Indian J. Dryland Agric. Res. & Dev. 2019 34(1) : 01-08

10.5958/2231-6701.2019.00001.0

Effect of Integrated Nutrient Management on Soil Quality Indicators and Soil Quality Indices in Hill and Mountainous Inceptisol Soils in Northern India under Maize (*Zea mays*) - Black gram (*Vigna mungo*) System

K.L. Sharma[1], G. Ravindra Chary[1], K. Sammi Reddy[1], A.P. Singh[2], Vikas Abrol[2], Anil Sharma, Hemant Dadhich[2], Munna Lal[1], K.A. Gopinath[1], B. Narsimlu[1], M. Osman[1], K. Srinivas[1], A.K. Indoria[1], D. Suma Chandrika[1], M. Vasavi[1], P. Haindavi[1] and D. Lakshmi Aruna Gayatri[1]

[1]ICAR-Central Research Institute for Dryland Agriculture, Hyderabad-500 059, Telangana
[2]AICRP for Dryland Agriculture Dryland Agri. Res. Sub Station Rakh Dhiansar, Bari Brahmana,
Jammu -181 133, Jammu & Kashmir

Email: kl.sharma@icar.gov.in

ABSTRACT: A long term study was conducted in the rainfed Inceptisol soils at All India Coordinated Research Project (AICRPDA), Rakhdhiansar (J&K) from 1998 to 2005. The main objectives of the present study were to quantify the long-term effects of conjunctive nutrient management on soil quality parameters, to identify the key indicators of soil quality using data redundancy technique and to compute integrated soil quality Index (SQI) and relative soil quality Index (RSQI) as influenced by long term INM treatments in Hill and mountainous Inceptisol soils in Northern India under maize - black gram system. Six INM treatments were considered for the study *viz.,* T1: Control; T2: 100% N (inorganic); T3: 50% N (inorganic); T4: 25 kg N (compost); T5: 15 kg N (compost) + 10 kg N (inorganic) and T6: 15 kg N (compost) + 20 kg N (inorganic). After eight years of study, results revealed that the soil organic carbon was significantly higher with the long term application of 25 kg N (compost) (5.20 g kg^{-1}) and 15 kg N (compost) + 20 kg N (inorganic) (5.19 g kg^{-1}). Among the macronutrients, available N and P were significantly influenced by the integrated nutrient management treatments while available K was not influenced much. Significantly highest available N content of 156.5 kg ha^{-1} was observed with the application of 25 kg N through compost and significantly highest available P of 36.7 kg ha^{-1} was recorded with the application of 15 kg N (compost) + 20 kg N (inorganic). Among the secondary nutrients, irrespective of their significant influence, the content of both exchangeable Ca and Mg, varied from 2.47 to 3.76 cmol kg^{-1} and 0.43 to 0.52 cmol kg^{-1} respectively. Available S, being significantly influenced by the nutrient management treatments was observed to be highest under application of 25 kg N through compost (22.7 kg ha^{-1}). Among the micronutrients, available Zn and B were conspicuously influenced by the management treatments while Fe, Cu and Mn were not influenced. Among the biological parameters *viz.,* DHA, microbial biomass carbon (MBC) as well as labile carbon were significantly influenced by the management treatments. Application of 15 kg N (compost) + 20 kg N (inorganic) recorded significantly highest DHA (2.79 μg TPF hr^{-1}g^{-1}) as well as labile carbon (355.0 μg g^{-1} of soil) while application of 25 kg N (compost) recorded significantly highest MBC of 162.0 μg g^{-1} of soil. Among the physical soil quality parameters, both bulk density as well as mean weight diameter were significantly influenced by the management treatments. Soil quality assessment studies indicated that available N, exchangeable Ca, available Zn, & B, MBC and bulk density were found to be the key indicators of soil quality under maize-black gram. Among all the treatments practiced under maize-black gram system, application of 25 kg N through compost had significantly highest RSQI of 0.97 which was at par with application of 15 kg N (compost) + 20 kg N (inorganic) (0.94) (P=0.05). The order of performance of the treatments in terms of soil quality was : 25 kg N (compost) (0.97) >15 kg N (compost) + 10 kg N (inorganic) (0.87) > T 100% N (inorganic) (0.83) > 50% N (inorganic) (0.81) > Control (0.63).

