Indian J. Dryland Agric. Res. & Dev. 2020 35(1): 27-35 10.5958/2231-6701.2019.00014.9

Impact of Conjunctive Nutrient Management Practices on Soil Quality Indicators and Soil Quality Indices under Maize (*Zea mays*) - Wheat (*Triticum aestivum*) Cropping System in Hill and Mountainous Inceptisol Soils of Northern India

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ABSTRACT: A field experiment was conducted in the rainfed Inceptisol soils of Rakh Dhiansar in Kandi areas of Western Himalayas of South Kashmir and Kumaon from 2001 to 2005. The main focus of the present study was to quantify the impact of conjunctive nutrient management practices on soil quality parameters, to identify the key indicators of soil quality using data redundancy technique and to compute integrated soil quality indices (SQIs) and relative soil quality indices (RSQIs) as influenced by the conjunctive nutrient management treatments in hill and mountainous Inceptisol soils in Northern India under maize - wheat system. Out of the total 10 treatments, five treatments *viz.,* T1: control, T2: FYM @ 10 t/ha + 20 kg N/ha, T3: FYM @ 10 t/ha + 30 kg N/ha, T4: FYM @ 10 t/ha + 40 kg N/ha and T5: green manuring with sunhemp + 20 kg N/ha were selected for the soil quality assessment studies. The nutrient management treatments significantly influenced the SQIs which varied between 3.69 to 5.66 across the management treatments, while the RSQIs varied between 0.63 to 0.96. Of all the nutrient management treatments, the application of FYM @ 10 t/ha + 40 kg N/ha maintained significantly highest SQI of 5.66, which was at par with the application of FYM @ 10 t/ha + 30 kg N/ha and green manuring with sunhemp + 20 kg N/ha both of which maintained SQI of 5.40. Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in maintaining the soil quality indices was: T4: FYM @ 10 t/ha + 40 kg N/ha (5.66) > T5: Green manuring with sunhemp + 20 kg N/ha (5.44) > T3: FYM @ 10 t/ha + 30 kg N/ha (5.40) > T2: FYM @ 10 t/ha + 20 kg N/ha (5.16) > T1: control (3.69). The per cent contributions of each of these key indicators towards SQIs were also computed. It was observed that almost all the key indicators contributed more or less equally towards the SQIs except available N and available Fe, which contributed to a minimum extent of 2.27% and 1.90%, respectively. The per cent contribution of the other key indicators was as follows: organic carbon (13.8%), available P (13.4%), available K (14.5%), available Zn (12.6%), microbial biomass carbon (13.7%), bulk density (15.2%) and mean weight diameter (11.6%).

Key words: Conjunctive nutrient management, inceptisol, key indicators and soil quality indices

Introduction

The Inceptisol soils are predominantly found in cool or dry climates which are weakly developed from resistant or new parent material. Taxonomically, Inceptisols possess a recognizable A horizon, but only a weak B horizon. The area under Inceptisol soils in India is about 95.8 million hectares, constituting 29.13% of total geographical area, which are mostly spread across the Indo-Gangetic Plain and along the lower courses of the country's major rivers, especially the deltas along the east coast. These Inceptisol soils are agriculturally very important but they suffer from problems like severe soil erosion, poor soil fertility, imbalanced use of nutrients and low soil organic matter, which hamper the productivity on a long-run basis.

The study location *viz.,* Rakh Dhiansar is situated in Kandi area of Western Himalayas of South Kashmir and Kumaon, and represents warm moist to dry sub-humid transitional eco-sub-region (AESR 14.2). Besides this, the other soil related problems in this region include water erosion with slight loss of topsoil (11-25% area), slight chemical deterioration (6-10% area) and slight water logging (6-10% area). The productivity of major crops in the study region is low due to several productivity related soil constraints. Manna *et al.* (2006) attributed the decline in the yields of most of the crops grown in Inceptisol soils to gradual depletion of nutrients, variations in soil organic matter, and structural degradation. Whereas, Sharma *et al.* (2004) and Sharma and Chaudhary (2007) reported that some of the important factors that contribute to increased depletion of micronutrients and secondary nutrients in Inceptisol soils could be intensive cultivation using high analysis nitrogen (N), phosphorus (P) and potassium (K) fertilizers, limited use of organic manures, and low or very low recycling of crop residues back to the soil. However, Singh *et al.* (2004) have clearly established that building up of organic matter in the rainfed regions is quite difficult and should be a long-term goal, which can be achieved only if application rates of organics exceed the decomposition rate. Parr *et al.* (1990) reported that one of the important features of sustainability of agriculture is its lower dependence on chemical fertilizers, which can be achieved by recycling on-farm wastes to maintain or improve soil fertility. While highlighting the importance of minimizing tillage operations, Lal (1993) reported that intensive tillage operations may lead to decline in soil structure, accelerated erosion, depletion of soil organic matter (SOM) and fertility, and disruption in cycles of water, organic carbon and plant nutrients. According to Suri (2007) such degrading effects are more pronounced especially in stressed agro-ecologies such as hot semi-arid rainfed conditions, where the soils experience many constraints on account of physical, chemical, and biological health which lead to overall poor functional capacity i.e. quality and low productivity of these soils (AICRPDA, 2003).

