might have contributed towards higher PMN. PMN was found more in surface than subsurface and in vegetable based cropping systems than cereals based (29).

Soil respiration rate in surface soil (0-0.15 m) under rice-wheat, maize-wheat and vegetable based cropping systems ranged from 46.40 to 176.40, 78.30 to 123.40 and 69.90 to 207.30 µg CO_2 g^{-1}soil with mean values of 90.05, 100.70 and 115.87 µg CO_2 g^{-1} soil, respectively. Likewise in subsurface layer (0.15-0.30 m), it ranged from 42.40 to 172.40, 77.30 to 122.40 and 68.90 to 206.30 µg CO_2 g^{-1} soil with the mean values of 87.19, 98.61 and 68.90 µg CO_2 g^{-1} soil, respectively. Soil respiration rate was found decreased in sub soil depth in all the cropping systems. Higher respiration rate was observed in vegetable based cropping system than that of cereals, might be due to high amount of organic matter. The above results are in the same line with that of Law et al. (35). Respiration temporarily increases as a result of aeration (similar effect as tilling) by increasing the amount of oxygen available to break down organic matter more rapidly.

The data in (Table 10) with regard to soil health indices show better soils quality index (SQI) in vegetable based cropping systems of mid hill humid conditions of Himachal Pradesh than cereal based cropping systems. It can be summarized that health status of soil under vegetable based cropping system is at higher level as compared to cereal based cropping system. This may be attributed to proper adoption of crop rotation, which increases or maintain the quantity and quality of soil organic matter, and improve soil chemical and physical properties. Adequate application of fertilizers combined with farmyard manure may increase soil nutrients and soil organic carbon content.Similar results were reported by Chaudhury et al. (11) for rice-wheat cropping system in Indo-Gangetic plains of the country.

Table: 1 Sand, silt and clay content of soils under different cropping systems of HP

Cropping system	Sand (%)			
	0-0.15 m		0.15-0.30 m	
	Range	Mean(SD±)	Range	Mean(SD±)
Rice –Wheat	57.10-67.10	63.09 (3.21)	58.30-66.00	61.98 (2.32)
Maize-Wheat	58.50-69.50	65.94 (3.19)	55.50-67.50	64.01 (3.16)
Vegetable based**	56.00-68.00	62.02 (4.06)	55.10-64.80	59.95 (3.21)
Silt (%)				
Rice –Wheat	15.40-18.10	17.37 (0.73)	16.20-18.80	17.50 (0.82)
Maize-Wheat	15.50-25.00	18.20 (2.75)	13.00-22.00	16.13 (2.72)
Vegetable based**	16.00-26.00	21.40 (2.97)	15.00-25.00	20.07 (3.03)
Clay (%)				
Rice –Wheat	15.00-18.50	16.53 (1.25)	16.10-22.20	18.93 (1.69)
Maize-Wheat	15.80-17.50	16.77 (0.64)	17.10-20.15	18.49 (0.99)
Vegetable based**	16.00-19.20	17.32 (1.01)	16.40-20.20	18.44 (1.16)

**1.Capsicum/Tomato/Chilli-Cauliflower/Cabbage/Knolkhol/Broccoli-Capsicum/Tomato/Chilli, 2.Cucumber/Bottlegourd/Bittergourd- Radish/Turnip/early Pea, 3. Okra/Brinjal/Green onion-Radish/Turnip/Spinach- Okra/Brinjal

Table: 2. Bulk density, Mean weight diameter (MWD) and Water holding capacity (WHC) of soils under different cropping systems of HP

