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SHORT-TERM EFFECT OF CONSERVATION AGRICULTURE PRACTICES ON SOIL QUALITY OF A VERTISOL IN CENTRAL INDIA

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ABSTRACT

A field experiment was conducted to assess the effect of contrasting tillage systems *viz*., no- tillage, reduced tillage and conventional tillage with four cropping systems *viz*., soybean + pigeon pea (2:1), soybean - wheat, maize + pigeon pea (1:1) and maize - chickpea on yields and soil quality in a *Vertisols* of Central India. Surface soil samples were collected and analyzed for physicochemical properties. Correlation analysis of seven soil physicochemical attributes showed a significant correlation in eight (P < 0.01) and four (P < 0.05) attribute pairs out of the 49 soil attribute pairs. The results revealed that the soil properties such as soil reaction (pH), electrical conductivity, organic carbon, mean weight diameter, available nitrogen, available phosphorus and available potassium were influenced by tillage and cropping systems. Evaluation of soil quality using soil quality index (SQI) under different tillage and cropping system showed that soil quality was better in maize + pigeon pea (1:1) and soybean + pigeon pea (2:1) under reduced tillage and no tillage as compared to the other systems. The tillage that caused destructive effects on soil quality should be discouraged for long-term cultivation to maintain good soil health for sustainable agricultural production. The value of SQI was positively and significantly correlated with soybean grain equivalent yield for all the tillage and cropping system. This indicates that the index parameters may be used for computing the soil quality under different management practices.

Key words: Contrasting tillage, cropping system, soil quality, soil quality index, soil physic-chemical properties

INTRODUCTION

Soil is a vital natural resource for food production and security. Burgeoning population especially in developing countries like India has tremendously put pressure on limited soil resources for the enhancement of agricultural productivity. Worldwide there are rising concerns that crops yields of maize, rice and wheat may be stagnating or declining, which together produce ~57% of the world's agricultural calories, (Ray *et al*., 2012). Such trend in crop yields have profound implications on world food security (Tilman *et al*., 2011). Over past few decades, intensive tillage practices coupled with unsustainable management practices have led to soil erosion and depletion of organic matter and nutrients which result in irreversible soil degradation and productivity losses (Aziz *et al*., 2013). To meet the growing demand for high food grains through sustainable intensification with minimum degradation, the soil resources need to be efficiently managed to serve as a sink rather than source of atmospheric CO_2 (Corsi *et al*., 2012). Thus, conservation tillage along with some complimentary practices such as soil cover and crop diversity has emerged as a viable option to ensure sustainable food production and maintain environmental integrity.

Traditionally, tillage-based farming systems without residue retention have been followed for many decades. Reportedly these systems have led to decline in organic matter in the long-run thus making it unsuitable for tropical environments (Derpsch *et al*., 1986; Verhulst *et al*., 2010). On the other hand, conservation agriculture (CA) is a method of managing agroecosystem for improved and sustained productivity with increased profits, and provides food security while preserving and enhancing the soil quality. CA systems reduce soil erosion, slow-down soil physicochemical and biological degradation and reduce production costs (Haggblade and Tembo, 2003; Thierfelder and Wall, 2009). Hence, conservation agriculture is a resource-saving production system aimed at to achieve production intensification and high yields, and simultaneously enhance natural resource base along with good production practices of plant nutrition and pest management (Abrol and Sangar, 2006). Therefore, CA practices with different tillage and cropping systems are needed to optimize soil conditions to enhance soil health/quality and sustainability of the system (Aparicio and Costa, 2007).

The concept of soil quality emerged in literature as early in 1990s (Wienhold *et al*., 2004). It is 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). Soil quality is hard to assess directly due to collective and multiple functional effects but can be evaluated from change in soil properties due to management operations (Sinha *et al*., 2014a,b). Soil quality studies are focused on soil physico-chemical properties (Larson and Pierce, 1994) and recently soil biological properties too have been included as these serve as early and sensitive indicators in response to the change in management practices (Kennedy and Papendick, 1995; Islam and Weil, 2000). Therefore, quantification of physicochemical and biological properties under diverse agroecosystem may provide better understanding of soil quality and prove helpful in developing better management strategies to minimize soil degradation.

Vertisols are heavy soils having high clay particles with high shrink-swell potential and wide deep cracks when dry (Somasundaram *et al*., 2011, 2017). Globally, these soils contain about 2.5% of total earth area. In India, vertisols with vertic characteristics, cover about 72.9 M ha, constitute approximately 22.2% of total geographical area of which 30.1% area lies in Madhya Pradesh (Central India) alone. This region is characterized by erratic rainfall, vast amplitude variations of diurnal and annual temperature and high potential evapo-transpiration. The region's extreme climatic variation raises challenges for researchers to develop appropriate tillage and cropping system, which could be environmentally and economically viable for sustainable soil health. With this backdrop, the present study was aimed to assess the dynamics of soil quality status under contrasting tillage and cropping systems in vertisol of Central India.

