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Soil quality indicators under continuous cropping systems in the arid ecosystem of India

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Effect of cropping systems (CS) on the soil quality (SQ) and its determinants was assessed for the clay loam soil of Hisar, India. Collected surface soil samples were analyzed for four physical indicators viz. bulk density (BD), saturated hydraulic conductivity (SHC), porosity and mean weight diameter (MWD) seven chemical indicators viz. pH, electrical conductivity (EC), organic carbon (OC), nitrate nitrogen (NO_3-N), ammoniacal nitrogen (NH_4-N), available phosphorous (AV-P) and available potassium (AV-K) and two biological indicators viz. dehydrogenase activity (DA) and microbial biomass carbon (MBC). Correlation analysis of the 13 soil attributes representing soil physical, chemical, and biological parameters resulted in a significant correlation in twelve ($P < 0.01$) and nine ($P < 0.05$) attribute pairs out of the 47 soil attribute pairs. Each SQ indicator was compared with its value under different CS using Duncan Multiple Range Test (DMRT). The results indicated that, the soil properties such as BD, MWD, Av-P, Av-K, and DA were greatly influenced by the components of each CS. The adverse impact of CS on the SQ indicators resulted in deterioration of SQ. Evaluation of SQ using soil quality index (SQI) under CS showed that, SQ was better in T_2 (Cotton-wheat-fallow) and T_5 (Greengram-mustard+kasni) compared to other. The CS that exhibited negative impacts on SQ should be discouraged for long-term cultivation to maintain good soil health for sustainable agricultural production. Value of SQI was positively and significantly correlated ($R^2 = 0.50$, $P < 0.01$) with wheat equivalent yield for all the CS. This implies that, the index may have practical utility for quantifying the SQ.

Key words: Cropping system, soil quality, soil quality index, soil physical indicator, soil chemical indicator, and soil biological indicator.

INTRODUCTION

Agricultural sustainability has become a major concern in developing countries, including India. Population burst (> 1 billion), over-exploitation of natural resources, and excessive use of chemicals such as fertilizer, pesticide etc over many decades have resulted in steadily declining in agricultural productivity (Ladha et al., 2003; Masto et al., 2007). Issues of agricultural sustainability are related to soil quality, (SQ) assessment and the direction of change of SQ with time is a primary indicator of whether agriculture is sustainable (Karlen et al., 1997). It is therefore imperative to identify the soil characteristics responsible for changes in SQ, which may eventually be considered as determinants of SQ for assessing agricultural sustainability (Masto et al., 2007). SQ indicators are a

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composite set of measurable physical, chemical, and biological attributes which relate to functional soil processes and can be used to evaluate SQ status, as affected by management (Allen et al., 2011).

The concept of SQ emerged in the literature in the early 1990s (Wienhold et al., 2004) and defined as the capacity of a reference soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al., 1997). SQ can be used interchangeably with soil health (Karlen et al., 2001) although it is important to distinguish that, SQ is related to soil function (Karlen et al., 2003; Letey et al., 2003), whereas soil health presents the soil as a finite non-renewable and dynamic living resource (Doran and Zeiss, 2000; Kinyangi, 2007).

SQ can be expressed by a unique set of indicators that include the physical, chemical and biological properties of soil. The performance of various soil functions are dictated by these indicators and the reverse is equally true. The soil functions can alter the SQ indicators thereby reducing the capacity of the soil to function. An important soil function is the crop production. Different management practices are followed under different cropping systems (CS) to optimize the biomass/agronomic production per unit area, per unit time and per unit input (Lal, 2003) and the soil attributes that are most sensitive to these managements are most desirable SQ indicators. The effect of CS on SQ can be assessed by measuring a range of physical, chemical, and biological soil properties. Cropping system treatments have significant effects on all soil properties measured especially in the surface soil layer (Jokela et al., 2011).

A better understanding of the impact of continuous cropping on soil physical, chemical, and biological properties is needed to optimize the soil conditions necessary to enhance the cropping system sustainability (Aparicio and Costa, 2007). Wienhold et al. (2006) have provided excellent data for assessing how management practices under CS collectively affect agronomic and environmental soil functions through changes in its indicators. The effects of various CS on SQ is mainly due to accumulation of soil organic matter, which can be affected by the quantity and type of C input from crop biomass and manure and by management such as tillage that affect the decomposition rate and stratification of soil organic matter (Weil and Magdoff, 2004; Jokela et al., 2011). Soil organic matter accumulation can improve SQ by decreasing bulk density (BD), surface sealing and crust formation (Mohanty et al., 2007), and by increasing aggregate stability (Somasundaram et al., 2013), cation exchange capacity, nutrient cycling, and biological activity (Karlen and Andrews, 2004). Dependence on fertilizers and other input can be reduced by enhancing biological nitrogen fixation and efficient utilization of water and nutrients through adopting appropriate CS (Lal, 2003). Although advances in management have been adopted to enhance the cropping system performance through improvements in soil condition, research is needed to better understand the interactions of management, crop sequence, and cropping intensity on the broad spectrum of physical, chemical, and biological soil properties (Liebig et al., 2004).