Cropping system	Bulk density (Mg m^{-3})			
	0-0.15 m		0.15-0.30 m	
	Range	Mean(SD±)	Range	Mean(SD±)
Rice –Wheat	1.22-1.37	1.27 (0.04)	1.26-1.39	1.30 (0.04)
Maize-Wheat	1.14-1.28	1.22 (0.04)	1.19-1.31	1.25 (0.04)
Vegetable based	1.20-1.27	1.21 (0.02)	1.21-1.29	1.24 (0.02)
MWD (mm)				
Rice –Wheat	2.03-2.86	2.45 (0.32)	2.02-2.85	2.43 (0.31)
Maize-Wheat	2.03-2.88	2.43 (0.27)	1.01-2.71	1.78 (0.47)
Vegetable based	2.03-2.88	2.43 (0.27)	1.02-2.79	1.82 (0.47)
WHC (%)				
Rice –Wheat	38.10-53.30	47.41 (5.30)	40.10-58.30	50.81 (5.14)
Maize-Wheat	38.10-51.40	44.17 (4.61)	40.30-52.40	46.84 (4.22)
Vegetable based	40.30-55.20	50.82 (3.34)	50.40-58.30	54.55 (2.75)

Table: 3. Soil pH, EC and OC under different cropping systems of HP

Cropping system	pH

	0-0.15 m		0.15-0.30 m	
	Range	**Mean(SD+)**	**Range**	**Mean(SD+)**
Rice –Wheat	5.30-6.70	5.80 (0.46)	5.20-6.60	5.70 (0.46)
Maize-Wheat	5.40-6.60	6.11 (0.48)	5.10-6.50	5.87 (0.53)
Vegetable based	5.90-6.70	6.51 (0.24)	5.70-6.60	6.38 (0.25)
EC (dSm^{-1})				
Rice –Wheat	0.14-0.49	0.31 (0.10)	0.14-0.47	0.30 (0.10)
Maize-Wheat	0.22-0.44	0.36 (0.06)	0.21-0.43	0.34 (0.06)
Vegetable based	0.32-0.44	0.39 (0.04)	0.31-0.42	0.37 (0.04)
OC ($g\ kg^{-1}$)				
Rice –Wheat	6.0-10.8	8.3 (1.3)	6.0-10.7	7.6 (1.3)
Maize-Wheat	6.0-14.0	8.3 (2.1)	6.0-14.0	8.1 (2.1)
Vegetable based	6.5-13.0	10.1 (1.9)	6.1-12.9	9.3 (1.7)

Table: **4**. Available nitrogen, phosphorus and potassium content of soils under different cropping systems of HP

Cropping system	**Available N ($kgha^{-1}$)**			
	0-0.15 m		**0.15-0.30 m**	
	Range	**Mean(SD+)**	**Range**	**Mean(SD+)**
Rice –Wheat	205-347	258.80 (47.73)	204-346	257.27 (47.91)
Maize-Wheat	201-379	279.87 (44.43)	198-369	270.40 (44.19)
Vegetable based	238-467	332.87 (69.17)	219-457	319.93 (73.54)
Available P ($kgha^{-1}$)				
Rice –Wheat	15.30-26.40	20.20 (3.92)	13.60-25.40	18.93 (3.92)
Maize-Wheat	17.60-29.50	23.97 (3.94)	16.60-27.50	22.31 (3.50)
Vegetable based	17.40-38.30	29.90 (6.65)	17.10-37.30	28.68 (6.47)
Available K ($kgha^{-1}$)				
Rice –Wheat	124-201	154.87 (199.4)	114-199	145.67 (22.22)
Maize-Wheat	145-223	165.27 (20.63)	136-221	160.60 (21.66)
Vegetable based	158-243	196 .00 (28.36)	154-241	191.67 (29.43)

Table: 5. Available iron, manganese, zinc and copper content of soils under different cropping systems of HP

Cropping system	**Available Fe ($mg\ kg^{-1}$)**			
	0-0.15 m		**0.15-0.30 m**	
	Range	**Mean(SD+)**	**Range**	**Mean(SD+)**
Rice –Wheat	10.30-19.40	14.72 (2.95)	9.30-18.40	13.59 (2.79)
Maize-Wheat	10.40-19.40	14.40 (1.00)	9.40-18.40	12.67 (2.33)
Vegetable based	13.40-24.20	17.89 (3.25)	12.40-21.20	16.15 (2.97)