MATERIALS AND METHODS

Study site and soil sampling

A field experiment was initiated in August 2011 with three contrasting tillage *viz*., no-tillage, reduced tillage and conventional tillage in combination with four cropping systems to study crop productivity and soil properties under rainfed Vertisols of Central India at Research Farm, IISS, Bhopal, India. The soil of experimental site was classified as clayey vertisol (Vertisols, Isohyperthermic Typic Haplustert) having 58% clay, 22% silt and 20% sand. The geographical co-ordinate of experimental site is 23°18' N, 77°24' E, and situated 485 m MSAL. The climate of the area is characterised as hot sub humid type, with mean annual air temperature, mean annual rainfall and potential evapo-transpiration are 25°C, 1130 mm and 1400 mm, respectively.

The experiment was laid out in a split-plot design with three tillage systems *viz.*, conventional, reduced and no tillage, as the main treatments and four crop systems *viz.*, soybean (*Glycine max*) + pigeon pea (*Cajanus cajan*) [2:1], soybean-wheat (*Titricum aestivum*), maize (*Zea mays*) + pigeon pea (1:1), maize–chickpea (*Cicer arietinum*) as sub-treatments in plots of 10 x 5 m size. Each treatment was replicated thrice. The conventional tillage consisted of deep summer ploughing after residue burning (only in soybean-wheat rotation) and 3 to 4 pass tillage operations using tine cultivator followed by sowing in *kharif* and one pass tillage operation followed by sowing in *rabi* crops. The reduced tillage consisted of one pass tillage operation using duck foot cultivator followed by direct sowing through zero till seed drill in *kharif* and *rabi* crops while no tillage consisted of direct sowing of crops in undisturbed soil by opening a narrow slit of sufficient width and depth to place the seed. The residue retention under reduced tillage and no tillage treatment was >30% on soil surface.

The experimental soil had pH 8.17, electrical conductivity EC 0.15 dS m^{-1}, organic carbon (OC) 0.59%, available nitrogen (Av-N) 256.8 kg ha^{-1}, available phosphorus (Av-P) 19.47 kg ha^{-1} and available potassium (Av-K) 575.87 kg ha^{-1} at 0-15 cm soil depth. The recommended dose of fertilizers (soybean 30:60:30; pigeon pea 30:60:60; wheat 120:60:40; maize 120:60:40 and chick-pea 40:60:30 $N:P_2O_5:K_2O$ kg ha^{-1}) was applied to the crops as per recommended agronomic practices. Surface soil samples (0-15 cm) were collected randomly from 2-3 locations from the plots in May 2014 at the end of 3rd crop cycles. These samples were composited, processed, sieved through a 2-mm sieve after removing large plant material and analyzed for physic-chemical indicators of soil quality. These indicators were selected based on the performance of considered soil functions. The selected soil properties were mean weight diameter (MWD), as physical indicators; soil pH, OC, EC, Av-N, Av-P and Av-K as chemical indicators.

Sample analysis

The MWD was determined by wet sieving method (Kemper and Roseneu, 1986; John and Parkins, 2002). The soil pH and EC were measured in 1:2.5 soil-water suspensions at room temperature. Soil organic carbon was determined by wet digestion method (Walkley and Black, 1934), Av.-N by using alkaline permanganate method (Subbiah and Asija, 1956), Av.-P by Olsen's extraction method (Olsen *et al*., 1954) and Av.-K by neutral normal ammonium acetate extract, using flame photometric method (Jackson, 1967).

Soil quality index

For developing a soil quality index (SQI), first the raw data of soil quality indicators were transformed into normalized numerical linear 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 non-linear scoring functions (Karlen and Stott, 1994; Andrews *et al*., 2002) were constructed namely 1) more is better (upper asymptotic sigmoid curve), 2) less is better (lower asymptotic sigmoid curve); and 3) Optimum curve (Gaussian function). These curves were constructed using Curve Expert *v*.1.3. The weights of each parameter were assigned based on principal component analysis (PCA). This percentage, standardized to unity, provided the weight for variables chosen under a given principal component (Andrews *et al*., 2002). After determining the weight of each determinant of soil quality, SQI was calculated by the following equation:

$$SQI = \frac{1}{n} \sum Wi * Si$$

Where, n = number of indicators included in index, Si = linear or non-linear score of i^{th} indicator, Wi = weight assigned to i^{th} indicator.

