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Research Article

Effect of Cropping Systems Practiced at Farmers' Fields on Soil Quality Indicators, Soil Quality Index (SQI) and Relative Soil Quality Index (RSQI) in Rainfed Aridisols

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Abstract

Cropping systems and crop management practices significantly impact soil properties. Four cropping systems viz., i) Pearlmillet-Fallow, ii) Fallow-Chickpea, iii) Mungbean, and iv) Undisturbed system were chosen to assess the influence on soil quality in farmers' fields at operational research project (ORP) village (Dariyapur) of Hisar Centre (CCS Haryana Agricultural University) of All-India Coordinated Research Project for Dryland Agriculture (AICRPDA). After collection and processing, the samples were analyzed at ICAR-Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad. Results of the study revealed that the key soil quality indicators under different cropping systems included pH, available K, exchangeable Ca and Mg, available Cu, labile carbon and bulk density. The soil quality index (SQI) values varied from 2.87 to 4.13 while the relative soil quality index (RSQI) values varied between 0.65 and 0.93 across the cropping systems. The soil from the undisturbed system had the highest SQI of 4.13. Among the cropping systems, the mungbean system had the highest SQI of 3.82. The relative order of performance of the cropping systems in influencing soil quality in terms of SQI was: Undisturbed (4.13) > Mungbean (3.82) > Pearlmillet-Fallow (3.00) > Fallow-Chickpea (2.87). The average percent contribution of key indicators towards soil quality indices was in the order of pH (22%), bulk density (20%), available K (16%), labile carbon (15%), exchangeable Ca (14%), available Cu (9%) and exchangeable Mg (4%).

Keywords: Pearlmillet-Fallow; Fallow-chickpea; Mungbean; Undisturbed; SQI; RSQI; Aridisols

Introduction

In the Indian sub-continent, Aridisols represents about 4% of the total land surface area. Aridisol soil order is dominantly present in Rajasthan, Gujarat, Karnataka, Andra Pradesh, Punjab and Haryana states [1,2]. In the Haryana state, out of the total geographical area about 9.0% area is occupied by Aridisols. Globally, these soils are found in South Asia, northern and northeastern Africa, Australia, southwestern South America, southwestern and northern USA, South Africa and Russia [3]. Mostly, these soils are low in water holding capacity, low in plant available nutrients, deficient in SOC, poor in soil microbiological activities, suffer from soil crusting, salinity, etc. [2]. These soils are poor in formation of stable soil aggregates due to low amount of organic matter [4,2]. Prevailing high temperature during summer accelerates the rate of organic matter decomposition. Agronomic practices such as cropping systems, crop diversification, fertilization, crop rotation, irrigation, intercropping etc. impacted on soil quality [5]. Suitable cropping systems effectively contribute to maintaining soil productivity by supporting the cycling, retention and supply of plant nutrients, as well as conserving soil structure [6,7]. Although, initially cropping systems were designed to maximize the crop yield,but modern agriculture has become increasingly concerned about the soil and environmental sustainability of agro-systems [8]. It has been reported that different types of land use and agricultural management systems may cause alterations in soil physical, chemical and biological indicators [9,10].

Soil quality indices (SQI) are used to select and integrate soil quality indicators in a single index and serve as a management tool to provide land managers with all the most important information to facilitate decision-making in relation to agro-ecosystem management [11]. SQI are calculated from a minimum data set (MDS) formed by indicators selected by means of statistical techniques from an initial set of physical, chemical and biological soil indicators. Principal component analysis (PCA) is the most widely used statistical technique for selecting the indicators in MDS [12].

At research stations, numerous studies have been conducted and these studies have revealed that soil type, cropping system and management practices significantly influenced the soil quality indicators and soil quality indices [13-15]. But limited information is available on soil quality aspects and cropping systems in farmers' fields. Therefore, a study was conducted to assess soil quality in farmers' fields under different cropping systems with the following objectives: (i) to quantify the influence of cropping systems on soil quality parameters (ii) to find out the key soil quality indicators and (iii) to assess the soil quality and relative quality indices under different cropping systems.