Available Mn (mg kg^{-1})				
Rice –Wheat	8.20-12.10	9.70 (1.07)	7.40-11.10	8.89 (1.13)
Maize-Wheat	8.40-12.30	10.37 (1.37)	7.40-11.30	9.33 (1.25)
Vegetable based	10.30-14.50	12.70 (1.18)	9.20-13.50	11.62 (1.19)
Available Zn (mg kg^{-1})				
Rice –Wheat	1.5-4.1	2.51 (0.69)	1.2-3.7	2.18 (0.59)
Maize-Wheat	1.4-4.1	2.39 (0.72)	1.2-4.7	2.29 (0.79)
Vegetable based	1.5-5.2	3.02 (1.00)	1.4-5.1	2.79 (0.96)
Available Cu (mg kg^{-1})				
Rice –Wheat	0.11-0.24	0.19 (0.04)	0.11-0.21	0.17 (0.04)
Maize-Wheat	0.18-0.26	0.24 (0.03)	0.12-0.26	0.19 (0.04)
Vegetable based	0.28-0.34	0.30 (0.02)	0.18-0.31	0.25 (0.05)

Table: **6.** Microbial biomass carbon, Microbial biomass Nitrogen, Potential Minearlizable Nitrogen and Soil respiration of soils under different cropping systems of HP

Cropping system	**MBC (µg g^{-1})**			
	0-0.15 m		**0.15-0.30 m**	
	Range	**Mean(SD+)**	**Range**	**Mean(SD+)**
Rice –Wheat	145.40-352.10	251.52 (59.29)	135.40-342.10	239.45 (56.25)
Maize-Wheat	234.50-342.20	271.73 (35.07)	215.20-322.20	257.47 (35.58)
Vegetable based	309.40-432.20	365.45 (31.01)	307.40-431.20	352.65 (39.91)
MBN (µg g^{-}				
Rice –Wheat	9.40-20.20	15.15 (3.39)	9.30-19.20	14.77 (3.19)
Maize-Wheat	11.40-23.70	17.56 (3.79)	10.40-22.70	16.23 (3.85)
Vegetable based	14.20-26.30	20.30 (3.20)	12.20-24.30	18.43 (3.60)
PMN (µg g^{-1})				
Rice –Wheat	10.40-20.40	15.03 (2.89)	10.20-20.10	14.61 (2.94)
Maize-Wheat	10.40-23.30	16.18 (3.32)	10.20-21.30	14.63 (2.95)
Vegetable based	11.40-22.90	17.02 (3.63)	10.40-21.90	15.95 (3.69)
Soil respiration (µg CO_2 g^{-1} soil per 24 hrs)				
Rice –Wheat	46.40-176.40	90.05 (33.09)	42.40-172.40	87.19 (34.21)
Maize-Wheat	78.30-123.40	100.70 (15.50)	77.30-122.40	98.61 (14.70)
Vegetable based	69.90-207.30	115.87 (39.83)	68.90-206.30	68.90 (113.53)

Table: 7. Selected indicators of soil quality under different cropping systems of HP.

Available. Cu (mgkg^{-1})	**Available Mn (mgkg^{-1})**	**EC (dSm^{-1})**	**MWD (mm)**	**PMN (µg g^{-1})**	**Available N(kgha^{-1})**	**WHC (%)**
Rice- Wheat						
0.11	8.6	0.36	2.23	15.3	210	40.1
0.22	9.5	0.45	2.03	10.4	205	45.8
0.17	10.3	0.3	2.64	12.3	210	53.4
0.21	10.3	0.49	2.64	19.3	209	50.3
0.24	11.2	0.4	2.75	20.4	288	49.5
0.24	9.3	0.33	2.12	16.3	254	49.5
0.15	10.3	0.25	2.24	15.3	205	52.1
0.16	8.5	0.28	2.16	11.3	265	56.6
0.22	9.1	0.37	2.81	15.3	209	50.4