Standard statistical procedures including coefficient of correlation given by Karl Pearson (1896) were adopted to analyze and interpret the data using SAS v 9.3.

RESULTS AND DISCUSSION

Relationship between physical and chemical parameters

Pearson correlation analysis among the 7 studied soil parameters depicted 14 significant correlation pairs out of 49 soil parameters pairs (Table 1). Soil organic carbon (SOC) was significantly and positively correlated with MWD (0.59**), Av-N (0.60**), Av-P (0.42*), Av-K (0.84**) and EC (0.41*) but negatively correlated with pH (-0.74**). High correlation relationship between OC and MWD showed increase in aggregation with SOC. A good aggregation promotes plant growth by improving water infiltration, structural microbial community, soil biomass dynamics and biodiversity, nutrient adsorption and desorption, oxygen availability to the roots and arresting soil erosion. Somasundaram *et al*. (2012), Mohanty *et al*. (2013) and Sinha *et al*. (2014a) have emphasized to identify management systems that increase soil organic matter in different agroecosystems. Further, OC reportedly is linked to nutrient supply capacity in soil (Hossain, 2001). Similarly, Chen *et al*. (2016) found a significant positive relationship among SOC, total N, mineralizable N, microbial biomass and N uptake. However, there are thresholds of SOC below which no mineralization or above which high mineralization occur (Patrick *et al*., 2013).

The availability of soil P was enhanced due to the chelation of polyvalent cations by organic acids and other decay products. Seilsepour and Rashidi (2013) developed an exponential regression model for predicting soil available P from SOC and suggested available P as a function of SOC. Increases in the activity of enzymes participating in soil organic P mineralization in line with increases in SOC content have previously been reported (Allison and Vitousek, 2005; Sinsabaugh *et al*., 2008). Positive effect of SOC on P is attributed to more energy and C-structure materials provided to the microbes by higher organic C content, which leads to elevated production of phosphatase enzymes involved in soil organic P mineralization (Hou *et al*., 2014). Soil organic matter also provides binding sites for phosphatases thereby protect them from loss (Tabatabai *et al*., 2002). In present study, a positive significant correlation was observed between Av.-K and SOC and the results are in line with the findings of Yadav *et al*. (1999) and Saini and Grewal (2014).

Soil pH is a characteristic that describes relative acidity or alkalinity of a soil and largely regulates soil nutrient availability to the plant. High, negative and significant correlation between soil pH and SOC may be because of humic and fulvic acid formation due to organic matter decomposition. Both comprise a mixture of weak aliphatic and aromatic organic acids and contain number of -COOH group.

Principal component analysis

Selection of representative soil quality indicator is crucial to assess soil quality status under different management practices. In soil quality analysis PCA (multivariate statistical approach) has effectively been used to select minimum data set for soil quality assessment. It uses linear combination of soil properties to determine maximum variance within a data set consisting of a large number of soil properties. It groups soil variables in one or various principal components

Table 1: Correlation matrix of soil quality parameters (n = 34)

Parameters	pH	EC	OC	MWD	Av. N	Av. P	Av. K
pH	1.00						
EC (dS m^{-1})	-0.74**	1.00					
OC (%)	-0.74**	0.41*	1.00				
MWD (mm)	-0.37*	0.23	0.59**	1.00			
Av. N (kg ha^{-1})	0.28	-0.07	0.60**	0.22	1.00		
Av. P (kg ha^{-1})	-0.23*	0.13	0.42*	0.66**	-0.15	1.00	
Av. K (kg ha^{-1})	-0.65**	0.38*	0.84**	0.50**	-0.17	0.56**	1.00

**indicates significant at the P <0.01 level, * indicates is significant at the P <0.05 level.

Soil reaction (pH), Electrical conductivity (EC), Organic carbon (OC), Mean weight diameter (MWD), Available nitrogen (Av. N), Available phosphorus (Av. P) and Available potassium (Av. K)