The arid zone of India is characterized by low mean annual rainfall coupled with high coefficient of variation, large amplitude of fluctuations of diurnal and annual temperature, strong wind regimes and high potential evaporation. There are about 8.7% of such lands distributed in the Rajasthan, Gujarat, Punjab and Haryana (Anonymous, 2000). The region’s unpredictable climate has created challenge before agronomists and soil scientists to evolve suitable cropping system, which could be environmentally and economically sustainable. The paper summarizes;

(i) The relationship among soil physical, chemical and biological SQ indicators,
(ii) The effect of cropping system on soil properties, with particular focus on properties considered as SQ indicators,
(iii) Quantifying SQ under continuous cropping in arid ecosystem of India.

MATERIALS AND METHODS

Experimental site

The study area selected to achieve above-mentioned objective was Hisar center of Project Directorate for Farming Systems Research (PDFSR), Modipuram, Meerut, India. Hisar (29°5’N and 75°45’E) is located in the western agro climatic zone of Haryana. The climate of the center is tropical, arid, and hot, which is mainly dry with very hot summer and cold winter except during the monsoon season when moist air penetrates. The hot weather season starts from mid-March to last week of June with mean maximum temperature of about 41.6°C, followed by the south- west monsoon, which lasts up to September. The transition period from September to October forms the post-monsoon season. The winter season with mean minimum temperature of 5.5°C, starts in late November and remain up to the first week of March. The normal annual rainfall of the district is 459 mm (SD±178 mm), which is unevenly distributed over 23 rainy days. The southwest monsoon sets in from last week of June and withdraws in the end of September, contributing to about 81% of annual rainfall. July and August are the wettest months. Remaining 19% rainfall is received during the non-monsoon period in the wake of western disturbances and thunderstorms.

Experimental details and laboratory evaluation

The soil texture of the experimental site is clay loam containing 46% sand, 19% silt, and 35% clay and belongs to major soil group of alluvial soil. Seven CS, which were followed for more than ten years continuously on the same plot, were selected from the experiments conducted at the PDFSR center for this study (Table 1). Each CS was cultivated with standard management practice as recommended in arid eco-system and each cropping system was considered as one treatment. Soil samples from surface (0 to 15

Table 1. Seven cropping systems in Hisar under arid agro ecosystem.

Treatment	Kharif	Rabi	Summer
T_1	Pearl millet	Wheat	Fallow
T_2	Cotton	Wheat	Fallow
T_3	Pearl millet	Barley	Moong bean
T_4	Cluster bean	Broccoli	Onion
T_5	Moong bean	Mustard + Kasni	Fallow
T_6	Pearl millet	Wheat (Desi)	Cow pea
T_7	Pearl millet + moong	Wheat + Mustard	Fallow

Wheat (*Triticum aestivum*), Mustard (*Brassica juncea*), Cotton (*Gossypium spp.*), Cluster bean (*Cyamopsis tetragonoloba*), Broccoli (*Brassica oleracea*), Onion (*Allium cepa*), Kasni (*Cichorium intybus*), Cowpea (*Vigna unguiculata*), Pearl millet (*Pennisetum americanum*), Barley (*Hordeum vulgare*).

Table 2. Soil functions and appropriate soil quality indicator.

Soil function	Soil quality Indicators
Water and solute flow	Hydraulic conductivity, aggregate stability, organic carbon, bulk density and total porosity
Physical stability and support	Soil structure, soil texture, bulk density and aggregate stability
Nutrient cycling	Organic carbon, microbial biomass, enzyme activity, mineralizable nitrogen, pH and EC
Biodiversity, production	Organic carbon and nitrogen, ph, EC
Filtering and buffering	Texture, microbial biomass and organic carbon

cm) layer were collected from each treatment (cropping system) during year 2008 at the end of Rabi season (October to March) with three replications of each treatment. Each soil sample was analyzed for physical, chemical, and biological indicators of SQ.