Materials and Methods

Soil sampling and analysis

Four cropping systems from the farmers' fields of Hisar district viz., i) Pearlmillet – Fallow, ii) Fallow – Chickpea, iii) Mungbean and iv) Undisturbed system were chosen to assess the performance of these systems in influencing or sustaining the soil quality. During the year 2005, the soil samples were collected from farmers' fields at operational research project (ORP) village (Dariyapur) of Hisar Centre (Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana) of All-India Coordinated Research Project for Dryland Agriculture (AICRPDA). The soil samples from 20 farmers's fields for each cropping system representing Aridisols were collected from plough layer (0-15 cm depth) in triplicate and composited to form one sample for each farmer's field. Soil samples were air dried, ground and passed through prescribed sieves for different kinds of analysis. Air dried soil samples passed through 8 mm sieve size and retained on the 4.75 mm sieve size were used for aggregate analysis, while the samples passed through 0.2 mm sieve size were used for estimating organic carbon (OC) as well as labile carbon (LC). For other soil quality parameters viz., chemical and biological parameters, air dried soil samples passed through 2 mm sieves were used. Soil samples passed through 2 mm sieve were stored at 4-5°C for the analysis of microbial biomass carbon (MBC). Soil pH was measured in 1:2 soil water suspension with the help of pH meter [16]. Soil EC was measured in 1:2 soil water suspension using the EC meter (electrical conductivity meter) [17]. Organic C was analyzed by Walkley-Black method [18]. Available soil nitrogen (N) was estimated by alkaline-$KMnO_4$ method [19]. Soil available P was estimated using the method of [20]. Available potassium (K) was estimated by using inductively coupled plasma spectrophotometer (ICP OES). Exchangeable soil Ca and Mg were determined using atomic absorption spectrophotometer [21]. Soil sulphur was estimated by spectrophotometer. Soil micronutrients (Zn, Fe, Cu, and Mn) were extracted with DTPA reagent and were determined using ICP-OES [22]. Boron was estimated using DTPA-Sorbitol extraction method [23]. Soil dehydrogenase activity (DHA) was measured by TTC (triphenyl tetrazolium chloride) method [24]. Soil microbial biomass carbon (MBC) was determined using the chloroform fumigation incubation method [25]. Labile carbon (LC was estimated using the method given by [26].

Soil bulk density (BD) was measured by Keen's box method [27]. The distribution of water stable aggregates was estimated by wet sieving method using the sieves of 4.75, 2.0, 1.0, 0.5, 0.25 and 0.1 mm sizes [28] and mean weight diameter (MWD) was computed after oven drying the fractions [29] using the formula:

Where the mean diameter of any particular size range of aggregates separated by sieving, and is the weight of aggregates in that size range as a fraction of the total dry weight of soil.

The percentage of water stable aggregates (% SA) was calculated using the relationship given by [30].

Calculations of soil quality indices

The data set obtained for 19 soil quality parameters was statistically analyzed for their level of significance using one-way ANOVA. After the statistical analysis, the significant parameters were subjected to principal component analysis (PCA) using SPSS software (Version 12.0). The principal components (PCs) which received eigen values equal or more than one and explained at least 5% of the variation in the data [31,32] and variables which had high factor loading were chosen as the best representative of system attributes. Within each PC, only highly weighted factors (having absolute values within 10% of the highest factor loading) were selected for the minimum data set (MDS). The selected MDS variables were regressed with yield as management goals. The qualified variables were termed as the "key indicators" and were used for computation of soil quality index (SQI) after appropriate transformation and scoring.

To obtain SQI, the weighted MDS indicator scores for each observation were summed up using the following function:

$$SQI = \sum_{i=1}^{n} (W_i \times S_i)$$

Where, S_i is the score for the subscripted variable and W_i is the weighing factor obtained from the PCA. Here the assumption was that, higher index scores mean better soil quality or greater performance of soil function. For better understanding and relative comparison of the cropping systems, for the calculation of RSQI, the SQI values were reduced to a scale of 0-1 by dividing all the SQI values with the highest SQI value.