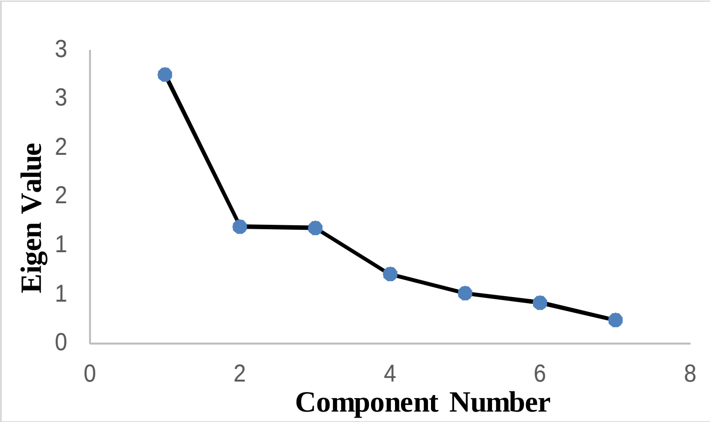

Fig. 1: Scree plot indicating Eigen value corresponding to each principle component of soil quality indicators

according to the importance and affinity of variables while reducing the dimensions of original data set without losing overall information of data set. In this study, all the 7 parameters under different tillage and cropping systems undergone through PCA and results are presented in Table 3. The scree plot (Fig. 1) showed that 3 PCs have >1 eigen value, hence PC1 to 3 were selected for further analysis. The cumulative variance explained by the selected PCs was 73.2. The soil pH, EC, OC, MWD and Av-K were selected from PC 1, whereas Av-N and Av-P were contributed from PC-3.

Table 3: Component matrix of soil quality determinant for rainfed cropping system

Parameters	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigen Value	*2.75*	*1.20*	*1.18*	*0.71*	*0.51*	*0.42*	*0.24*
Variance	39.25	17.08	16.88	10.10	7.31	5.97	3.42
Cumulative variance	39.25	56.32	73.20	83.30	90.61	96.58	100.0
pH	**-0.83**	0.28	0.23	0.20	0.09	0.07	0.37
EC (dS m^{-1})	**0.68**	-0.38	-0.39	-0.30	0.23	0.20	0.25
OC (%)	**0.66**	-0.05	0.37	0.54	0.23	0.28	-0.07
MWD (mm)	**0.63**	0.55	-0.12	0.01	-0.48	0.22	0.09
Av. N (kg ha^{-1})	0.05	0.64	**-0.67**	0.16	0.33	-0.09	-0.06
Av. P (kg ha^{-1})	0.31	0.51	**0.60**	-0.48	0.25	0.01	-0.04
Av. K (kg ha^{-1})	**0.82**	-0.01	0.17	0.18	-0.03	-0.49	0.17

Boldface factors loading are consider highly weighted, PC = principle component of soil quality indicators. Eigen values in italic correspond to the PCs examined for the selection of soil quality indicators. PC1 = principle component one to …….. PC7 = principle component seven. Soil reaction (pH), electrical conductivity (EC), organic carbon concentration (OC), mean weight diameter (MWD), available nitrogen (Av. N), available phosphorus (Av. P) and available potassium (Av. K)

Soil quality under different tillage and cropping systems

The calculated soil quality under different tillage and cropping systems was compared using DMRT. The higher index values implied that SQ under that management is better as compared to other treatments. Result indicated that soil quality under conventional tillage was at lower side as compared to reduced and no-tillage (Fig. 2). This indicated that minimum soil disturbances coupled with residue retention improved and/or optimized soil properties and provided better soil environment for plant growth. The type, frequency and intensity of tillage also determine the degree to which decomposition and mineralization process occur (Hati *et al*., 2015). Gallaher and Ferrer (1987) reported that the soil under no-tillage contains 20-43% more nitrogen than conventional tillage at 0-5 cm soil depth. Machado and Silva (2001) have demonstrated that reduced tillage frequencies along with crop rotation results in increased soil organic matter and soil fertility. In present study, higher soil quality was observed in soybean-wheat cropping system under conventional tillage; maize-pigeon pea (1:1) under reduced tillage and soybean + pigeon pea (2:1) under no-tillage system. Crop productivity is one of the reliable ways to assess soil quality. In present study, a significant correlation was observed between index values and soybean grain equivalent yield (Fig. 3). A positive correlation (R^2 = 0.59) between index values and yield implied that the index may have practical utility in quantifying the soil quality under various tillage and management systems.