Key words: Inceptisol, Integrated nutrient management, key indicators and soil quality indices

Introduction

The Inceptisol soils are weakly developed, and are predominantly found in cool or dry climates and are developed on resistant or new parent material. Taxonomically, Inceptisols typically have a recognizable A horizon, but only a weak B horizon. In India, the area under Inceptisols soils is 95.8 million hectares, constituting 29.13% of total geographical area, which are mostly spread throughout the Indo-Gangetic Plain and along the lower courses of the country's major rivers, especially the deltas along the east coast. These 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 hampers the productivity on a long-run basis.

The study location *viz.,* Rakhdhiansar is situated in Kandi areas of Western Himalayas of South Kashmir, and represents warm moist to dry sub-humid transitional eco-sub-region (AESR 14.2). In this region, other soil related problems 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 traditional crops/cropping systems of the region during the *kharif* are maize, pearl millet, cowpea, green gram, black gram, lentil, pea, mustard etc. The important sequence croppings systems are maize-wheat/ mustard/ barley/ toria/ chickpea, black gram-wheat/ rapeseed etc. Maize and pluses dominate in sequence cropping.

Over and above, the productivity of the crops is low owing to the several productivity related soil constraints. It has been reported that the decline in the yields of most of the crops grown in Inceptisol soils is largely attributed to gradual depletion of nutrients, variations in soil organic matter, and structural degradation (Manna *et al.,* 2006). However, 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. 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. 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 fertility of the soil. While emphasizing the role of minimization of tillage operations, Lal (1993) reported that intensive tillage may lead to a range of degradative processes, including 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. Such degrading effects are more pronounced especially in stressed agroecologies such as hot semi-arid rainfed conditions (Suri 2007), where the soils experience many constraints broadly on account of physical, chemical, and biological health and ultimately lead to overall poor functional capacity i.e., quality and low productivity (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 viewed 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 - black gram cropping system is considered as an important system for marginal lands of the Hill Mountainous Inceptisols soils. Besides this, maize crop has 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- black gram 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 is also showing decreasing trend thereby affecting the productivity and sustainability of these soils. The aim of the present study on integrated nutrient management was to reduce the use of inorganic fertilizers and supplement the nutrient supply through organic sources and to improve soil quality. Hence, the use of compost instead of 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 long-term 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 long term INM treatments.

Materials and Methods

A long term experiment, focusing on Integrated Nutrient Management (INM) in rainfed maize (Zea mays) - black gram (Vigna mungo) system cropping system, was conducted at All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Rakh Dhiansar, in the State of Jammu and Kashmir, situated at 32^o 17' N latitude and 75^o 36' E longitude, representing warm moist to dry sub-humid transitional eco-sub-region (AESR 14.2). The mean annual rainfall at the experimentation location is 1180 mm, of which 60 percent is received during July-August. Winter rains account for 225 mm. Length of growing period is 150-210 days. The soils are medium to deep loamy to clayey brown forest, podzolic and are medium deep sandy loam to loamy, representing Inceptisol soil order. Soils have medium available water capacity with near neutral soil reaction and suitable electrical conductivity. The experiment was initiated during *kharif* 1998 in a randomized block design (RBD) with six INM treatments with three replications using maize (Kanchan hybrid -510) and black gram (Pant U-19) as test crops. Six INM treatments *viz.,* T1: Control; T2: 100% N (inorganic); T3: 50% N (inorganic); T4: 25 kg N (compost); T5: 15 kg N (compost) + 10 kg N (inorganic) and T6: 15 kg N (compost) + 20 kg N (inorganic) were chosen for the present soil quality assessment study. Standard agronomic practices were adopted..

Soil sampling and analysis

After 8 years of the experiment, surface soil samples were collected from plough layer (0.0-0.15 m depth). These samples were ground, partitioned and passed through standard prescribed sieves for further use in different kind of analysis. 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 colorimetrically (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 & Raczkowski 1921). The distribution of water stable aggregates was determined by wet sieving technique using sieves of 4750 um, 2000 um, 1000 um, 500 um, 250 um and 100 um 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 mg 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 $25^{0}C \pm 1^{0}C$ temperature. Microbial biomass carbon 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 $K_{EC} = 0.25 \pm 0.05$ 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 Mini Spectrophotometer (Model SL 171 of Elico Ltd.).