Statistical analyses

Data was statistically analyzed for their level of significance using one-way ANOVA and the differences were compared by Least Significant Difference (LSD) test at a significance level of $p < 0.05$ [33]. Principal component analysis (PCA) was calculated using SPSS version 12.

Results and Discussion

Effect of cropping systems on soil quality parameters

The data obtained on soil quality parameters under the cropping systems is presented in Table 1. Soil pH in different cropping systems practiced in the farmer's fields ranged from 7.24 to 7.73, while the undisturbed field recorded a pH of 7.81. Electrical conductivity of soil in different cropping systems varied from 0.12 to 0.22 dS m^{-1} and did not differ with cropping systems. Organic carbon was significantly higher under pearlmillet–fallow system (2.54 g kg^{-1}) followed by mungbean system (2.43 g kg^{-1}) while the undisturbed site recorded the highest OC of 2.83 g kg^{-1}. The cropping systems did not show any significant difference in available N, which varied from 124.6 kg ha^{-1} under fallow-chickpea system to 138.7 kg ha^{-1} under mungbean system. Available P was almost similar in all the cropping systems of farmer's fields ranging from 21.9 to 23.4 kg ha^{-1}. Among the cropping systems, available K status was significantly higher under mungbean system (288.6 kg ha^{-1}). The undisturbed system showed the highest available K status of 359.6 kg ha^{-1}.

Cropping systems	pH	EC (dS m^{-1})	OC (g kg^{-1})	N	P	K
				(kg ha^{-1})		
Pearlmillet - Fallow	7.24	0.12	2.54	128.8	21.9	229.6
Fallow - Chickpea	7.34	0.12	2.34	124.6	23.4	228.5
Mungbean	7.73	0.22	2.43	138.7	23.3	288.6
Undisturbed	7.81	0.17	2.83	153.0	16.8	359.6
LSD (p = 0.05%)	0.25	NS	0.23	NS	4.27	81.2

Table 1: Influence of different cropping systems on physico-chemical and chemical soil quality parameters in farmer's fields in Aridisols of Hisar.

Among the secondary nutrients, available S ranging from 21.5 to 26.3 kg ha^{-1} was not significantly different under different cropping systems (Table 2). Among the cropping systems, exchangeable Ca (2.75 cmol kg^{-1}) and exchangeable Mg (1.93 cmol kg^{-1}) were higher under mungbean system. Undisturbed sample recorded the highest exchangeable Ca to the extent of 3.12 cmol kg^{-1}. Among the micronutrients, the cropping systems significantly influenced available Fe, Cu and B but not available Zn and Mn. Pearlmillet-fallow system recorded the highest available Fe of 5.11 µg g^{-1} while mungbean system recorded highest available B (1.61 µg g^{-1}). Available Zn varied from 0.25 to 0.42 µg g^{-1} while available Mn ranged from 3.74 to 4.66 µg g^{-1} across the cropping systems.

Cropping systems	Ca	Mg	S	Zn	Fe	Cu	Mn	B
	(cmol kg^{-1})		(kg ha^{-1})	(µg g^{-1})				
Pearlmillet-Fallow	1.65	1.06	21.5	0.30	5.11	0.14	4.42	0.38
Fallow – Chickpea	1.45	1.05	24.1	0.25	4.01	0.11	4.66	0.45
Mungbean	2.75	1.93	24.4	0.42	2.53	0.24	4.52	1.61
Undisturbed	3.12	1.47	26.3	0.34	3.14	0.37	3.74	1.26
LSD (p = 0.05%)	0.51	0.54	NS	NS	1.28	0.12	NS	0.26

Table 2: Influence of different cropping systems on secondary and micronutrients in farmers' fields in Aridisols of Hisar.