Doran and Parkin (1994) have defined soil quality as the "capacity of the soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health". Traditionally, the soil quality was viewed as the inherent capacity of the soil to supply essential plant nutrients. Later, it was considered as an abstract characteristic of soils that could not be defined because of its dependence on external factors such as land use and soil management practices, ecosystem and environmental interaction, socioeconomic and political priorities and so on (Doran *et al.,* 1996).

Maize-wheat cropping system is an important system for marginal lands of the hill and mountainous Inceptisol soils. Besides this, maize crop has been proved as a promising option for diversifying the agriculture in upland areas of India including marginal Inceptisols and this crop now ranks as the third most important food grain crop in India. The productivity of rainfed maize - wheat system in the marginal lands of the hill mountainous Inceptisol soils is constrained due to inherently poor soil fertility, low soil organic matter and also low water holding capacity. The recycling of biomass (crop residue and green manuring) back to the soil by the farmers is also showing decreasing trend, thereby affecting the productivity and sustainability of these soils. The present study on conjunctive nutrient management was aimed at reducing the use of inorganic fertilizers and to supplement the nutrient supply through organic sources and to improve the soil quality. Hence, the use of compost, along with FYM, need to be encouraged considering its short supply. Moreover, the inclusion of organic wastes in composting also serves as a means for organic recycling. Therefore, the present study was undertaken with the specific objectives: (i) to quantify the effects of conjunctive nutrient management on soil quality parameters (ii) to identify the key indicators of soil quality using data redundancy technique and (iii) to compute integrated soil quality index (SQI) and relative soil quality index (RSQI) as influenced by conjunctive nutrient management treatments.

Materials and Methods

In order to find out the effects of FYM and green manuring practices (sunhemp), along with different doses of nitrogen on soil quality, the present experiment was initiated at All India Coordinated Research Project for Dryland Agriculture (AICRPDA) sub centre, Rakh Dhiansar, in the state of Jammu and Kashmir, (now Union Territory) situated at 32^o 17′ N latitude and 75^o 36′ E longitude in Kandi areas of Western Himalayas of South Kashmir and Kumaon, which represent warm moist to dry sub-humid transitional eco-sub-region (AESR 14.2). The mean annual rainfall at the experimentation location is 1180 mm. The length of growing period in this area is 150-210 days. These soils are medium to deep, sandy loam to loamy in texture, representing Inceptisol soil order. Soils have medium available water capacity with near neutral soil reaction and suitable electrical conductivity. The experiment was initiated during the year 2001 in a randomized block design (RBD) with ten nutrient management treatments in three replications using maize (Kanchan-510) as the test crop. Out of the 10 treatments, only five important treatments *viz.,* T1: Control, T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}, T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}, T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1} and T5: Green manuring with Sunhemp + 20 kg N ha^{-1} were selected for the soil quality assessment studies. Soil quality studies were undertaken after fifth year of the experimentation.

Soil sampling and analysis

After 5^{th} year of the experimental study, surface soil samples were collected from plough layer (0-0.15 m depth) separately from each treatment. These samples were ground, partitioned and passed through standard prescribed sieves for further use in different kinds of analyses. Soil samples passed through 8 mm sieve and retained on the 4.75 mm sieve were used for aggregate analysis, while the samples passed through 0.2 mm sieve were used for estimating organic carbon (OC) as well as labile carbon (LC). For the rest of the soil quality parameters *viz.,* chemical and biological parameters, soil samples passed through 2 mm sieves were used. Soil pH was measured in 1:2 soil water suspensions where 10 gm of soil was taken and stirred intermittently for 30 minutes with 20 ml water and measured with pH meter (McLean, 1982). The electrical conductivity was measured in 1:2 soil water suspension using conductivity meter

