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Impact of long-term fertilization on soil quality and fertility under soybean-safflower cropping sequence in Vertisol

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ABSTRACT

The present study was undertaken during 2010-2013 in an ongoing long-term fertilizer Experiment initiated during 2006-2007 at Vasantrao Naik Marathwada Agricultural University, Parbhani with organic and inorganic applications to assess the impact of long-term fertilization on soil quality and fertility under soybean-safflower cropping sequence in Vertisol (*Typic Haplusterts*) having 12 treatments framed in randomized block design (RBD). The results indicated that the highest total soil quality index (SQI) (0.71) was noted with the application of 100% NPK + FYM @ 5 Mg ha^{-1}, followed by 150% NPK (0.69) and 100% NPK + $ZnSO_4$ @ 25 kg ha^{-1} (0.65) treatments with the lowest value (0.51) under absolute control treatment. Similar trend was observed in case of other analysis. Among the various treatments, application of NPK + FYM proved superior, which not only had better soil quality, but also the most promising for maintaining soil fertility in Vertisol.

1. INTRODUCTION

Soil is a key natural resource and soil quality is the integrated effect of management of most of soil properties that determine crop productivity and sustainability. Good soil quality not only produces good crop yield, but also maintains environmental quality, and consequently plant, animal and human health. A quantitative assessment of soil quality can provide much needed information on the adequacy of the world's soil resource base in relation to the food and fiber needs of a growing population. Continuous cropping without use of any fertilizer and imbalanced application of fertilizers leads to reduction in the level of soil organic matter in semi-arid region of central India. Unless soil management practices are improved, yield reduction continues and long-term production will be under threat. The inadequate and imbalanced chemical fertilizer use, decline in SOM and insufficient studies contribute the most to the loss of soil quality. For sustainable production, utilization of farm yard manure and fertilizers is an efficient management to maintain soil quality. For maintaining SOM, it is necessary to maintain soil organic carbon (SOC) under intensive cropping system (Meshram *et al*., 2018). Soil quality can be assessed by measuring soil attributes or properties that serve as soil quality indicators. The changes in these indicators signal the changes in soil quality (Brejda and Moorman, 2001). Declining soil fertility and soil loss are the predominant causes of soil degradation in rainfed regions, undoubtedly due to water erosion. In fact, the process of water erosion sweeps away the topsoil alongwith organic matter and exposes the sub-surface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition owing to high temperature prevailing in these regions. Several other farming practices such as reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of existing residue in the field itself for preparation of clean seed bed, open grazing etc. aggravate the process of soil degradation. As a result of several above-mentioned reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil quality, and ultimately end up with poor functional capacity (Sharma *et al*., 2007). In order to restore the quality of degraded soils and to prevent them from further degradation, it is of paramount importance to focus on restorative practices and conservation agricultural practices on long-term basis. To do so, several physical, chemical and biological indicators of soil quality were evaluated using data collected from a long-term organic manure and inorganic fertilization management experiment. Strategies for using these indicators to develop an overall SQI that is meaningful to crop grown under semi-arid agro-ecosystem were evaluated and used to gauge the level of improvement or decline in soil condition.

2. MATERIALS AND METHODS

The present study was conducted during 2012-2013 in an ongoing field experiment started during 2006-2007 at Long-Term Fertilizer Experiment Research Farm situated at 76°46'E longitudes and 19°16'N latitudes with an elevation of 408.46 m above mean sea level in the Department of Soil Science and Agricultural Chemistry, Vasantrao Naik Marathwada Agricultural University, Parbhani, Maharashtra, India. The farm represents semi-arid tropic region with hot summers and mild winters where annual maximum temperature ranged from 29.2°C to 42°C in the month of May and minimum temperature ranged from 9.2°C to 27.8°C in the month of December in the year 2012-2013, the study period. Total annual rainfall was 720.5 mm during 2012-2013. The soil of the experimental site is Vertisol, particularly montmorillonitic, hyperthermic family of *Typic Haplustert*.