Among the biological soil quality parameters, the cropping systems showed a significant influence on labile carbon in soils but not dehydrogenase activity as well as microbial biomass carbon (Table 3). Though the highest labile carbon was recorded under undisturbed system, among the cropping systems, it was the mungbean system, which recorded significantly highest labile carbon (230.7 µg g^{-1}) of soil. Dehydrogenase activity varied from 1.23 to 1.39 µg TPF hr^{-1}g^{-1} while MBC ranged from 102.2 to 129.4 µg g^{-1} of soil. Among the physical soil quality indicators, bulk density under both pearlmillet-fallow system as well as fallow-chickpea system was 1.37 Mg m^{-3}, while in the mungbean system it was 1.42 Mg m^{-3}. It was observed that almost all the cropping systems in farmer's fields recorded a mean weight diameter of 0.17 mm except the undisturbed, which recorded a mean weight diameter of 0.30 mm.

Cropping systems	DHA (µg TPF hr^{-1}g^{-1})	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
Pearlmillet- Fallow	1.39	102.2	161.7	1.37	0.17
Fallow – Chickpea	1.23	127.1	143.8	1.37	0.16
Mungbean	1.30	129.4	230.7	1.42	0.17
Undisturbed	2.25	126.0	250.5	1.72	0.30
LSD (p = 0.05%)	NS	NS	66.1	0.05	0.03

Table 3: Influence of different cropping systems on biological and physical soil quality parameters in farmer's fields in Aridisols of Hisar.

Effect of cropping systems on soil quality indices

Data pertaining to the influence of various cropping systems practiced under farmer's fields on 19 soil quality indicators were statistically analyzed and it was observed that 7 variables viz., EC, available N, S, Zn, Mn, dehydrogenase assay, and microbial biomass carbon did not show significant differences and hence were dropped from further PCA analysis. In remaining 12 variables, the eigen values >1 recorded in two PCs and it explained 84.3% variance in the data set (Table 4). In PC1, six variables viz., pH, available K, exchangeable Ca, available Cu, labile carbon and bulk density were the highly weighted variables while in PC2 only one variable i.e., exchangeable Mg was highly weighted.

Variables	PC1	PC2
Total Eigen values	7.749	2.364
% of Variance	64.58	19.70
Cumulative %	64.58	84.28
Eigen Vectors		
pH	0.864	0.297
OC	0.712	-0.535
P	-0.635	0.583
K	0.908	-0.117
Ca	0.950	0.133
Mg	0.494	0.742
Fe	-0.666	-0.528
Cu	0.902	-0.106
B	0.772	0.610
LC	0.880	0.142
BD	0.883	-0.361
MWD	0.844	-0.504

Table 4: Effect of different cropping systems under farmers' fields on principal component analysis of soil quality parameters.

The correlation analysis run between the variables individually under PC1 showed that the correlations were significant, and the variables were also well correlated (>0.70) (Table 5). But considering their importance in these soils, all the highly weighted variables under PC1 were retained to be included under MDS. Hence, the final MDS included pH, available K, exchangeable Ca and Mg, available Cu, labile carbon and bulk density and were termed the key indicators for different cropping systems practiced in farmer's fields of Hisar district.

Soil quality index (SQI) and relative soil quality index (RSQI)

Soil quality indices were computed using seven key soil quality indicators viz., pH, available K, exchangeable Ca and Mg, available Cu, labile carbon and bulk density. The soil quality indices varied from 2.87 to 4.13 in different cropping systems (Table 6). The undisturbed system had the highest SQI of 4.13. But among the cropping systems, mungbean system had the highest SQI of 3.82. The relative order of cropping systems in terms of SQI was: Undisturbed (4.13) > Mungbean (3.82) > Pearlmillet- Fallow (3.00) > Fallow – Chickpea (2.87). Relative soil quality indices ranged from 0.65 to 0.93 and followed the same trend as SQI. The average percent contribution of key indicators towards soil quality indices was: pH (22%), available K (16%), exchangeable Ca (14%), exchangeable Mg (4%), available Cu (9%), labile carbon (15%) and bulk density (20%) (Figure 1).