Computation of soil quality indices

The rigorous data set obtained for all the 19 soil quality parameters was statistically analysed for their level of significance using randomized block design. 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 representative 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.,* 2002a). 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 eigenvectors > 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:

$$\mathrm{SQI} = \sum_{i=1}^{n} (\mathrm{Wi\ X\ Si})$$

where, Si is the score for the subscripted variable and Wi 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' (RSQI). Further, the percent 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 was performed using SPSS 12 version.

Results and Discussion

Effect on physico-chemical and chemical soil quality parameters

From the data presented in Table 1 it was observed that the soil pH varied from 6.10 to 6.35 across the INM treatments while EC varied from 0.06 to 0.09 dS m^{-1}. Soil organic carbon as influenced by these INM treatments was medium ranging from 3.24 to 5.20 g kg^{-1} and was significantly highest under application of 25 kg N (compost) (5.20 g kg^{-1}) as well as under application of 15 kg N (compost) + 20 kg N (inorganic) (5.19 g kg^{-1}). Among the chemical soil quality parameters, available N and P were significantly influenced by the management treatments while available K was not influenced. Significantly highest available N content of 156.5 kg ha^{-1} was observed under application of 25 kg N through compost which was at par with other treatments while the lowest was observed under control plot (139.2 kg ha^{-1}). Available P in the treated plots was high in these soils and significantly highest available P was recorded under application of 15 kg N (compost) + 20 kg N (inorganic) (36.7 kg ha^{-1}) which was at par with other treatments. Available K, not being conspicuously influenced by the management treatments, varied from 161.7 to 207.1 kg ha^{-1} across the treatments (Figure 1).

Table 1: Effect of different integrated nutrient management treatments on physico-chemical and chemical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

Name of the treatments	pH	EC dSm^{-1}	OC (g kg^{-1})	N	P	K
				(kg ha^{-1})		
T1- Control	6.12	0.08	3.24	139.2	19.5	161.7
T2 - 100% N (inorganic)	6.26	0.06	4.65	155.4	31.6	186.2
T3 - 50% N (inorganic)	6.20	0.07	4.68	142.2	31.8	192.9
T4 - 25 kg N (compost)	6.11	0.07	5.20	156.5	32.8	183.9
T5 - 15 kg N (compost) + 10 kg N (inorganic)	6.35	0.07	4.28	143.0	34.4	204.7
T6 - 15 kg N (compost) + 20 kg N (inorganic)	6.10	0.09	5.19	147.9	36.7	207.1
CD @ 0.05	NS	NS	1.01	11.2	7.31	NS

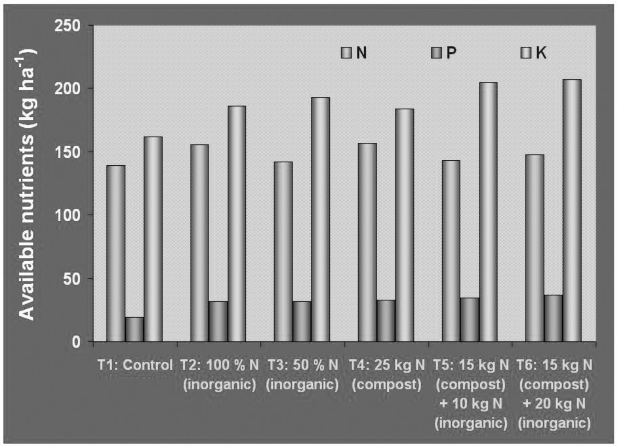

Fig. 1 : Effect of integrated Nutrient Management treatments on chemical soil quality parameters (macronutrients) under maize-black gram system in Inceptisols of Rakhdhiansar

Among the secondary nutrient parameters, both exchangeable Ca and Mg irrespective of their significant influence by the INM treatments, varied from 2.47 to 3.76 cmol kg^{-1} and 0.43 to 0.52 cmol kg^{-1} respectively (Table 2 & Figure 2). However, available S, being significantly influenced by the management treatments was observed to be highest under application of 25 kg N through compost (22.7 kg ha^{-1}) which was at par with other treatments while the lowest was recorded under control plot (13.7 kg ha^{-1}). Among the micronutrient parameters, available Zn and B were conspicuously influenced by the management treatments while Fe, Cu and Mn were not influenced. However, available Zn, Fe and Mn contents were found to be in high range varying from 0.96 to 2.14, 14.9 to 19.4 and 18.3 to 24.0 μg g^{-1} respectively across the treatments, while available Cu and B were observed to be in medium range varying from 0.76 to 0.91 and 0.28 to 0.51 μg g^{-1} respectively (Figure 3).