0.23	8.5	0.14	2.68	12.3	312	42.4
0.22	9.3	0.19	2.57	16.4	280	49.5
0.21	8.4	0.28	2.83	14.3	347	58.3
0.19	10.3	0.19	2.09	16.6	290	53.5
0.11	12.1	0.39	2.07	12.4	309	57.3
0.21	9.8	0.24	2.86	17.5	289	53.4
Maize-Wheat						
0.25	8.6	0.26	2.67	12.1	201	51.2
0.26	11.5	0.41	2.12	10.4	234	50.2
0.22	10.3	0.31	2.11	13.7	288	50.1
0.26	12.3	0.4	2.03	18.3	345	52.4
0.26	11.2	0.22	2.63	23.3	379	49.3
0.25	9.3	0.36	2.18	18.1	307	50.5
0.22	10.3	0.36	2.55	17.2	245	42.1
0.19	11.5	0.42	2.69	14.3	252	40.3
0.24	12.1	0.38	2.17	18.1	306	41.3
0.26	8.5	0.4	2.88	13.1	285	45.3
0.25	9.3	0.31	2.81	18.2	301	46.2
0.25	8.4	0.37	2.44	17.1	259	45.4
0.22	10.3	0.39	2.34	15.9	267	52.1
0.18	12.1	0.44	2.41	13.6	254	42.1
0.23	9.8	0.41	2.36	19.3	275	44.1
Vegetable based						
0.29	13.6	0.43	2.67	18.5	467	50.4
0.28	12.5	0.43	2.12	11.4	349	56.3
0.32	14.3	0.44	2.11	14.4	268	54.1
0.31	12.3	0.42	2.03	20.4	238	55.2
0.29	11.2	0.36	2.63	22.9	257	51.2
0.34	13.3	0.38	2.18	18.8	310	56.7
0.28	10.3	0.37	2.55	22.4	404	58.3
0.28	11.5	0.41	2.69	13.4	296	53.4
0.29	12.1	0.44	2.17	19.9	435	55.6
0.32	14.5	0.34	2.88	12.3	250	51.3
0.32	13.3	0.32	2.81	16.4	369	56.2
0.34	12.4	0.38	2.44	14.3	328	50.5
0.29	13.3	0.42	2.34	18.9	289	53.5
0.28	12.1	0.35	2.41	13.8	365	58.3
0.32	13.8	0.39	2.36	17.5	368	57.3

Table: 8. Indicators score under cereal and vegetable based cropping systems HP

Available Cu (mg kg^{-1})	Available Mn (mg kg^{-1})	EC (dSm^{-1})	MWD (mm)	PMN (µg g^{-1})	Available N (kgha^{-1})	WHC (%)
Rice- Wheat						
1.00	0.98	0.39	0.78	0.75	0.61	0.69
0.50	0.88	0.31	0.71	0.51	0.59	0.79
0.65	0.82	0.47	0.92	0.60	0.61	0.92
0.52	0.82	0.29	0.92	0.95	0.60	0.86
0.46	0.75	0.35	0.96	1.00	0.83	0.85
0.46	0.90	0.42	0.74	0.80	0.73	0.85
0.73	0.82	0.56	0.78	0.75	0.59	0.89
0.69	0.99	0.50	0.76	0.55	0.76	0.97
0.50	0.92	0.38	0.98	0.75	0.60	0.86