These indicators were selected based on the performance of considered soil functions (Table 2). When SQ is assessed for its capability to produce agricultural yield, the indicators selected to represent the soil were BD, porosity, mean weight diameter (MWD), and saturated hydraulic conductivity (SHC) as physical indicators; soil pH, organic carbon (OC), electrical conductivity (EC), ammonical nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), available phosphorous (AV-P) and available potassium (AV-K) as chemical indicators; microbial biomass carbon (MBC), and dehydrogenase activity (DA) as biological indicators. BD was determined by the core method (Blake and Hartge, 1986). Total porosity was calculated from the bulk and particle density. SHC was determined by constant head method (Klute and Dirkson, 1986). MWD was measured by wet sieving method (Yoder and McGuinness, 1956). NO_3-N and NH_4-N were determined by steam distillation method (Subbiah and Asija, 1956) using Kjeldhal apparatus. Soil pH and EC were measured in 1:2.5 soil-water suspensions. SOC was determined by wet digestion method (Walkley and Black, 1934). AV-P was determined using Olsen extractant (Olsen et al., 1954) and AV-K was determined in the neutral normal ammonium acetate extract of soil with the help of flame photometer (Jackson, 1967). MBC was measured by fumigation extraction method (Jenkinson and Ladd, 1979) and DH was determined using Casida method (Casida et al., 1964).

Soil quality index (SQI)

For developing a soil quality index (SQI), first the raw data of SQ indicators were transformed into normalized numerical scores ranging from 0 to 1 because different indicators are expressed by different numerical scales. The transformation of an indicator value to a score was achieved with the help of a scoring function. Three types of standardized nonlinear scoring functions were constructed namely:

(1) More is better (upper asymptotic sigmoid curve)
(2) Less is better (lower asymptotic sigmoid curve)
(3) Optimum curve (Gaussian function) (Karlen and Stott, 1994; Andrews et al., 2002). These curves were constructed using Curve Expert *v.*1.3. The shapes of the curves generated for various indicators were determined by their critical values. The weights of each parameter were assigned based on Principal Component Analysis (PCA). Each PC explained a certain amount of the variation in the total data set. This percentage, standardized to unity, provided the weight for variables chosen under a given PC (Andrews et al., 2002). After determining the weight of each determinant of SQ, SQI was calculated as Equation (1):

Table 3. Correlation matrix of soil quality indicators (n = 21).

Parameter	pH	EC	BD	Por	OC	SHC	MBC	DH	NO_3-N	NH_4-N	MWD	AV-P	AV-K
pH	1.00												
EC (dS cm^{-1})	-0.08	1.00											
BD (Mg m^{-3})	0.53**	-0.12	1.00										
Por (%)	-0.51**	0.12	-1.00**	1.00									
OC (%)	-0.13	-0.28*	-0.26*	0.27*	1.00								
SHC (cm h^{-1})	-0.29*	0.12	-0.48**	0.48**	0.29*	1.00							
MBC (µg g^{-1})	0.12	0.21	0.19	-0.12	0.01	0.14	1.00						
DH (µTPF g-1/24 hr)	-0.17	0.08	-0.36**	0.37**	0.23	.31*	-0.10	1.00					
NO_3-N (mg kg^{-1})	-0.01	-0.06	-0.08	0.08	0.04	0.23	-0.18	0.18	1.00				
NH_4-N (mg kg-1)	-0.09	0.12	-.28*	0.28*	-0.02	0.09	-0.30*	0.13	0.58**	1.00			
MWD (mm)	0.15	0.06	-0.19	0.18	0.01	-0.14	-0.03	0.19	-0.04	0.01	1.00		
AV-P (Kg ha^{-1})	-0.47**	0.04	-0.25	0.24	0.10	0.00	-0.22	0.11	-0.18	-0.11	-0.35*	1.00	
AV-K (Kg ha^{-1})	-0.46**	0.02	-0.10	0.10	-0.01	-0.13	0.11	-0.07	-0.11	-0.04	-0.28*	0.57**	1.00

**Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level.

$$\mathrm{SQI} = \frac{1}{n}\sum_{i=1}^{n} \mathrm{W_i} * \mathrm{S_i} \qquad (1)$$

Where, n = number of indicators included in the index, S_i = linear or non linear score of ith indicator, W_i= weight assigned to ith indicator.

RESULTS AND DISCUSSION

Relationship among soil physical, chemical, and biological attributes

Correlation analysis of the 13 soil attributes representing soil physical, chemical, and biological parameters resulted in a significant correlation in 12 (P < 0.01) and 9 (P < 0.05) of the 47 soil attribute pairs (Table 3). Among the highly correlated parameter, we found a negative but significant linear relationship between BD and porosity at the surface layer. It is common to find negative relationship between BD and porosity, because porosity is directly related to inverse BD. Cropping system *vis a vis* management practices that incorporates more residue to soil, increases the porosity, also able to increase water holding capacity and sorptivity of the soil (Shaver, 2010).