Table 2 : Effect of different integrated nutrient management treatments on chemical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansa

Name of the treatment	Ca	Mg	S	Zn	Fe	Cu	Mn	B
	cmol kg^{-1}		(kg ha^{-1})	µg g^{-1}				
T1 - Control	2.47	0.43	13.7	0.96	14.9	0.76	18.3	0.28
T2 - 100 % N (inorganic)	3.21	0.46	16.4	1.56	18.5	0.89	21.8	0.40
T3 - 50 % N (inorganic)	3.20	0.49	19.9	1.64	16.4	0.81	24.0	0.40
T4 - 25 kg N (compost)	3.76	0.49	22.7	2.14	18.3	0.83	21.3	0.51
T5 - 15 kg N (compost) +10 kg N (inorganic)	3.12	0.51	21.3	1.80	19.4	0.88	20.9	0.45
T6 - 15 kg N (compost) +20 kg N (inorganic)	3.66	0.52	20.2	2.06	18.2	0.91	23.7	0.49
CD @ 0.05	0.44	NS	5.12	0.44	NS	NS	NS	0.07

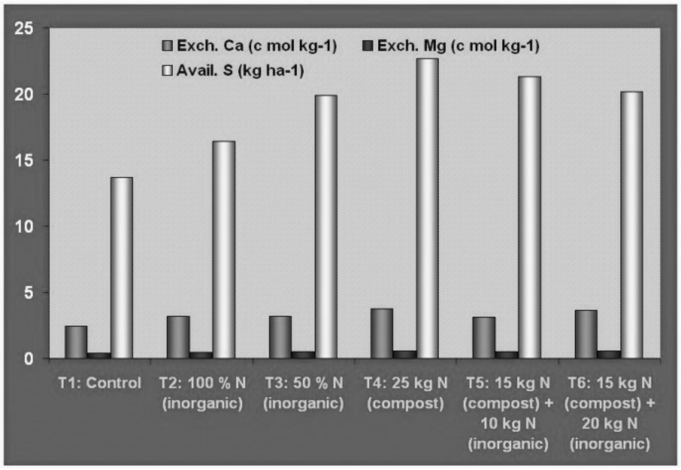

Fig. 2 : Effect of integrated nutrient management treatments on chemical soil quality parameters (Secondary nutrients) under maize-black gram system in Inceptisols of Rakhdhiansar

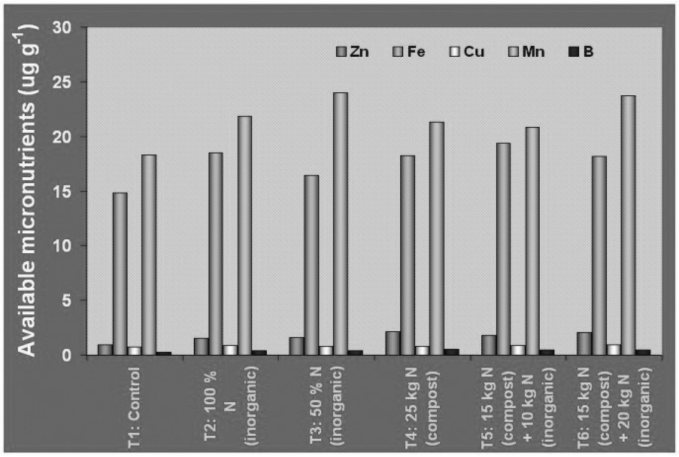

Fig. 3 : Effect of integrated nutrient management treatments on chemical soil quality parameters (micronutrients) under maize-black gram system in Inceptisols of Rakhdhiansar

The biological parameters *viz.,* DHA, microbial biomass carbon as well as labile carbon were significantly influenced by the management treatments (Table 3 & Figure 4). Across the management treatments, dehydrogenase assay varied from 1.76 to 2.79 µg TPF hr^{-1}g^{-1}, microbial biomass carbon varied from 102.7 to 162.0 µg g^{-1} of soil and labile carbon from 277.5 to 355.0 µg g^{-1} of soil. Application of 15 kg N (compost) + 20 kg N (inorganic) recorded significantly highest DHA (2.79 µg TPF hr^{-1}g^{-1}) as well as labile carbon (355.0 µg g^{-1} of soil) while application of 25 kg N (compost) recorded significantly highest MBC of 162.0 µg g^{-1} of soil. Among the physical soil quality parameters, both bulk density as well as mean weight diameter were significantly influenced by the management treatments and were observed to vary from 1.51 to 1.71 Mg m^{-3} and 0.17 to 0.35 mm, respectively across the treatments (Figure 5).