The present experiment was framed in randomized block design (RBD) with twelve treatments and four replications in soybean-safflower cropping system. The treatments comprise *viz.,* T_1 - 50% NPK, T_2 - 100% NPK, T_3 - 150% NPK, T_4 - 100% NPK + Hand weeding, T_5 - 100% NPK + $ZnSO_4$ @ 25 kg ha^{-1}, T_6 - 100% NP, T_7 - 100% N, T_8 - 100% NPK + FYM @ 5 Mg ha^{-1}, T_9 - 100% NPK (-) Sulphur through DAP (Di-ammonium phosphate), T_{10} - Only FYM @ 10 Mg ha^{-1}, T_{11} - Absolute control and T_{12} Fallow. The crops soybean (*cv.* JS - 335) and safflower (*cv.* PBNS - 12) were raised during rainy and post-rainy seasons, respectively with recommended package of practices. Soybean and safflower crops were sown with 45 cm × 5 cm and 45 cm × 10 cm spacing between row to row and plant to plant, respectively. The 100% NPK was 30:60:30 kg ha^{-1} for soybean and 60:40:00 kg ha^{-1} for safflower. The fertilizers used were urea, single super phosphate (SSP) and muriate of potash. FYM was applied before 15 days of sowing only for rainy season crop and NPK was applied through straight fertilizers (urea, SSP and muriate of potash) as per treatments. Whereas, in T_9 treatment di-ammonium phosphate was used in place of SSP to avoid sulphur application. In T_4 treatment only two hand weedings were undertaken for weed control, without use of any weedicide. Inorganic fertilizers were applied as per recommended dose of fertilizer, and micro-nutrient through chemical fertilizer $ZnSO_4$. $5H_2O$. Representative surface soil samples were collected from the 0-15 cm depth, which were air dried, powdered and passed through 0.2 mm sieve for determination of pH, electrical conductivity (EC), organic carbon (OC), $CaCO_3$, exchangeable cations (Ca, Mg, Na and K), cation exchange capacity (CEC) and available NPKS as per the standard procedure after Jackson (1973). Available micro-nutrients (Zn, Fe, Mn and Cu) and heavy metals (Ni and Pb) were determined by using Diethylene Triamine Penta Acetic Acid (DTPA) extraction with the help of atomic absorption spectrophotometer (Lindsay and Narvell, 1978). Available B in soil was measured by hot water soluble B method using Azomethine - H reagent (Berger and Troug, 1944). Microbial populations (bacteria, fungi and actinomycetes) were determined by serial dilution plate technique (Dhingra and Sinclair, 1993). Soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) determination were done using chloroform fumigation technique as described by Vance *et al*. (1987) and Brookes *et al.* (1985). CO_2 evolution of soil was determined by alkali trap method as given by Anderson (1982). Phosphomonoesterases (Acid and Alkaline Phosphatase) activity in soil determines the enzymatic hydrolysis of p-nitrophenyl phosphate to p-nitrophenol, which was extracted by $CaCl_2$ –NaOH solution (Tabatabai and Bremner, 1969). Dehydrogenase enzyme activity in soil (Klein *et al*., 1971) was determined by triphenylformazan (TPF) produced by the reduction of 2, 3, 5 - triphenyl tetrazolium chloride (TTC). In addition, bulk density of soil was determined by dry clod coating technique as described by Blake and Hartge (1986). Maximum water holding capacity (MWHC) of soil was determined by using Keen-Rocrko-Waske-Box at wet and dry basis of water content as described by Sankaram (1966). Infiltration rate and hydraulic conductivity of soil were determined by using double ring infiltrometer and constant head method as described by Michael (1987). The experimental data was subjected to analysis of variances (ANOVA) (Panse and Sukhatme, 1985).

To determine a SQI, four main steps were followed: (i) define the goal *i.e.* Principle Component Analysis (PCA), (ii) select a minimum data set (MDS) of indicators that best represent soil function, (iii) score the MDS indicators based on their performance of soil function and (iv) integrate the indicator scores into a comparative index of soil quality. To select a representative MDS (Doran and Parkin, 1994), only those soil properties that showed significant treatment differences were selected. Significant variables were chosen for the next step in MDS formation through PCA (Andrews *et al*., 2002). 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 closest fit to the n observation in p-dimensional space, subject to being orthogonal to one another. The PCs receiving high eigen values and variables with high factor loading were assumed to be variables that best represented system attributes. Therefore, only the PCs with eigen values ≥ 1 and those that explained at least 5% of the variation in the data (Wander and Bollero, 1999) were examined. Within each PC, only highly weighted factors were retained for MDS. Highly weighted factor loadings were defined as having absolute values within 10% of the highest factor loading. When more than one factor was retained under a single PC, multivariate correlation coefficients were employed to determine if the variables could be considered redundant and therefore eliminated from the MDS. Well-correlated variables were considered redundant and only one was considered for the MDS having highest total sum of squared loadings. The rest were eliminated from the data set. If the highly weighted variables were not correlated, each was considered important and was retained in the MDS. After determining the MDS indicators, every observation of each MDS indicator was transformed using a linear scoring method (Andrews *et al*., 2002). Indicators were arranged in order depending on whether a higher value was considered "good" or "bad" in terms of soil function. For 'more is better' indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For 'less is better' indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value received a score of 1. In the present study, as all the indicators that were retained in the MDS were considered good when in increasing order, they were scored, as "more is better". Once transformed, the MDS variables for each observation were weighted using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigenvectors >1, provided the weighted factor for variables chosen under a given PC. We then summed up the weighted MDS variables scores for each observation using the following equation:

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

Total SQI = Σ Individual soil property index values

SQI = Total SQI / Maximum possible total soil quality index for properties measured.

Where, S is the score for the subscripted variable and W_i is the weighing factor derived from the PCA. Here the assumption is that higher index scores meant better soil quality or greater performance of soil function. Further, the percent contribution of each final key indicator was also calculated. The SQI values so obtained were tested for their level of significance at P = 0.05.

3. RESULTS AND DISCUSSION

Effect on Physical Properties

Significantly ($p<0.05$) maximum improvement in physical properties *viz*., bulk density, porosity, MWHC, infiltration rate and hydraulic conductivity were observed with super optimal dose of NPK with organic manure (100% NPK+ FYM) followed by 150% NPK and 100% NPK + $ZnSO_4$ @ 25 kg ha^{-1} which were found at par with each other, whereas less improvement was noted in absolute control (Table 1). The higher improvement in the treatments of integrated use of chemical fertilizers and organic manures may be attributed to better aggregation and improvement in soil structure caused due to increase in SOM which helps to maintain high pore spaces. The loose, porous, and well aggregated structure resulted into increased infiltration rate of soil (Badanur *et al.,* 1990). While decrease in the infiltration rate of soil due to increase in compaction leads to decrease in macro and micro-pores in soil (Bellakki and Badanur, 1994: Meshram *et al*., 2019).

Effect on Chemical Properties

The conjunctive use of organics and chemical fertilizers on long term basis (100% NPK + FYM @ 5 Mg ha^{-1}) significantly influenced the pH, EC, OC, available NPKS, DTPA-Zn, Fe, Mn, Cu, Ni, Pb and HWS-B except $CaCO_3$ of soil (Tables 1and 2). Considering the critical limits (Katyal and Rattan, 2003) of DTPA-Zn, Fe, Mn and HWS-B (0.6, 4.5, 2.0, 0.2 and 0.5 mg kg^{-1}, respectively), all the micronutrients are in sufficient amount. However, in inorganic applications, only150% NPK showed superiority, may be due to addition of organic matter in the form of root residue (Meshram *et al*., 2019). In contrast, continuous cultivation, use of organic and inorganic fertilizers and regular absorption by plants possibly keep the concentrations of heavy metals in soil within safe limits (Awashthi, 2000).

Exchangeable Ca, Mg, Na, K, CEC and BS were significantly higher with 100% NPK + FYM @ 5 Mg ha^{-1} followed by 150% NPK which were found to be at par with each other. Lowest values were observed in absolute control (T_{11}). Moreover, the application of 100% N alone and 50% NPK could not show a prominent result in soil quality, suggesting less aggregative effect of these treatments (Table 1). Bellaki and Badanur (1997) observed that continuous application of organics alongwith inorganic fertilizers significantly increased the CEC and exchangeable Ca and decrease in Na. In general, the increase in nutrients may be ascribed to the higher content of these nutrients in the compost amendments in first hand, and organic acids produced during the process of decomposition on the other hand, which enhanced the solubility of native exchangeable cations (Ca, Mg, Na and K) and their retention by organic colloids (Meshram *et al*., 2019).