In this study, BD and porosity is also showing high correlation with pH. Shaffer (1988) also observed pH is highly correlated with BD and porosity at the surface layer, but did not explain any reason. Sakin et al. (2011) further investigated the relationship between BD and pH and concluded that, there is no direct link existing between these two, but BD may be affected by pH because of its link with total exchangeable capacity, exchangeable Al hydroxyl, clay (content and nature) and iron-oxide.

The high OC is important for sustainability since it influences the determinants of SQ. Soil OC showed a significant correlation with all the physical properties *viz.* BD (r = -0.26), porosity (r = 0.27), HC (r = 0.29), and MWD (r = 0.71) consider in this study. Table 3 emphasized the role of OC in infiltration, water retention and movement in soil. Similar result has been observed by Sakin (2012) for BD and porosity, Aparicio and Costa (2007) for HC and Somasundaram et al. (2013); Mohanty et al., (2013) for MWD. In present investigation, soil pH is negatively and significantly correlated with Av-P (-0.47) and Av-K (-0.46). It indicated that, at higher pH, these nutrients are less available to crop. Wright et al. (2012) have critically reviewed the availability of plant nutrient under varying pH and suggested that, nutrients in soils are strongly affected by soil pH due to reacting with soil colloids and other nutrients, so; in fact, availability of many nutrients has been determined as a function of soil pH.

The DA showed significant correlation with BD, porosity and SHC (Table 3.). It indicates that, the soil physical environment may affect microbial activity in soil under arid ecosystem. Araújo et al. (2009) suggested that, measurement of soil property such as BD and porosity provides a relative value of soil compaction and reflects significant changes in macro-porosity and soil aeration, and consequently affects the soil microbial activity.

Soil physical quality indicator

The impacts of various management practices and CS on four soil physical indicators under the seven CS are exhibited in Table 4. Lowest and highest values of BD were observed under T_2 (Cotton - Wheat - Fallow) and T_1 (Pearl Millet - Wheat- Fallow), respectively. It is a well-known fact that, if BD increases, porosity goes down. Hence, maximum porosity was observed under T_2 and minimum under T_1 CS. For different soil textures, there are different ranges of optimum BD. In this study, the texture of soil was determined as clay loam, for which the ideal BD should be less than 1.40 Mg m^{-3} (USDA-NRCS, 2013). The comparison of BD after the rabi crops in the seven CS showed that, most of them leave soil with BD higher than the critical value (1.40 Mg m^{-3}) for clay loam soil. Only cotton- wheat-fallow (T_2) system maintained the most desirable BD (1.41 Mg m^{-3}). The pearl millet - wheat - fallow (T_1) system affected BD adversely to the maximum extent (1.61 Mg m^{-3}), which was significantly higher than T_2 system. To test the significance among CS, DMRT was performed and result showed that, BD under T_3, T_5, T_6, and T_7 were comparable, and it is higher than the critical limit in there CS. Generally, the values of BD higher than the critical limit may be due to the arid nature of the climate and clay loam soil texture. The hot and dry weather influences the clay loam soil to compact more and develop high BD, as the weather does not leave any water in top 15 cm soil and soil particles become dense. Porosity followed exactly the reverse trends.

In the present study, T_3 (Pearl Millet - Barley - Moong bean) showed maximum SHC whereas T_7 (Pearl Millet + Moong – Wheat + Mustard - Fallow) showed minimum SHC. This indicator of SQ is highly dynamic in nature and strongly influenced by the pore size distribution in soil rather than total porosity. The pore size distributions as well as surface pores are affected by many factors of management and rooting pattern of crop, which in turn are influenced by the arid nature of the agro ecosystem. Although, soil texture has a direct impact on SHC, indirect ecosystem influence is also important.

Mean weight diameter is an index of measurement of soil aggregation, which is important for the resistance of land surface to erosion, and it influences the ability of soil to remain productive (Pinheiro et al., 2004). Treatment T_6 (Pearl Millet – Wheat (Desi) –Cow Pea showed highest MWD (2.81 mm), and this is quite obvious because this cropping system includes cow pea, which has dense rooting pattern that binds the soil and reduces erosion.

Under T_4 (Clusterbean - Broccoli - Onion) MWD was lowest, and it was attributed to the presence of two vegetable crops in this treatment. Vegetable crops normally do not incorporate organic matter to soil and also have a very shallow root system which affects adversely soil aggregation (Sorensen, 2005).

