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Effect of Cropping Sequences and Nutrient Management Practices on Soil Quality under Rainfed Semiarid (Hot dry) Vertisol Soils of Western India

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ABSTRACT: In order to study the effect of cropping sequences grown under different practices of nutrients management on soil quality, a long term experiment was conducted at research centre of All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Targhadia, Rajkot falling under the jurisdiction of Junagadh Agricultural University. The experiment was conducted in a two-factor randomized block design (RBD) with three replications. The cropping sequences followed were: Sesamum-cotton, Sesamum-sesamum, Sesamum-groundnut, Bajra-groundnut, Bajra-bajra, Bajra-cotton, Castor-cotton, Castor-castor, Castor-groundnut, Cotton-groundnut, Cotton-cotton, Groundnut-groundnut. The nutrient management practices were: i) control without fertilizer, ii) recommended dose of fertilizer (RDF), iii) integrated nutrient management (INM) and iv) sole organic sources of nutrients. The results of the study indicated that the organic carbon was found to be medium (5.3 to 7.4 g kg^{-1}) across the cropping sequences. The application of sole organic sources resulted in highest available N (197.9 kg ha^{-1}) followed by INM treatments (182.3 kg ha^{-1}). Available P was found highest under cotton–groundnut cropping sequence (24.72 kg ha^{-1}). Cotton-cotton cropping sequence recorded significantly highest available K (449.1 kg ha^{-1}) and also available Zn, Fe, Cu, B to the extent of 1.06, 25.0, 3.36, 0.52 µg g^{-1} respectively. Among the nutrient treatments, application of sole organic sources resulted in significantly highest amounts of available Zn, Fe, Mn and B. Significantly highest dehydrogenase activity was observed under sesamum-sesamum sequence, MBC under sesamum-cotton and labile carbon under castor-castor system. Application of sole organic sources of nutrients recorded significantly highest dehydrogenase activity (DHA), Microbial Biomass Carbon (MBC) and labile carbon followed by INM treatments. The relative order of performance of the cropping sequences in terms of relative soil quality indices (RSQI), when averaged over nutrient management treatments was as follows: Cotton-cotton (1.00) >Cotton-groundnut (0.93) > Castor-castor (0.88) > Bajra-groundnut (0.86) > Sesamum-sesamum (0.8) > Bajra-cotton (0.68) > Groundnut-groundnut (0.68) > Sesamum-groundnut (0.66) > Sesamum-cotton (0.64) > Castor-cotton (0.64) > Castor-groundnut (0.6) > Bajra-bajra (0.56). But when averaged over cropping sequences, the order of superiority of the treatments in terms of RSQI was: sole organic (1.00) > INM (0.72) > RDF (0.47). The results of the present study will be highly useful for improving the soil quality by using suitable combinations of crop sequences and nutrient management.

Key words: Crop sequence, INM, soil fertility, soil quality

Introduction

The adoption of high yielding varieties and intensive cropping have decreased the recycling of organic matter, resulting in lower unsustainable yield, imbalance of nutrients, and ultimately resulting in poor soil quality. Nutrient management on farm lands play an important role in crop production and environmental protection (Prasad 2009, Tilman *et al.,* 2002). An adequate nutrient supply system through integrated nutrient management with more reliance on low-cost, on-farm/local resources (Lelei, Onwonga, and Freyer 2009) and reduced dependence on chemical fertilizers (Davari and Mirzakhani 2009; Kannan *et al.,* 2013) is essential for regulated nutrient supply and reduced losses, besides lowering costs, improving nutrient-use efficiency (Sheoran *et al.,* 2016b) and soil biodiversity (Sharma and Banik 2016; Subba Rao *et al.,* 1998). Moreover, crop response to fertilizer is also dependent upon rainfall pattern, type of soils, previous crop taken etc. Adoption of suitable crop rotations coupled with balanced fertilization and use of organic manure becomes inevitable.