Effect on Biological Properties

Integrated use of 100% NPK + FYM significantly increased CO_2 evolution, SMBC, SMBN, bacteria, actinomycetes, fungi, dehydrogenase enzyme activity, and acid and alkaline phosphatase activity over their initial

Table: 1
Soil fertility status after harvest of 7th cycle of soybean-safflower cropping sequence (2012-2013)

Tr. No.	BD	Porosity	MWHC	IR	HC	pH	EC	OC	$CaCO_3$	Exchangeable cations				CEC	BS	N	P_2O_5	K_2O
										Exch. Ca	Exch. Mg	Exch. Na	Exch. K					
T_1	1.32	50.58	53.84	1.75	0.98	8.11	0.233	5.87	5.72	32.39	13.94	0.24	0.51	51.63	91.33	219.06	16.37	766.65
T_2	1.30	52.32	55.27	1.83	1.04	8.15	0.245	6.05	5.56	34.68	15.76	0.28	0.54	54.53	94.01	228.78	17.89	775.49
T_3	1.28	54.19	57.61	2.05	1.15	8.21	0.253	6.32	5.65	35.86	18.95	0.32	0.59	57.40	97.07	253.85	19.61	805.69
T_4	1.29	52.55	56.12	1.87	1.07	8.16	0.234	6.21	5.58	34.93	16.39	0.28	0.55	55.15	94.53	226.48	18.10	775.40
T_5	1.26	53.01	56.79	1.91	1.11	8.19	0.245	6.23	5.55	35.17	17.83	0.29	0.56	56.13	95.94	233.56	18.47	776.33
T_6	1.30	52.15	55.19	1.80	1.03	8.17	0.239	5.63	5.53	33.13	15.68	0.27	0.53	53.51	92.78	223.39	18.05	766.15
T_7	1.31	48.81	53.34	1.69	0.92	8.14	0.232	5.54	5.78	31.84	13.48	0.23	0.50	51.37	89.72	214.56	15.56	753.55
T_8	1.22	55.13	58.28	2.12	1.17	7.95	0.235	6.62	5.30	37.03	19.82	0.33	0.61	59.64	98.13	269.67	19.90	810.35
T_9	1.27	51.84	54.12	1.87	1.03	8.16	0.231	5.64	5.51	33.73	15.75	0.27	0.54	53.60	93.81	228.04	17.81	767.19
T_{10}	1.24	52.06	56.25	1.84	1.06	7.90	0.215	6.43	5.29	32.82	14.87	0.26	0.53	53.33	90.99	227.52	19.28	768.42
T_{11}	1.36	47.05	52.12	1.68	0.89	8.15	0.225	5.45	5.85	29.12	12.52	0.21	0.47	49.56	85.42	182.36	12.71	734.71
T_{12}	1.37	46.12	51.17	1.65	0.86	8.08	0.226	5.54	5.78	30.15	12.93	0.22	0.48	50.79	86.32	208.45	15.92	765.26
Mean	1.29	51.32	55.01	1.84	1.02	8.11	0.234	5.96	5.59	32.39	15.66	0.26	0.53	53.86	92.54	226.31	17.47	772.10
SE±	0.007	0.75	0.76	0.021	0.008	0.023	0.003	0.049	0.40	0.56	0.16	0.007	0.005	0.80	1.51	4.67	0.36	6.08
CD at (P=0.05)	0.021	2.18	2.19	0.061	0.025	0.068	0.010	0.141	NS	1.64	0.47	0.022	0.014	2.31	4.33	13.46	1.04	17.52
Initial status	3.36	48.22	52.18	1.75	0.89	8.18	0.243	5.50	6.12	32.53	11.86	0.23	0.56	54.72	82.56	216.00	18.32	766.15

NS: Non significant; BD: Bulk density (Mg m^{-3}); MWHC: Maximum water holding capacity (%); IR: Infiltration rate (cm ha^{-1}); HC: Hydraulic conductivity (cm ha^{-1}); EC: Electrical conductivity (dS m^{-1}); OC: Organic carbon (g kg^{-1}); $CaCO_3$ (%); Exchangeable (Ca, Mg, Na and K., cmol(p^+) kg^{-1} soil); CEC: Cation exchange capacity (cmol(p^+) kg^{-1} soil); BS: Base saturation (%); Available N, P_2O_5 and K_2O (kg ha^{-1}).

status in soil under the soybean-safflower cropping system. Further, treating plots with 150% NPK was found equally good in improving SMBC and SMBN due to addition of root biomass (Table 2). The continuous application of 100% N alone and 50% NPK caused an increase in yield over control but response exhibited declining yield with time due to imbalanced use of nutrients, apparently the higher stress due to inadequate nutrient supply in control. Super optimal fertilizer level restricted crop production and thus carbon substrate (root exudates) with consequent reduction in CO_2 evolution. The organic addition coupled with NPK fertilizer exerted a stimulating influence on the preponderance of soil microbial community *viz.,* bacteria, actinomycetes and fungi. This might be ascribed to the decomposed food material available from organic sources and the relatively higher rate of microbes multiplication in soil (Meshram *et al*., 2016; Meshram *et al*., 2018).