0.48	0.99	1.00	0.94	0.60	0.90	0.73
0.50	0.90	0.74	0.90	0.80	0.81	0.85
0.52	1.00	0.50	0.99	0.70	1.00	1.00
0.58	0.82	0.74	0.73	0.81	0.84	0.92
1.00	0.69	0.36	0.72	0.61	0.89	0.98
0.52	0.86	0.58	1.00	0.86	0.83	0.92
Maize-Wheat						
0.72	0.98	0.85	0.93	0.52	0.53	0.98
0.69	0.73	0.54	0.74	0.45	0.62	0.96
0.82	0.82	0.71	0.73	0.59	0.76	0.96
0.69	0.68	0.55	0.70	0.79	0.91	1.00
0.69	0.75	1.00	0.91	1.00	1.00	0.94
0.72	0.90	0.61	0.76	0.78	0.81	0.96
0.82	0.82	0.61	0.89	0.74	0.65	0.80
0.95	0.73	0.52	0.93	0.61	0.66	0.77
0.75	0.69	0.58	0.75	0.78	0.81	0.79
0.69	0.99	0.55	1.00	0.56	0.75	0.86
0.72	0.90	0.71	0.98	0.78	0.79	0.88
0.72	1.00	0.59	0.85	0.73	0.68	0.87
0.82	0.82	0.56	0.81	0.68	0.70	0.99
1.00	0.69	0.50	0.84	0.58	0.67	0.80
0.78	0.86	0.54	0.82	0.83	0.73	0.84
Vegetable based						
0.97	0.76	0.74	0.93	0.81	1.00	0.86
1.00	0.82	0.74	0.74	0.50	0.75	0.97
0.88	0.72	0.73	0.73	0.63	0.57	0.93
0.90	0.84	0.76	0.70	0.89	0.51	0.95
0.97	0.92	0.89	0.91	1.00	0.55	0.88
0.82	0.77	0.84	0.76	0.82	0.66	0.97
1.00	1.00	0.86	0.89	0.98	0.87	1.00
1.00	0.90	0.78	0.93	0.59	0.63	0.92
0.97	0.85	0.73	0.75	0.87	0.93	0.95
0.88	0.71	0.94	1.00	0.54	0.54	0.88
0.88	0.77	1.00	0.98	0.72	0.79	0.96
0.82	0.83	0.84	0.85	0.62	0.70	0.87
0.97	0.77	0.76	0.81	0.83	0.62	0.92
1.00	0.85	0.91	0.84	0.60	0.78	1.00
0.88	0.75	0.82	0.82	0.76	0.79	0.98

Table: 9. Results from the principal components analysis of soil quality indicators cereals and vegetable based cropping systems of HP

Principal components:	**P C 1**	**P C 2**	**P C 3**	**P C 4**
Eigen value	7.576	2.547	2.203	1.606
Variability (%)	28.060	9.435	8.160	5.949
Cumulative %	28.060	37.495	45.655	51.604
Weight	0.540	0.182	0.158	0.115
Eigen vectors:				
p H	0.237	-0.078	0.132	0.010

EC	0.160	***0.286***	-0.095	-0.194
BD	-0.203	-0.273	-0.153	-0.050
MWD	-0.019	-0.142	***0.419***	-0.052
WHC	0.147	-0.121	-0.145	***0.395***
OC	0.183	-0.139	-0.167	-0.131
Available N	0.205	-0.188	0.003	***0.313***
Available P	0.230	0.116	0.050	-0.199
Available K	0.223	0.125	-0.246	-0.072
Available Cu	***0.303***	-0.016	0.155	0.020
Available Fe	0.164	-0.243	-0.104	0.255
Available Mn	***0.286***	0.144	-0.072	0.046
Available Zn	0.134	-0.283	0.238	-0.017
MBC	0.259	0.098	-0.059	-0.119
MBN	0.244	-0.179	0.032	0.004
PMN	0.099	-0.077	***0.390***	0.100
Soil respiration	0.123	0.240	0.304	-0.171

Bold italic factor loadings are considered highly weighted ;while bold italic underlined factor loadings were retained in MDS..

Table: 10. Score, weight and soil quality index (SQI) values of selected minimum data set (MDS) variable under different cropping systems of HP

Available Cu (mgkg^{-1})		**Mn (mg kg^{-1})**		**MWD (mm)**		**WHC (%)**		$SQI = \sum_{i=1}^{n} WiXSi$
Rice- Wheat								
Score (S)	**Weight (W)**	**Score (S)**	**Weight (W)**	**Score (S)**	**Weight (w)**	**Score (s)**	**Weight (w)**	
1.00	0.54	0.65	0.18	0.78	0.16	0.69	0.12	0.73
0.50	0.54	0.90	0.18	0.71	0.16	0.79	0.12	0.72
0.65	0.54	1.00	0.18	0.92	0.16	0.92	0.12	0.87
0.52	0.54	0.95	0.18	0.92	0.16	0.86	0.12	0.81