Rainfed semiarid (Hot dry), Rajkot region, representing Vertisol soil order receiving on an average 590 mm of rainfall characterized by low rainfall with high spatial and temporal variability leading to risk of severe drought (Snyder and Tartowski 2006). Soils are clay loam to clayey and alkali, predominantly dominated by Vertisols. Drought occurs once in five years and water erosion is of high severity with moderate loss of topsoil. The traditional cropping system in *kharif* are groundnut, sorghum, cotton, greengram, pigeon pea, cluster bean, sesame, castor, maize, etc. and intercropping systems are groundnut + castor / pigeon pea / sesame, pearlmillet, + pigeon pea / kidney bean, cotton + green gram, etc. Length of growing period is 60-90 days. Growing groundnut with sesame endowed with varying rooting depth and growth pattern help better extraction of soil moisture and nutrients from different soil profile (Bhuva *et al.,* 2017). Groundnut and cotton occupies prominent position in rainfed area of Gujarat besides pearlmillet, castor and sesamum. In Gujarat, groundnut alone is cultivated in 1.69 million hectares under rainfed conditions and thus exposed to the vagaries of monsoon (Chaudhari *et al.,* 2017). Failure in adoption of proper crop rotation might be one of the reasons for low average yields of these crops, which fluctuate widely.

Beside several other factors, low organic matter, low overall soil fertility and susceptibility of the soil to extreme erosion, leading to frequent moderate loss of productive top soil are the predominant soil related productivity constraints in the Vertisols of western India , especially Rajkot region of Gujarat.

Keeping in view the above constraints, a study on the effects of different cropping sequences on soil quality under different nutrient management practices was initiated during the year 1999 at research centre of All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Targhadia, Rajkot falling under the jurisdiction of Junagadh Agricultural University, with the specific objectives viz. (i) to assess the impact of different cropping sequences and different nutrient management practices on soil quality parameters (ii) to identify the key indicators of soil quality and (iii) to compute the soil quality indices under different cropping sequences and nutrient management practices.

Materials and Methods

Experimental details

The experiment was conducted with twelve different cropping sequences and four nutrient management practices with three replications in a two factor randomized block design. The twelve cropping sequences followed were: sesamum-cotton; sesamum-sesamum; sesamum-groundnut; bajra-groundnut; bajra-bajra; bajra-cotton; castor-cotton; castor-castor; castor-groundnut; cotton-groundnut; cotton-cotton; groundnut-groundnut. The four nutrient management practices were: i) control without fertilizer, ii) recommended dose of fertilizer, iii) integrated nutrient management and iv) sole organic sources of nutrients. Thus, a total of 48 treatment combinations were taken up in the study.

Soil sampling and analysis

Soil samples were collected after 7th year of study during 2005 from plough layer (0.0-0.15 m depth) to assess soil quality. These samples were 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 sample passed through 0.2 mm sieve was used for estimating organic carbon (OC) as well as labile carbon (LC). For the rest of the soil quality parameters *viz.,* chemical (pH, electrical conductivity (EC), available N (N), available P (P) & available K (K), exchangeable calcium (Ca), exchangeable magnesium (Mg), available sulphur (S), and micronutrients such as available zinc (Zn), iron (Fe), copper (Cu), manganese (Mn) and boron (B) and biological (microbial biomass carbon (MBC) and dehydrogenase assay (DHA) parameters, soil samples passed through 2 mm sieves were used. The standard protocols adopted for estimating different 19 soil quality parameters were as follows. Soil pH and EC were measured in 1:2 soil water suspension (Rhoades 1982), organic carbon by wet oxidation with $H_2SO_4 + K_2Cr_2O_7$ (Walkley and Black 1934), available N by alkaline-$KMnO_4$ oxidizable N method (Subbaiah and Asija 1956), available P by 0.5M $NaHCO_3$ extraction method (Olsen *et al.,* 1954), available K (Hanway and Heidal 1952) and exchangeable Ca and Mg using neutral normal ammonium acetate method, DTPA extractable Zn, Fe, Cu, Mn by Diethylene triamine penta acetic acid (DTPA) reagent (0.005 M DTPA + 0.1 M Triethanolamine (TEA) + 0.01M Calcium chloride ($CaCl_2.2H_2O$); pH 7.3) using Inductively Coupled Plasma Spectrophotometer (ICP-OES, GBC Australian model) (Lindsay and Norvell 1978), extractable Boron by DTPA-Sorbitol extraction (Miller *et al.,* 2001), bulk density (BD) by Keen's Box method, aggregate stability using wet sieve technique (Yoder 1936), mean weight diameter (MWD) (Van Bevel 1949), microbial biomass carbon (MBC) by fumigation- incubation (Jenkinson and Powlson 1976), dehydrogenase activity by Triphenyl tetrazolium chloride method (TTC) (Lenhard 1956) and Labile carbon by $KMnO_4$ method by using 0.01 M $KMnO_4$ instead of 0.02 M originally suggested by Weil *et al.* (2003). Analysis of variance (ANOVA) was performed using 'Drysoft' design package. Principal component analysis was performed using SPSS 12 version.