Selection of Indicators

Soil responses to different nutrient management supply systems had significantly influenced all the soil parameters except $CaCO_3$ over the initial status, and data are presented in Table 4. Among the 34 variables, DTPA extractable Zn had the most significantly high negative loadings and DTPA extractable Cu had the high positive. For initial screening of indicators, parameters showing significant effect were considered important and retained for PCA analysis. $CaCO_3$ of soil was found non-significant and dropped from PCA analysis and remaining 34 parameters were selected for PCA analysis.

Results of Principal Component Analysis (PCA)

PCA was performed on standardized 34 soil attributes. After two years residual effect for soybean-safflower system, the first four PCs showed 88.395% of variability of data. The PCs which explained 2.113% or more of the variability within the measured data were retained. For each PC, loadings of each attribute on components were obtained and are shown in Table 3. The insight of PCA findings (Table 4) clearly indicates that the first PC that explained 73.786% of the variance had high positive loadings on DTPA extractable Cu, followed by DTPA extractable Pb, DTPA extractable Fe, exchangeable Mg, DTPA extractable Ni, CO_2 evolution, hydraulic conductivity, DTPA extractable Mn, hot water soluble B, acid phosphatase enzyme activity, exchangeable K, dehydrogenase enzyme activity, alkaline phosphatase enzyme activity, SMBC, infiltration rate, exchangeable Na, OC, SMBN and exchangeable Ca within 10% of the highest loading (0.977). The second PC, which explained 8.489% of the variance, had high

Table: 2
Soil fertility status after harvest of 7th cycle of soybean-safflower cropping sequence (2012-2013)

Tr. No.	S	Zn	Fe	Mn	Cu	B	Ni	Pb	Bacteria	Fungi	Actino	SMBC	SMBN	Co_2	DHA	Acid Phosphatase	Alkaline Phosphatase
T_1	25.46	0.77	4.71	8.25	2.34	0.72	0.24	0.71	127.69	5.19	30.20	221.65	38.02	41.85	39.82	62.46	138.16
T_2	28.12	0.81	5.02	9.17	2.52	0.83	0.32	0.80	139.75	6.45	33.19	237.46	44.73	45.18	43.76	66.30	142.23
T_3	31.33	0.79	5.37	11.46	2.71	0.92	0.45	0.92	138.45	7.92	42.21	290.71	51.24	56.67	47.18	72.24	157.30
T_4	28.22	0.82	5.12	9.57	2.55	0.84	0.33	0.81	169.01	6.67	35.13	247.50	46.36	47.81	42.96	67.09	145.67
T_5	29.31	1.33	5.26	10.16	2.64	0.90	0.37	0.84	147.54	7.10	39.03	270.18	48.79	49.46	44.52	69.14	148.21
T_6	25.73	0.76	4.82	9.07	2.50	0.81	0.32	0.78	135.03	5.34	31.16	230.56	41.52	43.63	41.15	64.74	141.12
T_7	23.21	0.74	4.65	7.96	2.29	0.68	0.23	0.68	117.68	5.19	28.12	207.20	35.75	36.05	37.86	58.15	134.13
T_8	32.13	1.08	5.49	12.29	2.81	0.97	0.47	0.94	216.91	8.49	55.96	297.22	53.16	59.51	52.35	76.22	161.81
T_9	23.10	0.78	4.81	9.01	2.48	0.79	0.31	0.77	134.95	5.31	36.04	228.78	49.75	42.18	40.89	63.13	139.47
T_{10}	30.12	0.93	5.17	9.43	2.53	0.82	0.34	0.82	196.94	9.03	52.25	280.02	42.67	53.26	45.21	66.75	143.91
T_{11}	22.37	0.69	4.61	7.71	2.25	0.64	0.21	0.65	103.49	4.46	25.28	195.96	29.14	34.56	34.76	56.24	132.31
T_{12}	24.39	0.87	4.63	7.82	2.27	0.67	0.22	0.67	95.34	5.01	26.86	212.16	31.86	36.15	36.35	57.73	133.75
Mean	26.96	0.86	4.97	9.32	2.49	0.80	0.32	0.78	143.56	6.34	36.28	243.28	42.75	45.52	42.23	65.01	143.17
SE±	0.43	0.006	0.017	0.048	0.012	0.009	0.007	0.007	3.77	0.26	0.67	3.14	0.69	0.69	0.67	0.83	0.84
CD at (P=0.05)	1.23	0.018	0.049	0.140	0.036	0.028	0.020	0.020	10.86	0.75	1.94	9.05	2.00	1.98	1.93	2.39	2.43
Initial status	30.50	0.98	5.12	9.74	2.86	0.85	0.32	0.81	156.23	7.69	41.36	235.71	42.53	51.18	42.51	65.10	132.76