0.46	0.54	0.57	0.18	0.96	0.16	0.85	0.12	0.71
0.46	0.54	0.53	0.18	0.74	0.16	0.85	0.12	0.64
0.73	0.54	0.94	0.18	0.78	0.16	0.89	0.12	0.83
0.69	0.54	0.74	0.18	0.76	0.16	0.97	0.12	0.78
0.50	0.54	0.47	0.18	0.98	0.16	0.86	0.12	0.7
0.48	0.54	0.75	0.18	0.94	0.16	0.73	0.12	0.72
0.50	0.54	0.55	0.18	0.90	0.16	0.85	0.12	0.7
0.52	0.54	0.96	0.18	0.99	0.16	1.00	0.12	0.86
0.58	0.54	0.94	0.18	0.73	0.16	0.92	0.12	0.79
1.00	0.54	0.93	0.18	0.72	0.16	0.98	0.12	0.9
0.52	0.54	0.75	0.18	1.00	0.16	0.92	0.12	0.79
Maize-Wheat								
0.72	0.54	0.87	0.18	0.93	0.16	0.98	0.12	0.87
0.69	0.54	0.90	0.18	0.74	0.16	0.96	0.12	0.82
0.82	0.54	0.99	0.18	0.73	0.16	0.96	0.12	0.87
0.69	0.54	0.88	0.18	0.70	0.16	1.00	0.12	0.82
0.69	0.54	0.72	0.18	0.91	0.16	0.94	0.12	0.81
0.72	0.54	0.60	0.18	0.76	0.16	0.96	0.12	0.76
0.82	0.54	0.70	0.18	0.89	0.16	0.80	0.12	0.80
0.95	0.54	0.85	0.18	0.93	0.16	0.77	0.12	0.87
0.75	0.54	1.00	0.18	0.75	0.16	0.79	0.12	0.82
0.69	0.54	0.67	0.18	1.00	0.16	0.86	0.12	0.80
0.72	0.54	0.47	0.18	0.98	0.16	0.88	0.12	0.76
0.72	0.54	0.88	0.18	0.85	0.16	0.87	0.12	0.83
0.82	0.54	0.59	0.18	0.81	0.16	0.99	0.12	0.80
1.00	0.54	0.81	0.18	0.84	0.16	0.80	0.12	0.86
0.78	0.54	0.44	0.18	0.82	0.16	0.84	0.12	0.72

Vegetable based								
0.97	0.54	0.94	0.18	0.93	0.16	0.86	0.12	0.92
1.00	0.54	0.96	0.18	0.74	0.16	0.97	0.12	0.91
0.88	0.54	0.94	0.18	0.73	0.16	0.93	0.12	0.86
0.90	0.54	0.98	0.18	0.70	0.16	0.95	0.12	0.87
0.97	0.54	0.94	0.18	0.91	0.16	0.88	0.12	0.92
0.82	0.54	0.98	0.18	0.76	0.16	0.97	0.12	0.87
1.00	0.54	1.00	0.18	0.89	0.16	1.00	0.12	**1.00**
1.00	0.54	0.97	0.18	0.93	0.16	0.92	0.12	**1.00**
0.97	0.54	0.96	0.18	0.75	0.16	0.95	0.12	0.90
0.88	0.54	0.95	0.18	1.00	0.16	0.88	0.12	0.92
0.88	0.54	0.95	0.18	0.98	0.16	0.96	0.12	**1.00**
0.82	0.54	0.96	0.18	0.85	0.16	0.87	0.12	0.87
0.97	0.54	0.98	0.18	0.81	0.16	0.92	0.12	0.92
1.00	0.54	0.98	0.18	0.84	0.16	1.00	0.12	**1.00**
0.88	0.54	1.00	0.18	0.82	0.16	0.98	0.12	0.91

4. CONCLUSION

The study conclusively indicated that vegetable based cropping system with balanced fertilization along with manures, maintained soil quality as well the productivity. Therefore farmers are advised to adopt cropping systems comprised of vegetables and cereals crops with integrated nutrient management practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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