Soil quality assessment methodology

In order to assess soil quality, the data obtained for 19 chemical, physical and biological soil quality parameters were statistically tested for their level of significance using double factor randomized block design. After the statistical analysis, the parameters which were found significant were subjected to principal component analysis (PCA) (Andrews *et al.,* 2002a, b; Doran and Parkin 1996) using SPSS software (Version 12.0). The PCA was done to reduce the dimensionality (number of variables) of the dataset and to retain most of the original variability in the data. 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).

Further, in order to reduce the spurious groupings among the highly weighted variables within each principal component, inter-correlations were worked out (Andrews *et al.,* 2002a). Based on the inter-correlation values, variables were labelled as well-correlated variables when 'r' value was > 0.70. Among the well correlated variables, only one variable was considered for the MDS. However, in some cases, as an exception, more than one variable were also retained for the MDS depending upon the important role of the variables in regulating the soil functions. When the correlations were not significant between the highly weighted variables, reflecting their independent functioning, then all the variables were considered important and retained for the MDS. As a check of how well the MDS represented the management system goals, multiple regressions were also performed considering the indicators retained in the MDS as independent variables and the functional goals such as long-term average yields of crop as dependent variable. 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.

As suggested by Andrews *et al.,* (2002a), all the observations of each identified key MDS indicator were transformed using linear scoring technique. 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 transformation, using linear scoring, 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:

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

In this relation, S_i is the score for the subscripted variable and W_i is the weighing factor obtained from the PCA. Here the assumption is 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 radar chart. The radar charts are very effective way to display multivariate observations and to identify which variables are dominant for a given observation. In this graph, each ray represents one variable and the length of each ray is proportional to the size of the variable (in the present study, the percent contributions).

Results and Discussion

The soil pH of the experimental plots was observed to be saline-alkaline and ranged from 7.29 to 8.67 and was significantly influenced by the cropping sequence and the nutrient treatments. Among the cropping sequences followed, almost under all the cropping sequences soil pH was in the saline to alkaline range of which castor-castor recorded significantly lowest pH of 8.17 followed by castor-groundnut (8.29). Electrical conductivity of the soils was recorded in the range of 0.12 to 0.31 dS m^{-1} across the cropping sequences. Application of organic sources of nutrients resulted in decrease in the soil conductivity. Among the cropping sequences, groundnut-groundnut system resulted in lower electrical conductivity (0.15 dS m^{-1}) while among the nutrient management treatments, application of nutrients through sole organic sources lowered the electrical conductivity (0.16 dS m^{-1}) compared to control. Organic carbon in these soils was observed to be in the range of 5.3 to 7.4 g kg^{-1} of soil across the cropping sequences. Significantly highest organic carbon was observed under groundnut-groundnut system (6.51 g kg^{-1}), which was at par with cotton-groundnut cropping sequence (6.45 g kg^{-1}), while the lowest amount was observed under sesamum-sesamum sequence (5.71 g kg^{-1}). Among the fertilizer treatments, application of sole organic sources resulted in significantly highest organic carbon content of 6.43 g kg^{-1}, which was at par with INM treatments (6.42 g kg^{-1}). The interaction effects of cropping sequences and fertilizer treatments also had a significant influence on the soil carbon content where cotton-groundnut + integrated nutrient management treatments resulted in significantly highest organic carbon content of 7.43 g kg^{-1} followed by cotton-cotton + INM practices (6.81 g kg^{-1}) (Table 1).

Table 1 : Effect of cropping sequences and nutrient management treatments on physico-chemical soil quality parameters in Vertisol soils at Targhadia, Rajkot