(Rhoades, 1982). Organic C was determined by the modified Walkley-Black wet digestion method (Walkley and Black 1934). Available nitrogen was estimated by alkaline-$KMnO_4$ method (Subbaiah and Asija 1956). Bicarbonate-extractable P was extracted with 0.5 M sodium bicarbonate (pH of 8.5) and was determined calorimetrically (Olsen *et al.,* 1954). Available potassium (K) was extracted with neutral normal ammonium acetate solution and the extract was analyzed for potassium on inductively coupled plasma spectrophotometer (ICP-OES, GBC, Australian Model) (Hanway and Heidal 1952). Exchangeable Ca and Mg were also determined in the extract by using 1N ammonium acetate solution as extractant and using atomic absorption spectrophotometer (GBC906, Australian Model) (Lanyon and Heald 1982). Sulphur was extracted with 0.15% $CaCl_2$ reagent (Williams and Steinbergs 1959) and was estimated turbidimetrically with a colorimeter using blue filter in spectrophotometer at 340 nm. The micronutrients *viz.,* Zn, Fe, Cu and Mn were estimated using the method suggested by Lindsay and Norvell (1978) with inductively coupled plasma spectrophotometer (ICP), (model ICP-OES simultaneous system, GBC-Australia) while, boron was estimated using DTPA-Sorbitol extraction method (Miller *et al.,* 2001).

Bulk density was measured by Keen's box method (Keen and Raczkowski 1921). The distribution of water stable aggregates was determined by wet sieving technique using sieves of 4750 µm, 2000 µm, 1000 µm, 500 µm, 250 µm and 100 µm sizes (Yoder, 1936) and mean weight diameter (MWD) was computed after oven drying (Van Bevel, 1949). Dehydrogenase activity in the soils was measured by triphenyl tetrazolium chloride method (TTC) (Lenhard, 1956). The results were expressed as μg TPF formed per hour per gm soil. Soil microbial biomass carbon (MBC) was determined using the chloroform fumigation incubation technique (Jenkinson and Powlson 1976). Immediately after collection, the portion of the 2 mm sieved samples was preserved in a horizontal refrigerator at 4-5 ^{o}C. Before analyzing MBC, these samples were taken out of the refrigerator and primed in BOD incubator at field capacity (15% w/w) moisture regime for 10 days at 25 °C ± 1^{0}C temperature. MBC was calculated using the following relationship

$$\text{MBC } (\mu g\ g^{-1} \text{ of soil}) = (EC_F - EC_{UF}) / K_{EC}$$

Where EC_F is the total weight of extractable carbon in fumigated sample, EC_{UF} is the total weight of the extractable carbon in unfumigated samples and K_{EC}= 0.25 ± 0.05 represents the efficiency of extraction of microbial biomass carbon. Labile carbon, which is also considered as one of the important biological soil quality indicators, was estimated using the method suggested by Weil *et al.* (2003) with slight modification. In this method, moist fresh air dried soil was equilibrated with 20 ml 0.01 M $KMnO_4$ solution for 15 minutes. The soil-solution suspension was centrifuged at 3000 rpm for 5 min. The absorbance was measured at 550 nm using spectrophotometer (Model SL 171 of Elico Ltd.).

Computation of soil quality indices (SQIs)

Statistical analysis was done for the rigorous data set obtained for all the 19 soil quality parameters for their level of significance using randomized block design (RBD). After the statistical analysis, the parameters which were found significant were subjected to principal component analysis (PCA) using SPSS software (Version 12.0). The principal components (PC) which received eigen values ≥1 (Brejda *et al.,* 2000a, b) and explained at least 5% of the variation in the data (Wander and Bollero 1999) and variables which had high factor loading were considered as the best representatives of system attributes. Within each PC, only highly weighted factors (having absolute values within 10% of the highest factor loading) were retained for the minimum data set (MDS). The final MDS variables were regressed with the yield as management goals. The variables qualified under these series of steps were termed as the 'key indicators' and were considered for computation of soil quality index (SQI) after suitable transformation and scoring.