Available S (Kg ha^{-1}); DTPA extractable Zn, Fe, Mn, Cu, Ni and Pb (mg kg^{-1}); B: Hot water soluble B (mg kg^{-1}), Bactria (CFU X 10^7 g^{-1} soil); Fungi (CFU X 10^4 g^{-1} soil); Actino: Actinomycets (CFU X 10^6 g^{-1} soil); SMBC, Soil microbial biomass carbon (µg g^{-1}); SMBN: Soil microbial biomass nitrogen (µg g^{-1}); CO_2, CO_2 evolution in soil (mg 100^{-1} soil 24 hr^{-1}); DHA: Dehydrogenase enzyme activity in soil (µg TPF g^{-1} soil 24 hr^{-1}); Acid and alkaline phosphatase enzyme activity in soil (µg p-NP g^{-1} soil hr^{-1}).

Table: 3
Total variance explained by PCA

Component	Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %
PC1	25.825	73.786	73.786
PC2	2.971	8.489	82.276
PC3	1.402	4.006	86.282
PC4	0.740	2.113	88.395

positive loadings on pH (0.858). No other component was observed within the range of 10%. The third PC, which explained 4.006% of the variance, had high positive loadings on EC (0.437) and available S (0.408). No other component was observed within the range of 10%. The fourth PC, which explained 2.113% of the variance, had high negative loadings on DTPA extractable Zn (-0.597). Andrews *et al*. (2002) reported that choice among well-correlated variables could also be based on the practicability of the variables. Hence, one could use the options to retain or drop the variables from the final MDS considering the ease of sampling, cost of estimation and logic and interpretability. Considering these reports, options were utilized to retain or eliminate the variables from the MDS. Hence, the final MDS consisted of MBC, N, K, HC and S. The most significant variables in the components represented by high loadings have been taken into consideration in evaluating the components. The components with larger variances are more desirable as they give more information about the data (Sharma *et al*., 2005; Meshram and Syed Ismail, 2015). Recently, (Saikia *et al*., 2019) noticed during principal component analysis and identified β-glucosidase, cellulase and phenol oxidase activities as the most sensitive and reliable indicators for assessing soil quality under rice-wheat based system.

Soil Quality Index (SQI)

After seven years residual effect on SQI for soybean-safflower cropping system, 34 soil attributes were analyzed for the determination of SQI. Out of these 34 attributes, 23 soil attributes contributed high indicator scoring of the MDS indicators based on their performance of soil functions for SQI. All of these soil quality indicators were tested significantly at the level ($p<0.05$) as considered for determination of SQI. The highest value of total SQI was observed with the integrated use of NPK and FYM (0.71) and towards the improvement with the applications of super optimal dose of fertilizer (150% NPK) (0.69) and micro-nutrient (Zn) incorporated with recommended dose of fertilizer (0.65). The super optimal dose of fertilizer (150% NPK) was significantly superior in case of inorganic application due to higher amount of root residue added in soil to contribute higher OC.