Treatments	pH				EC (dS m^{-1})				Organic carbon (g kg^{-1})			
	Control	RDF	INM	Organic	Control	RDF	INM	Organic	Control	RDF	INM	Organic
Sesamum-cotton	8.33	8.54	8.54	8.30	0.31	0.20	0.19	0.18	0.57	0.67	0.68	0.60
Sesamum-sesamum	8.60	8.55	8.67	7.74	0.17	0.23	0.19	0.16	0.54	0.59	0.58	0.58
Sesamum-groundnut	8.53	8.66	8.51	8.53	0.22	0.17	0.16	0.19	0.57	0.61	0.58	0.62
Bajra - groundnut	8.58	8.59	8.58	8.53	0.17	0.20	0.20	0.18	0.56	0.58	0.61	0.66
Bajra-bajra	8.52	8.52	8.64	8.54	0.18	0.17	0.20	0.15	0.54	0.54	0.65	0.70
Bajra-cotton	8.59	8.45	8.61	8.50	0.19	0.23	0.20	0.17	0.57	0.60	0.65	0.68
Castor-cotton	8.42	8.67	8.62	8.41	0.19	0.17	0.20	0.20	0.53	0.58	0.62	0.62
Castor-castor	8.56	8.59	7.29	8.25	0.14	0.20	0.16	0.12	0.53	0.60	0.65	0.62
Castor-groundnut	8.40	7.84	8.56	8.38	0.13	0.16	0.15	0.17	0.54	0.60	0.60	0.67
Cotton - groundnut	8.55	8.49	8.42	7.61	0.13	0.14	0.14	0.15	0.60	0.61	0.74	0.63
Cotton-cotton	8.51	8.52	8.42	8.48	0.16	0.15	0.20	0.13	0.58	0.59	0.68	0.67
Groundnut-groundnut	7.47	8.59	8.44	8.60	0.15	0.16	0.16	0.14	0.63	0.66	0.66	0.66
Main treatments	0.06				0.02				0.32			
Sub treatments	0.03				0.01				0.19			
Main treatments x sub treatments	0.11				0.04				0.64			

Available nitrogen content in these soils varied from 162.3 to 196.0 kg ha^{-1} across the management treatments. The cropping sequences had no significant influence on the available nitrogen content in the soils, while the fertilizer treatments showed significant influence on the available nitrogen content of the soils. Among the fertilizer nutrient management practices, application of sole organic sources of nutrients resulted in highest available nitrogen content of 197.9 kg ha^{-1} followed by INM treatments (182.3 kg ha^{-1}). Available phosphorus in these soils was found to be in the range of 13.9 to 32.63 kg ha^{-1}. When

Table 2 : Effect of cropping sequences and nutrient management treatments on soil quality parameters (macronutrients) in Vertisol soils at Targhadia, Rajkot

Treatments	Nitrogen (kg ha^{-1})				Phosphorus (kg ha^{-1})				Potassium (kg ha^{-1})			
	Control	RDF	INM	Organic	Control	RDF	INM	Organic	Control	RDF	INM	Organic
Sesamum-cotton	162.3	175.3	177.1	193.8	18.60	19.55	20.75	19.14	306.7	389.2	306.7	400.9
Sesamum-sesamum	163.9	193.0	175.0	216.0	18.32	20.89	26.76	19.93	369.3	371.3	487.8	375.2
Sesamum-groundnut	178.9	181.1	184.9	211.8	15.75	18.93	21.01	19.12	306.0	319.6	370.2	444.3
Bajra - groundnut	172.8	182.6	179.8	193.8	16.02	25.59	30.14	17.50	348.7	349.9	406.8	421.2
Bajra-bajra	174.3	182.1	186.1	199.2	15.79	25.47	32.63	20.27	254.0	254.1	257.3	279.0
Bajra-cotton	178.4	183.2	187.7	207.5	19.03	22.38	25.68	20.41	359.3	380.0	363.0	414.7
Castor-cotton	173.6	178.5	186.1	209.1	18.30	21.60	30.30	20.24	354.7	361.7	422.7	361.7
Castor-castor	170.5	174.6	184.8	193.6	20.75	23.29	28.18	22.05	372.3	418.8	374.8	449.0
Castor-groundnut	173.5	180.9	182.4	186.9	16.82	26.73	31.58	18.86	319.0	339.5	327.7	394.0
Cotton - groundnut	170.2	187.3	173.7	195.1	14.20	25.10	30.06	29.52	346.5	430.5	442.1	475.2
Cotton-cotton	168.9	187.3	174.5	181.3	13.91	16.21	29.28	17.04	348.8	419.1	588.3	439.9
Groundnut-groundnut	168.7	176.2	196.0	186.8	14.08	20.49	23.12	15.75	351.7	417.2	387.6	356.8
Main treatments	NS				2.07				16.2			
Sub treatments	4.88				1.19				9.35			
Main treatments x sub treatments	NS				4.13				32.4			

averaged over nutrient management treatments, the highest available P (24.72 kg ha^{-1}) was recorded under cotton-groundnut cropping sequence, while the lowest (18.7 kg ha^{-1}) was observed under sesamum-groundnut cropping sequence. When averaged over the cropping sequences, integrated nutrient management practices resulted in significantly highest availability of soil phosphorus (27.5 kg ha^{-1}) followed by recommended dose of fertilizer (22.2 kg ha^{-1}). Even the interaction effects of cropping sequences and nutrient management treatments were found to be significant and bajra-bajra system + integrated nutrient management practices recorded highest available phosphorus of 32.63 kg ha^{-1} .