All the observations of each identified key MDS indicators were transformed using linear scoring technique (Andrews *et al.,* 2002). To assign the scores, indicators were arranged in order depending on whether a higher value was considered "good" or "bad" in terms of soil function. In case of '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. After the transformation using linear scoring method, the MDS indicators 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 when divided by the total percentage of variation explained by all PCs with eigen vectors > 1, gave the weighted factors for indicators chosen under a given PC. After performing these steps, to obtain soil quality index (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 meant better soil quality or greater performance of soil function. For better understanding and relative comparison of the long-term performance of the conjunctive nutrient use treatments, the SQI values were reduced to a scale of 0-1 by dividing all the SQI values with the highest SQI value. The numerical values thus obtained, clearly reflect the relative performance of the management treatments, and hence were termed as the 'relative soil quality indices (RSQIs)'. Further, the per cent contributions of each final key indicator towards SQI were also calculated and plotted in a pie chart.

Statistical analyses

Analysis of variance (ANOVA) was performed using 'Drysoft' design package. The randomized block design (RBD) was used for the experiment and the differences were compared by least significant difference (LSD) test at a significance level of $p < 0.05$ (Snedecor *et al.,* 1989). Principal component analysis (PCA) was performed using SPSS version 12.

Results and Discussion

Effect on physico-chemical and chemical soil quality parameters

The results, presented in Table 1, revealed that the nutrient management treatments had no significant influence on the physico-chemical parameters *viz.,* pH and electrical conductivity. However, the soil pH varied from near neutral to neutral ranging from 6.75 to 7.22, while electrical conductivity varied from 0.09 to 0.13 dS m^{-1}. Soils were observed to be medium in organic carbon content varying from 3.18 to 4.53 g/kg. Application of FYM @ 10 t/ha + 40 kg N/ha recorded significantly highest organic carbon content of 4.53 g/kg and was at par with other treatments since all the treatments received either FYM or green manure as a component of nutrient source which could improve and maintain the organic carbon in the long run. The chemical soil quality parameters i.e. available N, P and K were significantly influenced by the management treatments. Available N was low varying from 130.0 to 164.7 kg/ha, available P was high ranging from 19.7 to 34.0 kg/ha and available K also being high ranged from 194 to 262.8 kg/ha. Of all the treatments, the application of FYM @ 10 t/ha + 40 kg N/ha had significantly highest available N (164.7 kg/ha), available P (34.0 kg/ha) and available K (262.8 kg/ha) and was at par with other treatments (Figure 1). Sharma *et al.*(2016) reported that FYM based integrated nutrient management treatments significantly influenced pH, EC, available N, available P and available K under groundnut-finger millet system.

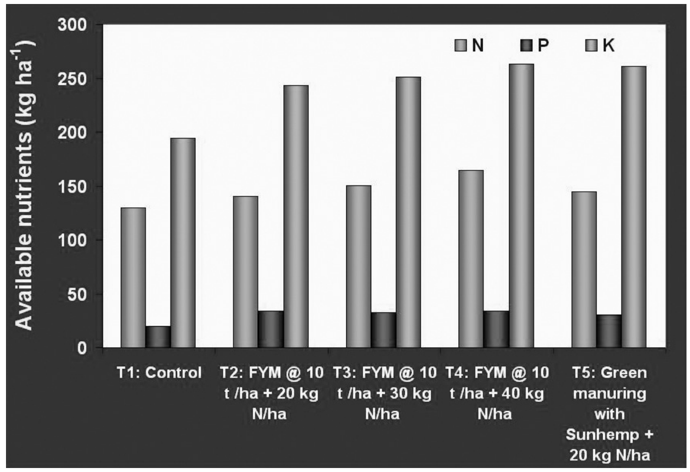

Fig. 1 : Influence of different nutrient management treatments on chemical soil quality parameters (macronutrients) under maize-wheat rotation system in Inceptisols of Rakh Dhiansar

Among the secondary nutrient parameters, available S was significantly influenced by the management treatments while exchangeable Ca and Mg were not (Table 2). However, exchangeable Ca varied from 2.97 to 3.83 cmol/kg and exchangeable Mg from 0.47 to 0.58 cmol/kg across the management treatments. Available S was found to be significantly highest under green manuring with sunhemp + 20 kg N/ha (19.5 kg/ha) which was at par with other treatments barring control plot (Figure 2). Among the micronutrients, the significant influence of the management treatments was observed on available Fe and Mn while no conspicuous influence was observed on Zn, Cu and B. However, irrespective of their significance, available Zn was found high in soils varying from 0.75 to 1.73 μg/g, Cu from 0.78 to 0.95 μg/g and B from 0.33 to 0.64 μg/g across the management treatments. Available Fe and Mn ranging high in these soils varied from 9.19 to 15.0 μg/g and 11.1 to 16.6 μg/g,