Table: 4
Principal components analysis (PCA) of soil parameters based on 12 treatments under soybean-safflower system (after 7th cycle of crops)

Component Matrix[a]				
Factor loading / eigen vector variable	Component			
	PC1	PC2	PC3	PC4
Physical indicators				
Bulk density (Mg m^{-3})	**-0.839**	0.102	0.378	0.201
Porosity (%)	0.857	0.220	-0.246	-0.042
Maximum water holding capacity (%)	0.828	0.073	-0.053	-0.058
Infiltration rate (cm hr^{-1})	0.941	0.126	0.051	**0.005**
Hydraulic conductivity (cm hr^{-1})	0.966	0.145	-0.058	-0.074
Physico-chemical indicators				
pH	-0.079	**0.858**	0.197	-0.170
EC (dS m^{-1})	**0.387**	0.696	**0.437**	0.111
Organic carbon (g kg^{-1})	0.905	-0.281	0.057	0.042
Exchangeable Ca (Cmol (p^+) kg^{-1}soil)	0.888	0.088	-0.083	0.105
Exchangeable Mg (Cmol (p^+) kg^{-1}soil)	0.972	0.114	0.098	-0.052
Exchangeable Na (Cmol (p^+) kg^{-1}soil)	0.929	0.095	-0.061	0.080
Exchangeable K (Cmol (p^+) kg^{-1}soil)	0.962	0.116	-0.041	-0.041
Cation exchange capacity (Cmol (p^+) kg^{-1}soil)	0.884	0.067	0.019	-0.145
Base saturation (%)	0.790	0.132	-0.043	0.212
Available N (kg ha^{-1})	0.861	0.119	0.013	0.026
Available P_2O_5 (kg ha^{-1})	0.862	0.062	-0.145	0.097
Available K_2O (kg ha^{-1})	0.783	0.115	**-0.326**	**0.319**
Available S (kg ha^{-1})	0.765	-0.310	0.408	0.195
DTPA extractable Zn (mg kg^{-1})	0.511	-0.320	0.385	**-0.597**
DTPA extractable Fe (mg kg)	0.973	-0.095	0.109	-0.040
DTPA extractable Mn (mg kg^{-1})	0.966	0.041	0.095	0.012
DTPA extractable Cu (mg kg^{-1})	**0.977**	0.092	0.035	-0.044
Hot water soluble B (mg kg^{-1})	0.964	0.135	0.015	-0.094
DTPA extractable Ni (mg kg^{-1})	0.968	0.094	0.039	0.010
DTPA extractable Pb (mg kg^{-1})	0.975	0.090	**0.002**	-0.004
Biological indicators				
Bacteria (CFU x 10^7 g^{-1} soil)	0.823	0.378	-0.311	-0.036
Actinomycetes (CFU x 10^6 g^{-1} soil)	0.874	**-0.391**	-0.182	-0.020
Fungi (CFU x 10^4 g^{-1} soil)	0.636	-0.522	-0.172	0.077
Co_2 evolution (mg 100^{-1} soil 24 hr^{-1})	0.968	-0.120	-0.006	0.089
Soil microbial biomass carbon (μg g^{-1})	0.952	-0.173	0.054	0.008
Soil microbial biomass nitrogen (μg g^{-1})	0.898	0.274	-0.121	-0.140
Dehydrogenase activity (μg TPF g^{-1}soil 24 hr^{-1})	0.956	-0.064	-0.060	0.031
Acid phosphatase activity (μg p-NP g^{-1} soil hr^{-1})	0.963	0.038	0.037	-0.017
Alkaline phosphatase activity (μg p-NP g^{-1} soil hr^{-1})	0.955	**0.031**	0.124	0.045
Weights	**73.786**	**8.489**	**4.006**	**2.113**

However, the SQI value was low (0.51) under treatment (T_{11}) absolute control due to continuous nutrient removal by crop resulting into declining soil quality. Moreover, the application of 100% N alone and 50% NPK could not show a prominent result in soil quality, suggesting less aggregative effect of these treatments. Thus, integrated use of recommended dose of fertilizer and organic manure (*i.e.* T_8 - 100% NPK + FYM @ 5 Mg ha^{-1}) took Ist rank, because of the highest SQI obtained in the treatment as compared to all other treatments shown in Table 5. It might be due to high quality and have a very low level of concern. A high score means a high potential and a low score means a low potential *i.e.* concern for negative impact (Sharma *et al*., 2005). Masto *et al*., 2007 and Meshram and Syed Ismail, 2015 also stated that the highest SQI was observed with the combined applications of NPK and manures.