Available potassium in these soils ranged between 306.3 to 588.3 kg ha^{-1} across the management practices and was significantly influenced by the cropping sequences, nutrient management practices and their interaction effects. Among the cropping sequences, cotton-cotton cropping sequence recorded significantly highest available potassium content of 449.1 kg ha^{-1} followed by cotton-groundnut system (523.5 kg ha^{-1}), while the lowest was observed under bajra-bajra cropping sequence. Application of nutrients through sole organic and integrated sources resulted in highest available potassium contents of 401.0 and 400.0 kg ha^{-1} and was found to be at par with each other (Table 2).

Exchangeable calcium and magnesium in these soils varied from 16.4 to 37.9 and 2.06 to 4.85 cmol kg^{-1} of soil respectively across the treatments. Cropping sequences, nutrient management treatments as well as their interaction effects significantly influenced the exchangeable calcium and magnesium contents. Sesamum-groundnut system recorded significantly highest exchangeable calcium and magnesium contents of 29.4 and 3.7 cmol kg^{-1} while cotton-ground nut system recorded the least. On an average, nutrient application through sole organic sources resulted in highest calcium content (27.0 cmol kg^{-1}) in the soils while exchangeable magnesium was highest under INM treatments (3.2 cmol kg^{-1}) of soil. Among all the treatments, sesamum-groundnut sequence + INM treatments recorded the highest exchangeable calcium (37.9 cmol kg^{-1}) and magnesium (4.85 cmol kg^{-1}) in soil. The exchangeable calcium contents were on considerably higher side. Similar to exchangeable Ca and Mg, the effect of the cropping systems as well as the nutrient management practices were also found to have a significant influence on available S and was found to range from 5.57 to 19.6 kg S ha^{-1} across the management treatments. Of the cropping systems, sesamum-sesamum cropping sequence recorded significantly highest content of available S (15.0 kg ha^{-1}) while among the nutrient management treatments, it was the application of sole organic sources of nutrients which recorded highest amounts of available S (13.8 kg ha^{-1}) followed by sole inorganic sources as well as integrated manner. Of all the treatments, application of sole organic sources of nutrients under groundnut-groundnut system recorded significantly highest available S to the extent of 19.6 kg ha^{-1} (Table 3).

Cropping sequences and the nutrient management practices and their interaction effects had a significant influence on the micronutrient contents of the soil (Tables 4 and 5). The range of micronutrients across the cropping systems in these soils were

Table 3 : Effect of cropping sequences and nutrient management treatments on soil quality parameters (secondary nutrients) in Vertisol soils at Targhadia, Rajkot

Treatments	Calcium (cmol kg^{-1})				Magnesium (cmol kg^{-1})				Sulphur (kg ha^{-1})			
	Control	RDF	INM	Organic	Control	RDF	INM	Organic	Control	RDF	INM	Organic
Sesamum-cotton	22.9	22.9	25.9	27.5	3.22	3.32	3.37	3.53	9.40	17.3	14.9	11.4
Sesamum-sesamum	23.1	23.5	21.6	29.3	3.04	3.21	3.44	3.66	10.7	17.5	13.0	18.6
Sesamum-groundnut	24.6	25.9	37.9	29.1	3.13	3.65	4.85	3.26	7.94	14.6	9.27	11.4
Bajra - groundnut	21.6	23.1	22.9	30.2	2.94	3.06	3.05	3.16	5.57	18.5	8.33	13.5
Bajra-bajra	19.6	22.1	24.5	24.1	2.68	3.02	3.24	2.76	6.26	9.54	11.1	8.52
Bajra-cotton	18.3	25.5	21.5	29.4	2.91	3.18	3.02	3.06	6.26	9.47	10.4	13.5
Castor-cotton	19.2	22.2	20.9	28.3	2.93	3.14	3.08	3.19	6.19	10.7	12.6	12.9
Castor-castor	20.4	22.1	21.1	24.8	2.96	3.10	3.51	3.19	7.00	10.7	10.6	16.9
Castor-groundnut	22.4	22.4	21.6	25.1	2.57	2.97	2.81	2.93	7.21	8.40	9.47	11.9
Cotton - groundnut	16.4	24.4	22.2	25.6	2.06	3.23	3.15	3.34	6.15	9.94	14.3	12.3
Cotton-cotton	22.5	28.8	28.2	28.3	3.23	3.62	3.58	3.27	6.68	10.6	15.4	14.7
Groundnut-groundnut	24.1	30.3	24.5	24.9	2.94	3.11	3.15	3.02	9.04	12.4	17.0	19.6
Main treatments	2.46				0.28				0.90			
Sub treatments	1.42				0.16				0.52			
Main treatments x sub treatments	4.92				0.56				1.80			