Table 1 : Effect of different nutrient management treatments on physico-chemical and chemical soil quality parameters under maize-wheat rotation system in Inceptisols of Rakh Dhiansar

Name of the treatment	pH	EC	OC	N	P	K
		dS m^{-1}	g kg^{-1}	kg ha^{-1}		
T1: Control	6.75	0.09	3.18	130.0	19.7	194.0
T2: FYM @ 10 t ha^{-1} + 20 kg N ha^{-1}	7.22	0.11	4.30	140.5	33.9	243.2
T3: FYM @ 10 t ha^{-1} + 30 kg N ha^{-1}	7.12	0.10	4.35	150.7	32.4	251.2
T4: FYM @ 10 t ha^{-1} + 40 kg N ha^{-1}	6.96	0.13	4.53	164.7	34.0	262.8
T5: Green manuring with Sunhemp + 20 kg N ha^{-1}	6.82	0.07	4.17	144.6	30.6	260.8
CD @ 0.05	NS	NS	0.91	18.8	8.77	35.4

Table 2 : Effect of different conjunctive nutrient management treatments on chemical soil quality parameters under maize-wheat rotation in Inceptisols of Rakh Dhiansar

Name of the treatment	Ca	Mg	S	Zn	Fe	Cu	Mn	B
	cmol/kg		kg/ha	µg/g				
T1: Control	2.97	0.47	11.6	0.75	9.19	0.78	11.1	0.33
T2: FYM @ 10 t/ha + 20 kg N/ha	3.67	0.55	16.0	1.61	11.7	0.84	16.2	0.46
T3: FYM @ 10 t/ha + 30 kg N/ha	3.83	0.58	18.1	1.73	11.3	0.95	16.6	0.51
T4: FYM @ 10 t/ha + 40 kg N/ha	3.57	0.55	18.7	1.49	15.0	0.89	15.6	0.64
T5: Green manuring with Sunhemp + 20 kg N/ha	3.70	0.58	19.5	1.55	11.7	0.91	16.0	0.50
CD @ 0.05	NS	NS	5.14	0.49	2.91	NS	3.51	0.13

respectively across the management treatments. Application of FYM @ 10 t/ha + 40 kg N/ha recorded significantly highest available Fe of 15.0 µg/g, while the application of FYM @ 10 t /ha + 30 kg N/ha recorded significantly highest available Mn of 16.6 µg/g which were at par with other treatments. Sharma *et al.* (2013) reported that use of organic sources of nutrients alone or conjunctively with inorganic sources help in improving the physico-chemical and chemical soil quality parameter.

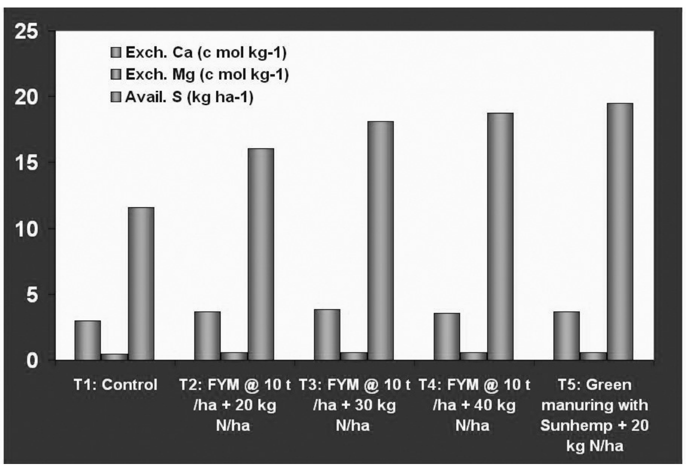

Fig. 2 : Effect of different conjunctive nutrient management treatments on chemical soil quality parameters (secondary nutrients) under maize-wheat rotation in Inceptisols of Rakh Dhiansar