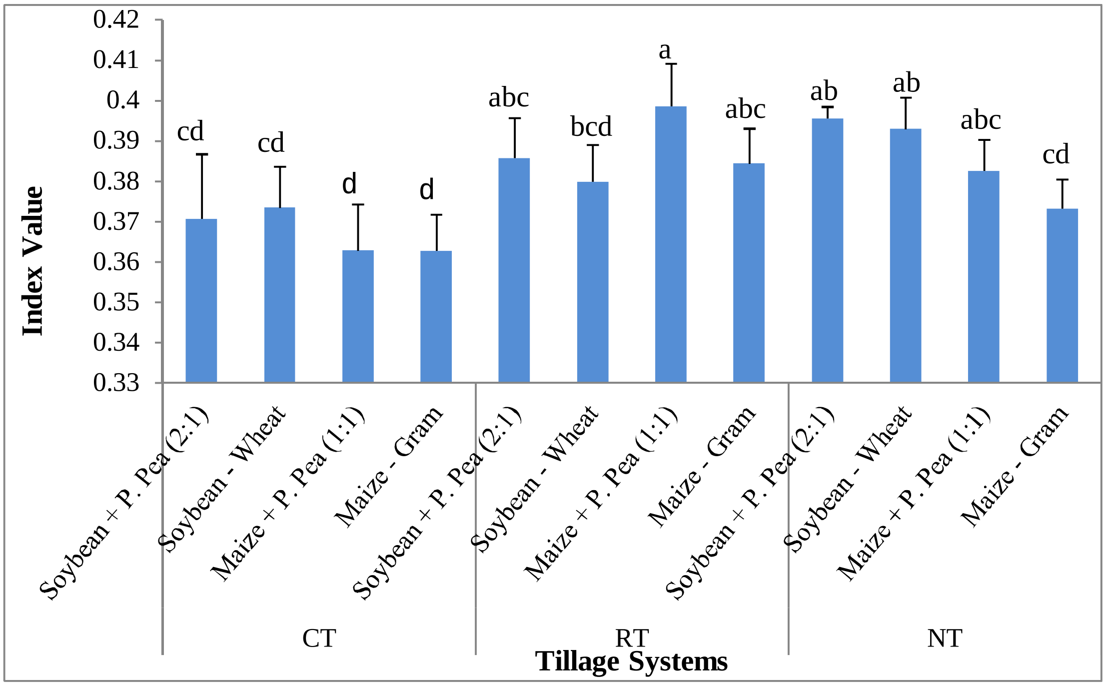

Fig. 2: Soil quality index under different tillage and cropping systems. Same letter (a, b, c and d) are not significantly different as per Duncan's multiple range test (P<0.05); conventional tillage (CT), reduce tillage (RT) and no tillage (NT)

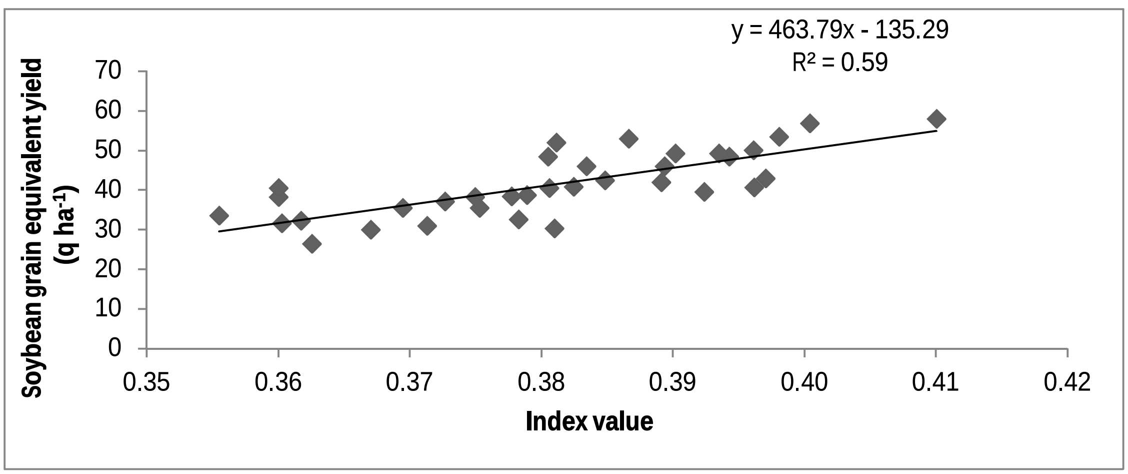

Fig. 3: Correlation between SQI and soybean grain equivalent yield

Conclusion: The study revealed that conventional tillage system deteriorated soil physical condition as it resulted in very low MWD and poor soil aggregation. PCA analysis showed that 73.2% cumulative variance was explained by the selected (soil pH, EC, MWD, OC and Av-K) PC1, whiles Av-N and Av-P were contributed from PC-3. Further, the soil quality under conventional tillage was low as compared to conservation agricultural practices which indicated that minimum soil disturbances coupled with residue retention improves and/or sustains soil properties and provides better soil environment for plant growth. It is evident that crop productivity is one of the reliable ways to evaluate soil quality. SQI was positively and significantly correlated with soybean grain equivalent under all the tillage and cropping systems. This implies that the index parameters are useful for computing the soil quality under different management practices.

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