Soil chemical and biological quality indicators

The measured values of soil chemical and biological indicators under the seven CS are mentioned in Table 5 and 6. When pH and EC of soil under all CS were compared using DMRT, no significant difference between CS was observed. Changes in pH of soil are attributed to the parent material and climate under which soil formation takes place. It has been reported that there is very little changes in pH within landscape units of few hectares (Shukla et al., 2004; Cox et al., 2003), which also corroborate our results. The detrimental effects of soil salinity are quantified in terms of soil EC. It occurs may be due to inappropriate soil drainage and use of saline water for irrigation. In this study, soil samples were collected from research center, which were irrigated with good-quality non-saline water and the soil was well drained. Hence, we did not find any difference in EC between the treatments of various CS. The comparison of AV-P and AV-K under different treatments, showed that the treatment T_4 (Clusterbean - Broccoli - Onion) exhibited maximum values for these indicators.

This may be due to the two vegetable crops of this cropping system. The uptake of phosphorous and potassium is much less in vegetable crops than in cereal crops and most of these nutrient uptake in vegetable are used for production of fruits, tuber or bulbs of the plants (Sainju, 2006). This causes high build-up of phosphorous and potassium in the soil leading to high values of these indicators. The minerals nitrogen in the forms of NH_4-N and NO_3-N were not affected much by the CS under arid agro ecosystems. The reason could be that the differences in soil mineral nitrogen due to CS were dominated by the influences of high temperatures existing after *rabi* harvest. This overshadowed the CS influences and resulted in non-significant differences of NH_4- and NO_3-N among the treatments. OC and MBC under the CS were non significant as indicated by DMRT. DA determines the metabolic activity of microorganism in soils. It is different from MBC and OC in the sense that it only constitutes living part of organic matter. Lowest dehydrogenase activity was observed under T5 (Moongbean Mustard + Kasni - Fallow) (Table 6). It could be because this system includes a medicinal plant ‘Kasni’ that has anti-microbial affects and suppresses the activity of micro-organism (Nishimura et al., 2000).

Table 4. Multiple comparisons (Duncan's method) of mean values of soil physical indicator among cropping systems.

Treatment	Cropping systems	BD ($Mg\ m^{-3}$)	SHC ($cm\ h^{-1}$)	Porosity (%)	MWD (mm)
T_1	Pearl millet - wheat - fallow	1.61^{b}	1.33^{a}	40.33^{a}	1.47^{ab}
T_2	Cotton -wheat - fallow	1.41^{a}	2.01^{ab}	46.95^{b}	2.20^{bc}
T_3	Pearl millet - barley - moongbean	1.50^{ab}	3.30^{b}	43.35^{ab}	1.72^{abc}
T_4	Clusterbean - broccoli - onion	1.57^{b}	1.70^{a}	40.93^{a}	0.70^{a}
T_5	Moongbean - mustard + kasni - fallow	1.54^{ab}	2.45^{ab}	42.06^{ab}	1.22^{ab}
T_6	Pearl Millet - wheat (desi) - cowpea	1.52^{ab}	1.41^{a}	42.46^{ab}	2.81^{c}
T_7	Pearl Millet + moong - wheat + mustard - fallow	1.52^{ab}	1.06^{a}	42.47^{ab}	2.39b^{c}

Mean followed by same letter are not significantly ($P < 0.05$) different according to Duncan's Multiple Range Test (DMRT at $P<0.05$). Wheat (Triticum aestivum), Mustard (Brassica juncea), Cotton (Gossypium spp.), Cluster bean (Cyamopsis tetragonoloba), Broccoli (Brassica oleracea), Onion (Allium cepa), Kasni (Cichorium intybus), Cowpea (Vigna unguiculata), Pearl millet (Pennisetum americanum), Barley (Hordeum vulgare).

Table 5. Multiple comparisons (Duncan's method) of mean values of soil chemical indicator among cropping systems.

Treatment	Cropping systems	pH	EC ($dS\ cm^{-1}$)	OC (%)	NH_4-N ($mg\ kg^{-1}$)	NO_3-N ($mg\ kg^{-1}$)	AV-P ($Kg\ ha^{-1}$)	AV-K ($Kg\ ha^{-1}$)
T_1	Pearl millet - wheat - fallow	7.58^{a}	0.48^{a}	0.95^{a}	87.74^{b}	50.21^{a}	28.41^{a}	289.71^{a}
T_2	Cotton - wheat - fallow	7.51^{a}	0.48^{a}	1.00^{a}	80.57^{b}	44.71^{a}	45.53^{a}	351.31^{a}
T_3	Pearl millet -barley - moongbean	7.55^{a}	0.52^{a}	0.97^{a}	81.73^{b}	48.82^{a}	36.06^{a}	279.63^{a}
T_4	Clusterbean - Broccoli - Onion	7.31^{a}	0.49^{a}	0.95^{a}	63.35^{b}	32.34^{a}	135.49^{b}	686.19^{b}
T_5	Moongbean - mustard + kasni – fallow	7.51^{a}	0.61^{a}	0.76^{a}	80.13^{b}	33.77^{a}	25.86^{a}	349.07^{a}
T_6	Pearl millet - wheat (desi) - cowpea	7.45^{a}	0.51^{a}	1.08^{a}	29.43^{a}	24.78^{a}	74.30^{ab}	233.71^{a}
T_7	Pearl millet + moong - wheat + mustard- fallow	7.48^{a}	0.52^{a}	1.07^{a}	67.50^{b}	28.26^{a}	27.32^{a}	297.55^{a}