The nutrient management treatments showed a conspicuous influence on the biological soil quality parameters *viz.,* DHA, MBC and LC. Dehydrogenase activity varied between 1.98 to 2.68 µg TPF $hr^{-1}g^{-1}$, while the microbial biomass carbon varied between 107.1 to 171.4 µg/g of soil across the management treatments. The nutrient management treatments similarly performed in influencing and maintaining DHA and MBC, where application of FYM @ 10 t/ha + 40 kg N/ha significantly maintained highest DHA and MBC of 2.68 µg TPF $hr^{-1}g^{-1}$ and 171.4 µg/g of soil, respectively which was at par with green manuring with sunhemp + 20 kg N/ha with corresponding values of 2.47 µg TPF hr^{-1} g^{-1} and 166.2 µg/g of soil, respectively. Similar to DHA and MBC, labile carbon content was significantly highest under application of FYM @ 10 t/ha + 40 kg N/ha (363.8 µg/g of soil) which was at par with two other treatments (Figure 3). The physical soil quality parameters were significantly influenced by the management treatments and bulk density varied from 1.46 to 1.65 Mg/m while mean weight diameter varied from 0.14 to 0.30 mm across the treatments (Table 3 & Figure 4). Sharma *et al.* (2016, 2013), Gayatri and Mathur (2009) and Valpassos *et al.* (2001) reported that use of organic sources of nutrients alone or conjunctively with inorganic sources help in improving the biological and physical soil quality parameter

Table 3 : Effect of different nutrient management treatments on biological and physical soil quality parameters under maize-wheat rotation system in Inceptisols of Rakh Dhiansar

Name of the treatment	DHA (µg TPF $hr^{-1}g^{-1}$)	MBC (µg/g of soil)	LC (µg/g of soil)	BD (Mg m^{-3})	MWD (mm)
T1: Control	1.98	107.1	236.5	1.65	0.14
T2: FYM @ 10 t/ha + 20 kg N/ha	2.27	133.9	285.5	1.48	0.22
T3: FYM @ 10 t/ha + 30 kg N/ha	2.34	155.0	361.1	1.47	0.25
T4: FYM @ 10 t/ha + 40 kg N/ha	2.68	171.4	363.8	1.46	0.30
T5: Green manuring with Sunhemp + 20 kg N/ha	2.47	166.2	308.5	1.48	0.30
CD @ 0.05	0.30	16.5	27.6	0.07	0.05

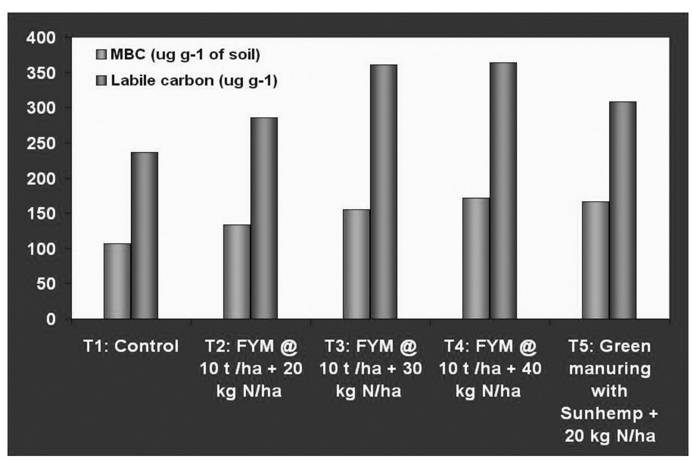

Fig. 3 : Effect of different nutrient management treatments on biological soil quality parameters under maize-wheat rotation in Inceptisols of Rakh Dhiansar

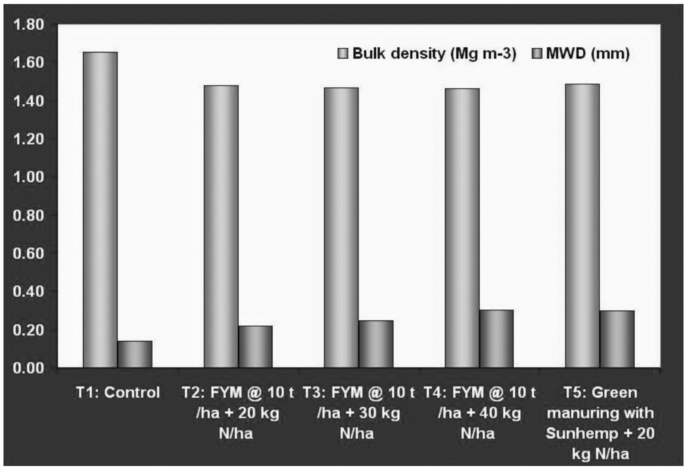

Fig. 4 : Effect of different nutrient management treatments on physical soil quality parameters under maize-wheat rotation in Inceptisols of Rakh Dhiansar

Results of principal component analysis (PCA)