Variables under PCs	pH	K	Ca	Cu	LC	BD
pH	1.00	0.669*	0.818**	0.712**	0.723**	0.693*
K	0.669*	1.00	0.886**	0.880**	0.871**	0.786**
Ca	0.818**	0.886**	1.00	0.866**	0.925**	0.768**
Cu	0.712**	0.880**	0.866**	1.00	0.883**	0.856**
LC	0.723**	0.871**	0.925**	0.883**	1.00	0.688*
BD	0.693*	0.786**	0.768**	0.856**	0.688*	1.00
Correlation sum	4.615	5.092	5.263	5.197	5.09	4.791

Table 5: Pearson's correlation matrix for highly weighted variables under PC's with high factor loading.

*correlation is significant at P = 0.05 level: **correlation is significant at P = 0.01 level.

Cropping systems	SQI	RSQI
Pearlmillet- Fallow	3.00	0.68
Fallow – Chickpea	2.87	0.65
Mungbean	3.82	0.86
Undisturbed	4.13	0.93
$LSD_{p = 0.05\%}$	0.48	0.11

Table 6: Soil quality indices and relative soil quality indices of the cropping systems.

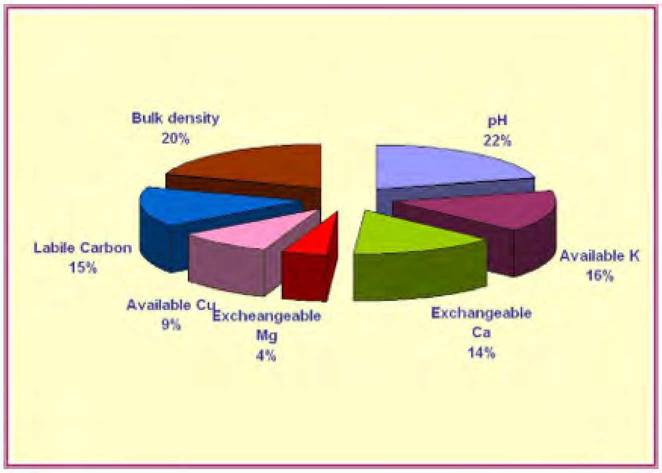

Figure 1: Percent contribution of key indicators towards soil quality indices under different cropping systems in farmer's fields in Aridisols of Hisar.

Largely, soils under mungbean cropping system recorded higher physical, chemical and biological indicators values compared to other cropping systems although it recorded lower values of these indicators when compared with undisturbed soils. Cropping systems influenced the soil quality indicators, SQI and RSQI. The undisturbed soils recorded the higher SQI and RSQI values as compared to the other cropping systems, which might be due to higher soil organic carbon content and no disturbance by tillage leading to congenial condition for formation of the stable soil aggregates. Earlier studies also revealed that ploughed soils have a lower soil quality than soils with limited ploughing or which are undisturbed [34]. It is reported that suitable cropping systems improved the soil quality indicators and nutrient use efficiency [35,36]. It is well known that inclusion of legumes in the cropping systems increased the soil fertility and strongly influenced the various soil biological, chemical, and physical indicators [37,38]. [39] reported that legume crops can fulfil about 90% of their own N requirement through the biological N fixation. It has been also reported that yearly it can save about150-200 kg N ha^{-1} [40]. Inclusion of legumes in cropping system trigger the diversity of soil micro-organisms [41,42] and enhance the soil nutrient and microbial activity [43-45]. [46] reported that the change in the soil indicators depends on the type of legumes, root systems, and nutrient requirement of the pulse crop. They further reported that lentil and chickpea utilized high soil N during growing season as compared to pea. The rate of the decomposition of the root biomass under different cropping systems largely depends on their C : N ratios, and therefore a quite variable effect was observed on soil properties and nutrient availability [47]. In the present study, we also obtained the variable results in soil quality indicators under different cropping systems, and it might be linked with the C : N ratio of the below-ground biomass and their rate of decomposition.

Conclusion

This study clearly established the influence of different cropping system on soil physical, chemical and biological quality indicators and soil quality indices. Among the cropping systems, the mungbean cropping system recorded the higher values of the different soil quality indicators, which play important role in maintaining higher soil quality. Adoption of mungbean cropping system could benefit the farmers by improving soil quality. The methods used in this study for computing soil quality and the results of the study will be highly useful to the researchers, land managers and other stakeholders for managing these soils.

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