4. CONCLUSIONS

Maintaining soil quality and fertility by application of 100% NPK + FYM @ 5 Mg ha^{-1} was found to be beneficial with respect to soil fertility build up and overall soil quality under soybean-safflower cropping sequence grown in Vertisol. Among the various treatments, application of 150% NPK was found superior in case of only inorganic applications and better option for inorganic means. Integration of organic and inorganic fertilizers and balanced

Table: 5
Soil quality index (SQI) as influenced by different nutrient management practices under soybean-safflower cropping sequence

Soil parameters	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}
Infiltration rate (cm hr^{-1})	0.69	0.72	0.81	0.74	0.75	0.71	0.67	0.84	0.74	0.73	0.66	0.65
Hydraulic conductivity (cm hr^{-1})	0.71	0.76	0.83	0.78	0.81	0.75	0.67	0.85	0.75	0.77	0.65	0.62
pH	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
EC (dS m^{-1})	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Organic carbon (g kg^{-1})	0.76	0.78	0.82	0.80	0.81	0.73	0.72	0.86	0.73	0.83	0.71	0.72
Exchangeable Ca (cmol (p^+) kg^{-1} soil)	0.73	0.76	0.80	0.78	0.79	0.74	0.71	0.83	0.74	0.78	0.65	0.68
Exchangeable Mg (cmol (p^+) kg^{-1} soil)	0.58	0.66	0.79	0.68	0.74	0.65	0.56	0.83	0.62	0.66	0.52	0.54
Exchangeable Na (cmol (p^+) kg^{-1} soil)	0.60	0.69	0.80	0.70	0.73	0.69	0.57	0.83	0.67	0.71	0.53	0.55
Exchangeable K (cmol (p^+) kg^{-1} soil)	0.70	0.73	0.79	0.75	0.76	0.73	0.68	0.83	0.72	0.74	0.64	0.66
CEC (cmol (p^+) kg^{-1} soil)	0.72	0.75	0.80	0.77	0.79	0.75	0.72	0.83	0.75	0.77	0.70	0.71
Available S (kg ha^{-1})	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.01
DTPA extractable Fe (mg kg^{-1})	0.78	0.80	0.82	0.80	0.81	0.79	0.78	0.82	0.79	0.81	0.77	0.78
DTPA extractable Mn (mg kg^{-1})	0.55	0.61	0.77	0.64	0.68	0.61	0.53	0.82	0.60	0.63	0.52	0.52
DTPA extractable Cu (mg kg^{-1})	0.68	0.74	0.80	0.74	0.77	0.73	0.67	0.82	0.73	0.74	0.66	0.66
Hot water soluble B (mg kg^{-1})	0.65	0.74	0.82	0.75	0.80	0.73	0.61	0.86	0.70	0.73	0.57	0.60
DTPA extractable Ni (mg kg^{-1})	0.41	0.57	0.78	0.58	0.64	0.55	0.40	0.82	0.54	0.59	0.36	0.38
DTPA extractable Pb (mg kg^{-1})	0.62	0.70	0.81	0.71	0.74	0.69	0.59	0.81	0.68	0.72	0.57	0.59
Soil microbial biomass carbon (µg g^{-1})	0.61	0.65	0.79	0.68	0.74	0.63	0.57	0.81	0.63	0.77	0.58	0.54
Soil microbial biomass nitrogen (µg g^{-1})	0.58	0.68	0.78	0.70	0.74	0.63	0.54	0.80	0.75	0.65	0.48	0.44
CO_2 evolution (mg 100^{-1} soil 24 hr^{-1})	0.54	0.59	0.74	0.62	0.64	0.57	0.47	0.77	0.55	0.69	0.45	0.47
Dehydrogenase activity(µg TPF g^{-1} soil 24 hr^{-1})	0.58	0.64	0.69	0.63	0.65	0.60	0.56	0.77	0.60	0.66	0.51	0.53
Acid phosphatase (µg p-NP g^{-1} soil hr^{-1})	0.62	0.66	0.72	0.67	0.69	0.64	0.58	0.76	0.63	0.67	0.56	0.58
Alkaline phosphatase (µg p-NP g^{-1} soil hr^{-1})	0.65	0.66	0.73	0.68	0.69	0.66	0.63	0.76	0.65	0.67	0.62	0.62
Total SQI	12.89	14.01	15.81	14.34	14.90	13.70	12.34	16.44	13.66	14.42	11.84	11.94
SQI	**0.56**	**0.61**	**0.69**	**0.62**	**0.65**	**0.60**	**0.54**	**0.71**	**0.59**	**0.63**	**0.51**	**0.52**
Rank	IX	VI	II	V	III	VII	X	I	VIII	IV	XII	XI

applications is the best way for restoring and maintaining soil quality in Vertisols.

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