The influence of the nutrient management treatments practiced under maize-wheat rotation on 19 soil quality parameters when statistically analyzed revealed that pH, electrical conductivity, exchangeable Ca & Mg and available Cu were statistically non significant and hence were not subjected to PCA analysis. In the PCA run with the remaining 14 variables, only two PCs had eigen values > 1 and explained 79.0% variance in the data set (Table 4). The variables qualified in PC1 were: organic carbon, available P, available K, available Zn, microbial biomass carbon, labile carbon, bulk density and mean weight diameter, while in PC2, only two variables *viz.,* available N and available Fe were highly weighted. The correlation coefficients (Table 5) between the variables qualified in PC1 despite being significant, except labile carbon, were retained based on their critical role in these Inceptisol soils. The correlations run between the variables in PC2 did not reveal significant correlation and hence were retained for the final MDS. Hence, the variables, which were retained for the final MDS for computing the soil quality indices included organic carbon, available N, available P, available K, available Fe & Zn, microbial biomass carbon, bulk density and mean weight diameter.

Table 4 : Principal component analysis of soil quality parameters as influenced by maize-wheat rotation systems in Inceptisols of Rakh Dhiansar

	PC1	PC2
Total Eigen values	9.503	1.553
% of Variance	67.876	11.096
Cumulative %	67.876	78.972
Eigen Vectors		
OC	0.832	-0.315
N	0.666	0.524
P	0.844	-0.284
K	0.910	-0.101
S	0.749	-0.424
Zn	0.820	-0.335
Fe	0.709	0.504
Mn	0.779	-0.389
B	0.810	0.276
DHA	0.804	0.481
MBC	0.896	0.211
LC	0.883	0.083
BD	-0.882	0.171
MWD	0.908	0.067

Soil quality indices

The key indicators *viz.,* organic carbon, available N, available P, available K, available Fe & Zn, microbial biomass carbon,

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

Variables under PCs								
PC1	**OC**	**P**	**K**	**Zn**	**MBC**	**LC**	**BD**	**MWD**
OC	1.00	0.867**	0.797**	0.656**	0.626*	0.677**	-0.712**	0.696**
P	0.867**	1.00	0.788**	0.685**	0.617*	0.693**	-0.758**	0.710**
K	0.797**	0.788**	1.00	0.616*	0.771**	0.760**	-0.762**	0.842**
Zn	0.656**	0.685**	0.616*	1.00	0.219	0.493	-0.552*	0.314
MBC	0.626*	0.617*	0.771**	0.219	1.00	0.803**	-0.762**	0.937**
LC	0.677**	0.693**	0.760**	0.493	0.803**	1.00	-0.782**	0.747**
BD	-0.712**	-0.758**	-0.762**	-0.552*	-0.762**	-0.782**	1.00	-0.700**
MWD	0.696**	0.710**	0.842**	0.314	0.937**	0.747**	-0.700**	1.00
PC2	N	Fe						
N	1.00	0.655**						
Fe	0.655**	1.00						
Correlation sum	1.655	1.655						

*Correlation is significant at P=0.05 level; **correlation is significant at P=0.01 level bulk density and mean weight diameter which were retained in the final MDS were used to compute the soil quality indices (SQIs) for the maize-wheat rotation system in Inceptisols of Rakh Dhiansar. The conjunctive nutrient management treatments significantly influenced the SQIs which varied between 3.69 to 5.66 across the management treatments, while the relative soil quality indices (RSQIs) varied between 0.63 to 0.96 (Table 6 & Figure 5). Of all the nutrient management treatments, the application of FYM @ 10 t/ha + 40 kg N/ ha maintained significantly highest SQI of 5.66 which was at par with application of FYM @ 10 t/ha + 30 kg N/ ha and green manuring with sunhemp + 20 kg N/ha both of which maintained SQI of 5.40. Irrespective of their statistical significance, the relative order of performance of the nutrient management treatments in maintaining the soil quality indices was T4: FYM @ 10 t/ha + 40 kg N/ha (5.66) > T5: Green manuring with Sunhemp + 20 kg N/ha (5.44) > T3: FYM @ 10 t/ha + 30 kg N/ha (5.40) > T2: FYM @ 10 t/ha + 20 kg N/ ha (5.16) > T1: Control (3.69). The per cent contributions of each of these key indicators towards SQIs were also computed. It was observed that almost all the key indicators contributed more or less equally towards the SQIs except available N and available Fe, which contributed to a minimum extent of 2.27% and 1.90%, respectively.