Table 3 : Effect of different integrated nutrient management treatments on biological and physical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

Name of the treatments	DHA (µg TPF hr^{-1}g^{-1})	MBC (µg g^{-1} of soil)	LC (µg g^{-1} of soil)	BD (Mg m^{-3})	MWD (mm)
T1: Control	1.76	102.7	277.5	1.71	0.17
T2: 100 % N (inorganic)	2.11	143.9	344.2	1.54	0.20
T3: 50 % N (inorganic)	2.01	125.3	338.2	1.56	0.29
T4: 25 kg N (compost)	2.25	162.0	335.1	1.49	0.27
T5: 15 kg N (compost) + 10 kg N (inorganic)	2.67	156.8	323.8	1.55	0.35
T6: 15 kg N (compost) + 20 kg N (inorganic)	2.79	156.4	355.0	1.51	0.34
CD @ 0.05	0.41	16.9	33.8	0.11	0.08

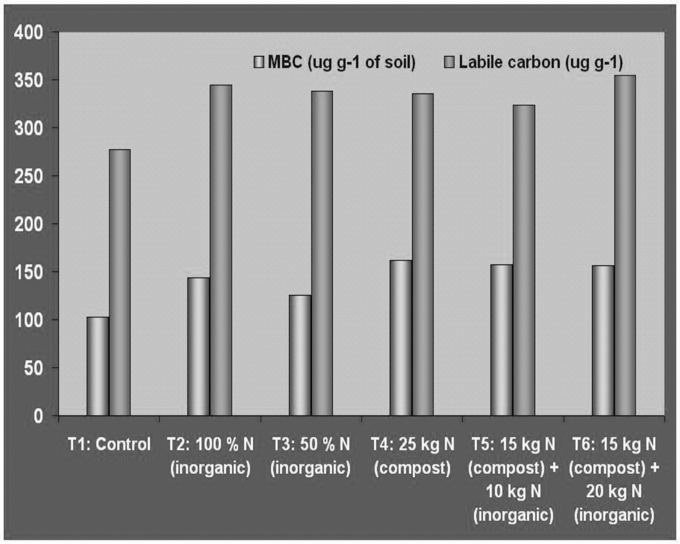

Fig. 4 : Effect of integrated nutrient management treatments on biological soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

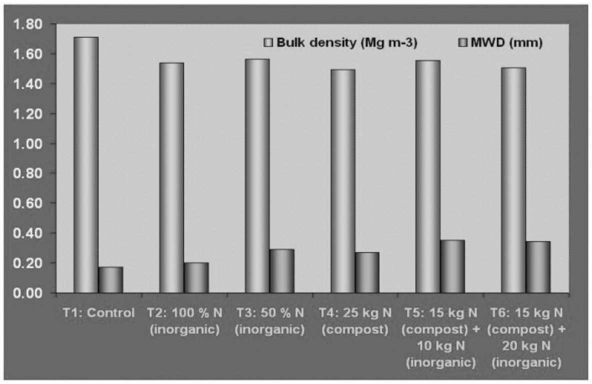

Fig. 5 : Effect of integrated nutrient management treatments on physical soil quality parameters under maize-black gram system in Inceptisols of Rakhdhiansar

Results of principal component analysis

The data on influence of integrated nutrient management treatments practiced under maize-black gram system on 19 soil quality indices has been statistically analyzed and it was observed that out of 19 soil quality parameters, 7 variables *viz.,* pH, EC, available K, Mg, Fe, Cu and Mn were insignificant and hence were dropped from further PCA analysis. In the PCA of 12 variables, two PCs had eigen values >1 and explained 74.2% variance in the data set (Table 4). In PC1, five variables *viz.,* exchangeable Ca, available Zn, B, microbial biomass carbon and bulk density were the highly weighted variables while in PC2 only single variable i.e., available N was highly weighted. Correlation analysis was run between the variables qualified under PC1. The correlation matrix showed that the parameters were significant and well correlated (Table 5). But considering their importance in these soils, all the highly weighted variables under PC1 were retained to be included under MDS. Hence, the final MDS included exchangeable Ca, available N, available Zn, & B, microbial biomass carbon and bulk density and were termed as the key indicators for maize-black gram system practiced in Inceptisols of Rakhdhiansar.