Mean followed by same letter are not significantly ($P < 0.05$) different according to Duncan's Multiple Range Test (DMRT at $P < 0.05$). Wheat (*Triticum aestivum*), Mustard (*Brassica juncea*), Cotton (*Gossypium* spp.), Cluster bean (*Cyamopsis tetragonoloba*), Broccoli (*Brassica oleracea*), Onion (Allium cepa), Kasni (*Cichorium intybus*), Cowpea (*Vigna unguiculata*), Pearl millet (*Pennisetum americanum*), Barley (*Hordeum vulgare*).

Soil quality (SQ) under different cropping system

SQ determinant under seven cropping system in arid ecosystem is included for PCA and based on eigen value (Eigen value >1) and cumulative variance explained by principal component (73.64%) first five PCs were selected for further analysis (Table 7). Porosity was not included for PCA because of its high correlation with BD (r = 1) BD (Table 3). From selected PCs, highly weighted variable (loading factor > 0.40) (Wander and Bollero, 1999) were selected. Out of the twelve initially selected variables, which were chosen based on soil function (Table 2), eleven variables were finally selected for SQ assessment. The minimum data set suggested by PCA is EC, BD, HC, OC, MWD, NO_3-N, NH_4-N, Av-P, Av-K, DH, and MBC.

The SQ was calculated with Equation (1) for seven predominant CS of arid agro-ecosystem and compared using the DMRT (Figure 1.). The higher value of index implied that SQ under that cropping system is better compared to other. In the present investigation, we have observed better SQ under T_2 and T_5 (cotton-wheat-fallow and green gram–mustard+kasni-fallow). This result indicates that, cotton-wheat cropping system on clay loam soil generally does not deteriorate the physical, chemical and biological SQ indicator.

These systems affect and retain the values of SQ indicators in the desired range for their best performance except in case of MWD, MBC and NO_3-N, where the values were outside the desirable range and ten out of thirteen soil indicators remained in the best performing range. Hulugalle et al. (2006) also reported minimum deterioration in soil properties under cotton-wheat-fallow system. Similarly in T_5 (green gram – mustard + kasni - fallow), all the value are either in the higher range or medium range of performance, resulting in good SQ. The poorest SQ observed in this study was found under T_6 (pearl millet - wheat (desi)-cowpea). This could be because; this system adversely affected the soil aggregation and MBC. Cowpea is generally used as erosion resistant crop and promotes the soil aggregation and its stability. In other CS, the SQ was moderately good having index value 70 or above. This implied that, these CS do not deteriorate the SQ much. Further observation indicates that, SQ under T_2 was 33% better than T_6. The CS of T_1, T_3, T_4, and T_7 are in low index

Table 6. Multiple comparisons (Duncan's method) of mean values of soil biological indicator among cropping systems.

Treatment	Cropping systems	DA (µTPF g^{-1}/24 h)	MBC (µg g^{-1})
T_1	Pearl millet - wheat - fallow	122.87^{b}	82.86^{a}
T_2	Cotton -wheat - fallow	100.80^{ab}	132.86^{a}
T_3	Pearl millet - barley - moongbean	104.87^{ab}	95.71^{a}
T_4	Clusterbean - broccoli - onion	84.27^{ab}	125.71^{a}
T_5	Moongbean - mustard + kasni - fallow	68.20^{a}	151.43^{a}
T_6	Pearl millet - wheat (desi) - cowpea	92.67^{ab}	112.86^{a}
T_7	Pearl millet + moong - wheat + mustard - fallow	107.67^{ab}	121.43^{a}

Mean followed by same letter are not significantly ($P < 0.05$) different according to Duncan's Multiple Range Test (DMRT at $P < 0.05$). Wheat (*Triticum aestivum*), Mustard (*Brassica juncea*), Cotton (*Gossypium* spp.), Cluster bean (*Cyamopsis tetragonoloba*), Broccoli (*Brassica oleracea*), Onion (*Allium* cepa), Kasni (*Cichorium intybus*), Cowpea (*Vigna unguiculata*), Pearl millet (*Pennisetum americanum*), Barley (*Hordeum vulgare*).