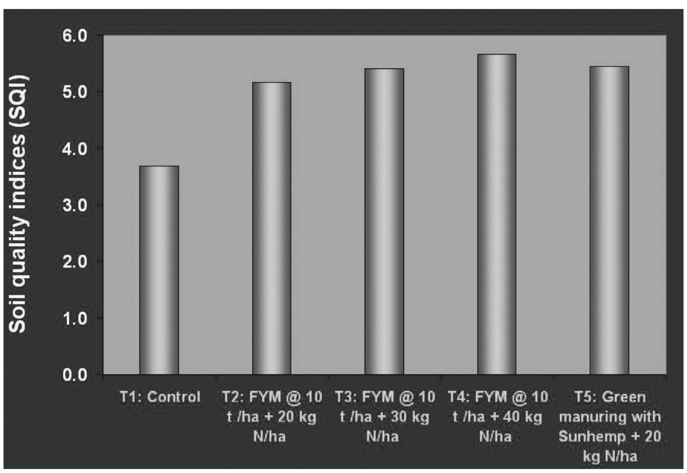

Fig. 5 : Soil quality indices (SQI) as influenced by different nutrient management treatments under maize-wheat rotation system in Inceptisols of Rakh Dhiansar

The per cent contribution of the other key indicators was as follows: organic carbon (13.8%), available P (13.4%), available K (14.5%), available Zn (12.6%), microbial biomass carbon (13.7%), bulk density (15.2%) and mean weight diameter (11.6%) (Figure 6). Sharma *et al.* (2013) reported pH, available N, available K, available Zn, available Cu and DHA to be the key soil quality parameters under INM treatments in pearl millet-mung bean system. These results are also in concurrence with the findings of Sharma *et al.* (2018, 2008, 2005).

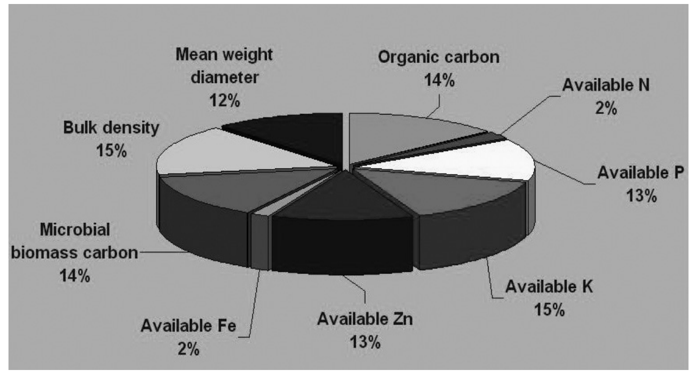

Fig. 6 : Percent contribution of key indicators towards relative soil quality indices (RSQIs) as influenced by different conjunctive nutrient management treatments under maize-wheat rotation system in Inceptisols of Rakh Dhiansar

Table 6 : Soil quality indices (SQI) and relative soil quality indices (RSQI) as influenced by different nutrient management treatments under maize-wheat rotation system in Inceptisols of Rakh Dhiansar

Name of the treatment	SQI	RSQI
T1: Control	3.69	0.63
T2: FYM @ 10 t/ha + 20 kg N/ha	5.16	0.88
T3: FYM @ 10 t/ha + 30 kg N/ha	5.40	0.92
T4: FYM @ 10 t/ha + 40 kg N/ha	5.66	0.96
T5: Green manuring with Sunhemp + 20 kg N/ha	5.44	0.92
CD @ 0.05	0.65	0.11

Conclusion

From the present study, it was clearly emerged that all the conjunctive nutrient management treatments *viz.* FYM @ 10 t/ha + 40 kg N/ha (RSQI 0.96), FYM @ 10 t/ha + 30 kg N/ha (RSQI 0.92), FYM @ 10 t/ha + 20 kg N/ha (RSQI 0.88) and Sunhemp + 20 kg N/ha (RSQI 0.92) played an important role in positively influencing the soil quality parameters and overall soil quality indices (SQIs) compared to control. While managing these soils, the key indicators identified in this study (OC, available N, P, K, Fe and Zn, MBC, BD and MWD) need to be given due consideration, and management of soils should be oriented towards improving these indicators to ensure overall higher soil quality index and in turn higher crop productivity. 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.

Acknowledgements

The authors are thankful to the Former Chief Scientists of the Rakh Dhiansar Center and the Co-ordinators of All India Coordinated Research Project for the facilitation of sample collection and other studies. The authors are also thankful to Dr. M. Prabhakar, PI, NICRA for financial and technical man power support.

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Received: July 2019; Accepted: March 2020