Table 4 : Principal component analysis of soil quality parameters as influenced by maize-black gram system in Inceptisols of Rakhdhiansar

	PC1	PC2
Total Eigen values	6.999	1.166
% of Variance	63.626	10.597
Cumulative %	63.626	74.223
Eigen Vectors		
OC	0.814	0.163
N	0.450	0.763
Ca	0.906	0.123
S	0.716	-0.269
Zn	0.891	0.017
B	0.914	-0.004
DHA	0.749	-0.417
MBC	0.899	0.033
LC	0.770	0.211
BD	-0.823	-0.088
MWD	0.728	-0.493

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

Variables under PCs	Ca	Zn	B	MBC	BD
Ca	1.00	0.826**	0.829**	0.738**	-0.839**
Zn	0.826**	1.00	0.865**	0.780**	-0.800**
B	0.829**	0.865**	1.00	0.812**	-0.675**
MBC	0.738**	0.780**	0.812**	1.00	-0.750**
BD	-0.839**	-0.800	-0.675**	-0.750**	1.00
Correlation sum	4.232	4.271	4.181	4.08	4.064

**correlation is significant at P = 0.01 level

Soil quality indices

Soil quality indices were computed using six soil quality indicators *viz.,* the available N, exchangeable Ca, available Zn & B, microbial biomass carbon and bulk density. Soil quality indices varied from 2.68 to 4.17 across the management treatments (Table 6). In order to have an easy comparison, soil quality indices were reduced to a scale of one termed as the relative soil quality indices, which varied from 0.63 to 0.97 across the management treatments (Figure 6). Among all the treatments practiced under maize-black gram system, application of 25 kg N compost had significantly highest RSQI of 0.97 which was at par with application of 15 kg N (compost) + 20 kg N (inorganic) (0.94). Irrespective of their statistical significance, the relative order of performance of the treatments in influencing the soil quality indices were: T4: 25 kg N (compost) (4.17) > T6: 15 kg N (compost) + 20 kg N (inorganic) (4.05) > T5: 15 kg N (compost) + 10 kg N (inorganic) (3.75) > T2: 100 % N (inorganic) (3.55) > T3: 50 % N (inorganic) (3.46) > T1: Control (2.68). The percent contributions of the key indicators towards the soil quality indices were as follows: available N (3.49%), exchangeable Ca (19.6%), available Zn (16.6%), available B (19.3%), microbial biomass carbon (19.7%), bulk density (21.4%) (Figure 7).

Table 6 : Soil quality indices (SQI) and relative soil quality indices (RSQI) as influenced by different integrated nutrient management treatments under maize-black gram system in Inceptisols of Rakhdhiansar

Name of the treatments	SQI	RSQI
T_1 - Control	2.68	0.63
T_2 - 100 % N (inorganic)	3.55	0.83
T_3 - 50 % N (inorganic)	3.46	0.81
T_4 - 25 kg N (compost)	4.17	0.97
T_5 - 15 kg N (compost) + 10 kg N (inorganic)	3.75	0.87
T6 - 15 kg N (compost) + 20 kg N (inorganic)	4.05	0.94
CD @ 0.05	0.29	0.07

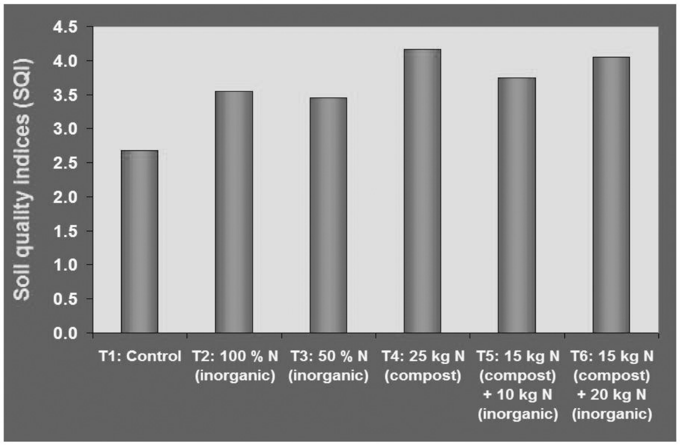

Fig. 6 : Soil quality indices (SQI) as influenced by different integrated nutrient management treatments under maize-black gram system in Inceptisols of Rakhdhiansar