Table 7. Component matrix of soil quality determinant for arid ecosystem.

Parameter	PC1	PC2	PC3	PC4	PC5
Eigen value	2.45	2.12	1.65	1.50	1.12
% of variance	20.38	17.65	13.78	12.53	9.30
Cumulative percentage of variance	20.38	38.03	51.81	64.35	73.64
pH	0.50	-0.23	0.01	-0.02	0.33
EC (dS cm^{-1})	-0.21	-0.71	0.47	0.14	-0.01
BD (Mg m^{-3})	-0.08	0.41	0.22	-0.68	-0.08
HC (cm h^{-1})	0.33	0.22	0.21	0.30	-0.64
OC (%)	0.15	0.76	-0.46	0.12	-0.16
MWD (mm)	0.26	-0.47	-0.72	0.14	0.06
NO_3-N (mg kg^{-1})	0.64	0.44	0.43	0.02	0.09
NH_4-N (mg kg^{-1})	0.37	-0.01	0.58	0.44	0.15
AV-P (Kg ha^{-1})	-0.66	0.33	-0.06	0.28	0.37
AV-K (Kg ha^{-1})	-0.69	0.43	0.21	0.27	0.29
DH (µTPF g-1/24h)	0.61	0.24	-0.19	0.41	0.39
MBC (µg g^{-1})	-0.36	-0.06	-0.08	0.62	-0.41

Boldface factor loading are consider highly weighted.

value subgroup whereas, T_2 and T_6 cropping system constituted high index value sub group in surface layer according to DMRT.

Crop productivity is one of the reliable ways to evaluate the SQ (Mohanty et al., 2007). In the present investigation, high and significant correlation was observed between index values and wheat equivalent yield (Figure 2). A positive correlation ($R^2 = 50$) between index values and yield implies that, the index may have utility for quantifying the SQ under the mentioned CS.

Conclusion

The assessment of SQ indicators under different CS in clay loam soil and under arid ecosystem showed that, the physical condition of soil is influenced by the cropping system. Pearl millet - wheat - fallow (T_1) cropping system deteriorated the physical condition of soil as is expressed by very high BD under this system, also inclusion of vegetables in the cropping system were not desirable from soil structure point of view as they did not result in optimum soil aggregation. The various CS did not influence chemical environment significantly with the only exception where onion is included in cropping system. In general, the CS does not affect MBC significantly; however, inclusion of kasni with cereal and pulses resulted in very low DA due to its anti microbial effect in soil. The adverse impact of CS on SQ indicators results in deterioration in quality of soil in such CS and these CS