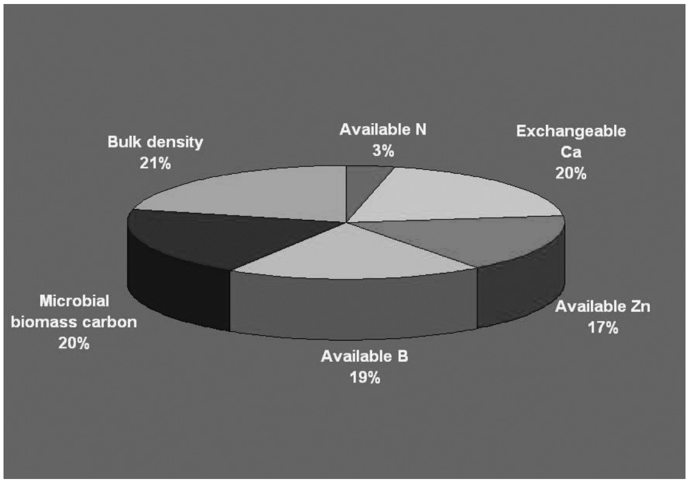

Fig. 7 : Percent contribution of key indicators towards soil quality indices (SQI) as influenced by different integrated nutrient management treatments under maize-black gram system in Inceptisols of Rakhdhiansar

Conclusion

From the present study, it was clearly emerged that among the several combinations of INM treatments , the treatments containing organics alone *viz.,* 25 kg N (compost) (0.97) , or in combination with inorganics *viz.,* 15 kg N (compost) + 20 kg N (inorganic) (0.94) and 15 kg N (compost) + 10 kg N (inorganic) (0.87) played an important role in positively influencing the soil quality parameters and overall soil quality indices. Beside the low organic C status and low soil fertility, the soils under study also suffer on account of structural infirmities. While managing these soils, the key indicators identified in this study need to give due consideration and management of soils should be focused to improving these indicators to ensure overall higher soil index and in turn higher crop productivity. Thus, 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 the soil.

Acknowledgements

The authors are thankful to the Former Chief Scientists of the Rakhdhiansar Center and the Co-ordinators of All India Coordinated Research Project for the facilitation of sample collection and other studies.

References

All India Coordinated Research Project for Dryland Agriculture (AICRPDA). 2003. Annual report, All India Coordinated Research Project for Dryland Agriculture (CRIDA), Hyderabad.

Andrews SS, Mitchell JP, Mancinelli R, Karlen DL, Hartz TK, Horwarth WR, Pettygrove GS, Scow KM and Munk DS. 2002a. On farm assessment of soil quality in California's Central Valley. *Agronomy Journal,* 94: 12-23.

Brejda JJ, Karlen DL, Smith JL and Allan DL. 2000b. Identification of regional soil quality factors and indicators: II. Northern Mississippi loess hills and Palouse prairie. *Soil Science Society of America Journal*, 64: 2125-2135.

Brejda JJ, Moorman TB, Karlen DL and Dao TH. 2000a. Identification of regional soil quality factors and indicators: I. Central and southern high plains. *Soil Science Society of America Journal,* 64: 2115-2124.

Doran JW, Sarrantonio M and Liebig MA. 1996. Soil health and sustainability. *Advances in Agronomy,* 56: 1-54.

Doran JW and Parkin TB. 1994. Defining and assessing soil quality. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA, editors. Defining soil quality for a sustainable environment. Madison (WI): *Soil Science Society of America Journal*, 3-21.

Hanway JJ and Heidel H. 1952. Soil analyses methods as used in Iowa State College soil testing laboratory. *Iowa Agriculture*, 57: 1-31.

Jenkinson DS and Powlson DS. 1976. The effects of biocidal treatments on metabolism in soil V. A method for measuring soil biomass. *Soil Biology and Biochemistry,* 8: 209-213.