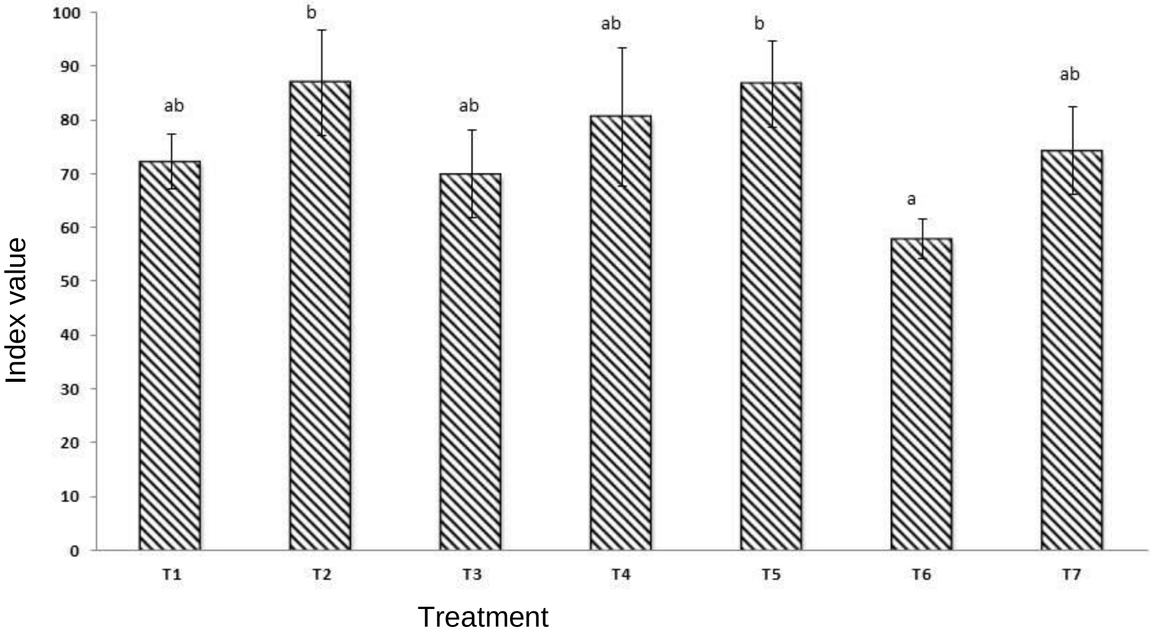

Figure 1. Soil quality under different cropping system. T_1; pearl millet - wheat – fallow, T_2; Cotton -wheat – fallow, T_3; Pearl millet - Barley - Moongbean, T_4; Clusterbean - Broccoli – Onion, T_5; Moongbean - Mustard + Kasni - Fallow, T_6; Pearl millet - Wheat (desi) – Cowpea, T_7; Pearl millet + Moong - Wheat + Mustard – Fallow. Same letter(a, b, c…) are not significantly different according to Duncan's Multiple range Test (DMRT at $P < 0.05$). Wheat (*Triticum aestivum*), Mustard (*Brassica juncea*), Cotton (*Gossypium* spp.), Cluster bean (*Cyamopsis tetragonoloba*), Broccoli (*Brassica oleracea*), Onion (*Allium cepa*), Kasni (*Cichorium intybus*), Cowpea (*Vigna unguiculata*), Pearl millet (*Pennisetum americanum*), Barley (*Hordeum vulgare*).

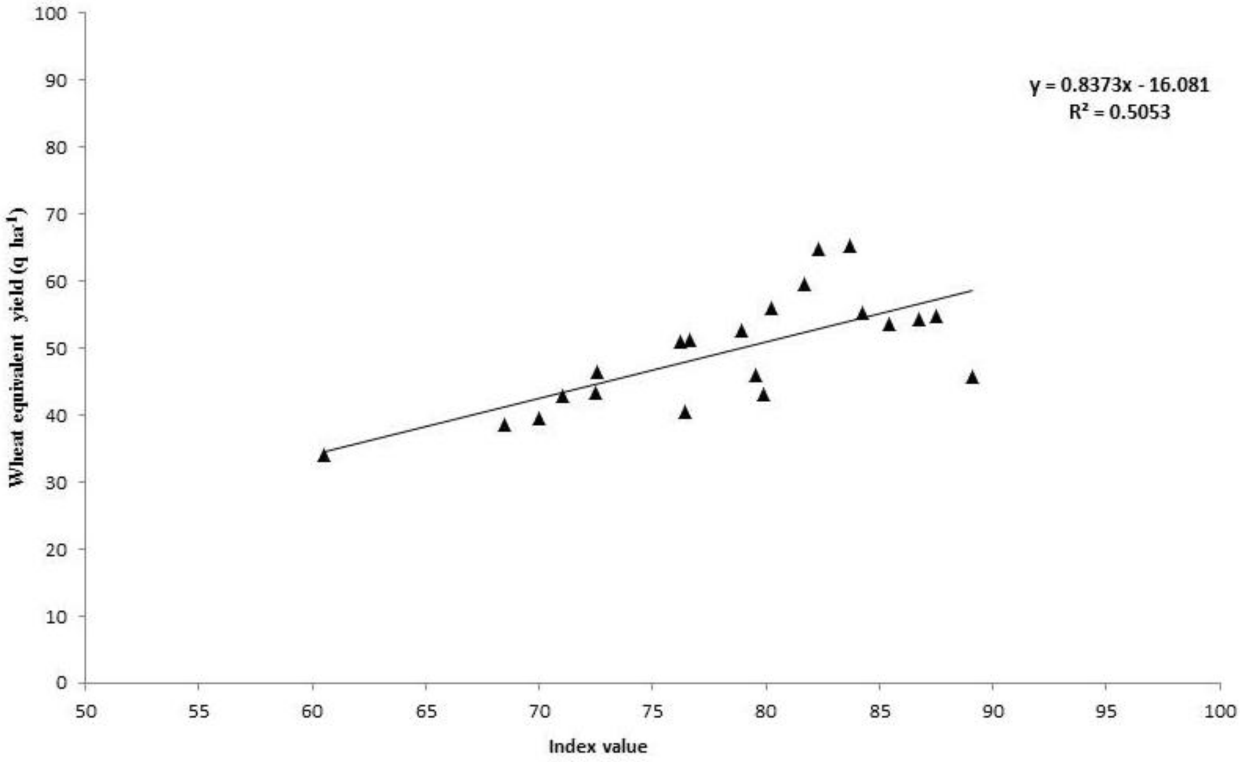

Figure 2. Correlation between SQI and wheat equivalent yield.

should be prevented for long-term cultivation.

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