Keen BA and Raczkowski H. 1921. Relation between the clay content and certain physical properties of a soil. *Journal of Agricultural Science,* 11: 441-449.

Lal R. 1993. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. *Soil and Tillage Research*, 27: 1-8.

Lanyon LE and Heald WR. 1982. Magnesium, calcium, strontium and barium. In "Methods of soil analysis". Part 22nd ed. Page (AL, Miller, RH, Keeney, DR. eds). *American Society of Agronomy*, 9: 247-262.

Lenhard G. 1956. Die dehydrogenase-activitat des Bodens als Mass fur die mikroorganis-mentatigkeit im Boden. Zeitschrift fur Pflanzenernaehr. *Dueng und Bodenkd*, 73: 1-11.

Lindsay WL and Norvell WA. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal*, 42: 421-428.

Manna MC, Swarup A, Wanjari RH, Singh YV, Ghosh PK, Singh KN, Tripathi AK and Saha MN. 2006. Soil organic matter in a West Bengal Inceptisol after 30 years of multiple cropping and fertilization. *Soil Science Society of American J*ournal, 70: 121-129.

McLean EO. 1982. Soil pH and lime requirement. In Page, AL, RH. Miller and DR Keeney (eds.) Methods of soil analysis. Part 2 - Chemical and microbiological properties. (2nd Ed.). *Agronomy*, 9: 199-223.

Miller RO Vaughan B and Kutoby-Amacher J. 2001. Extraction of soil boron with DTPA- sorbitol. *Soil and Plant Analys*t, 4-5: 10.

Olsen SR, Cole CU, Watanabe FS and Deen LA. 1954. Estimation of available phosphorus in soil by extracting with sodium bicarbonate. USDA Circular 939. Washington (DC): USDA.

Parr JF, Papendick RI, Hornick SB and Meyer RE. 1990. Sustainable agriculture in the United States. In: Edwards CA, Lal R, Madden P, Miller RH, House G, editors. Sustainable agricultural systems. Ankeny (IA): Soil and Water Conservation Society, 50-67.

Rhoades JD. 1982. Soluble salts. In "Methods of soil analysis, Part 2, chemical and microbiological properties" (AL Page, RH Miller, DR Keeney eds.) pp. 635-655. (Agron. Mono. 9, ASA and SSSA: Madison, Wisconsin).

Singh HP, Sharma KD, Subba Reddy G and Sharma KL. 2004. Dryland agriculture in India. In: Challenges and strategies for dryland agriculture. CSSA special publication no. 32. Madison (WI): Crop Science Society of America and American Society of Agronomy, 67–92.

Sharma JC and Chaudhary SK. 2007. Vertical distribution of micronutrient cations in relation to soil characteristics in lower Shiwaliks of Solan district of north-west Himalayas. *Journal of Indian Society of Soil Science,* 55: 40-44.

Sharma KL, Srinivas K, Mandal UK, Vittal KPR, Kusuma Grace J and Maruthi Sankar G. 2004. Integrated nutrient management strategies for sorghum and green gram in semi-arid tropical Alfisols. *Indian Journal of Dryland Agricultural Research and Development*, 19: 13-23.

Snedecor G, Cochran W and Cox D. 1989. Statistical Methods. (The Iowa State University Press: Ames).

Subbiah BV and Asija G L. 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science*, 25: 259-260.

Suri VK. 2007. Perspectives in soil health management – a looking glass. *Journal of Indian Society of Soil Science*, 55: 436-443.

Van Bevel CHM. 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. *Soil Science Society of America Proceedings*, 14: 20-23.

Walkley AJ and Black CA. 1934. Estimation of organic carbon by chromic acid titration method. *Soil Science*, 37: 29-38.

Wander MM and Bollero GA. 1999. Soil quality assessment of tillage impacts in Illinois. *Soil Science Society of America Journal,* 63: 961-971.

Weil RR, Islam KR, Stine MA, Gruver JB, Sampson- Liebeg SE. 2003. Estimatingactive carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, 18 (1): 3-17.

William CH and Steinbergs A. 1959. Soil sulphur fraction as chemical indices of available sulphur in some Australian soils. *Australian Journal of Agricultural Research,* 10: 340–352.

Yoder RE. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *Journal of American Society of Agronomy,* 28:337-351.

Received: January 2019; Accepted: May 2019