found to be as follows: available zinc: 0.73 to 1.24 µg g^{-1} of soil, available iron: 8.77 to 19.1µg g^{-1} of soil, available copper 2.16 to 4.31 µg g^{-1} of soil, available manganese: 3.32 to 10.4 µg g^{-1} of soil, and available boron 0.21 to 0.71 µg g^{-1} of soil. On an average, among the cropping sequences, cotton-cotton cropping sequence recorded significantly highest available Zn (1.06 µg g^{-1}) and availab le Cu (3.36 µg g^{-1}), while available B (0.52 µg g^{-1}) and available Fe (16.0 µg g^{-1}) under castor-cotton system. Whereas, castor-castor system recorded the highest available Mn content (7.88 µg g^{-1}). Sesamum-groundnut system recorded significantly lowest contents of available Zn (0.81 µg g^{-1}), bajra-bajra system recorded lowest available Fe (18.2 µg g^{-1}) while sesamum cotton cropping sequences recorded lowest amounts of available Cu (2.58 µg g^{-1}), available Mn (3.97µg g^{-1}) and available B (0.35 µg g^{-1}). Among the nutrient management treatments, application of sole organic sources of nutrients resulted in significantly highest amounts of available Zn (1.06 µg g^{-1}), available Fe (17.1 µg g^{-1}), available Mn (7.24 µg g^{-1}) and available B (0.55µg g^{-1}) while available Cu was found to be significantly highest under INM treatments (3.52 µg g^{-1}). Some of the micronutrients were also on slightly higher side compared to the critical limits suggested for these elements (Table 4 & 5).

Table 4 : Effect of cropping sequences and nutrient management treatments on micronutrient status in Rajkot in Vertisol soils at Targhadia, Rajkot

Treatments	Zinc (µg g^{-1})				Iron (µg g^{-1})				Copper (µg g^{-1})			
	Control	RDF	INM	Organic	Control	RDF	INM	Organic	Control	RDF	INM	Organic
Sesamum-cotton	0.73	0.74	0.77	1.04	9.43	12.5	13.2	14.6	2.34	3.03	2.56	2.41
Sesamum-sesamum	0.75	0.78	0.84	0.94	12.7	13.5	14.0	16.4	2.60	2.82	3.23	2.67
Sesamum-groundnut	0.66	0.77	0.79	1.01	10.5	11.6	13.7	15.8	2.72	2.80	3.37	2.78
Bajra-groundnut	0.78	0.82	0.84	1.03	10.7	14.8	15.6	17.7	2.56	3.71	4.05	2.62
Bajra-bajra	0.80	0.87	0.90	1.06	8.77	13.4	13.7	13.5	2.63	2.84	3.69	2.99
Bajra-cotton	0.82	0.84	0.88	1.04	11.5	12.4	14.6	16.7	2.49	2.95	3.81	3.08
Castor-cotton	0.85	0.99	0.98	1.24	11.6	15.1	17.9	19.1	2.42	2.65	4.31	3.29
Castor-castor	0.85	0.90	0.89	1.03	11.7	14.5	15.0	17.5	3.19	3.41	3.29	3.43
Castor-groundnut	0.85	0.91	0.90	1.09	12.5	14.0	14.1	18.6	2.16	2.73	3.61	3.53
Cotton-groundnut	0.80	0.81	0.83	1.11	12.6	13.3	14.4	18.2	2.37	2.85	3.79	3.85
Cotton-cotton	0.94	0.97	1.15	1.18	12.6	14.3	15.7	19.0	2.21	3.53	3.54	4.16
Groundnut-groundnut	0.84	0.91	0.94	0.97	11.7	15.5	16.1	18.1	2.19	3.22	2.99	3.18
Main treatments	0.12				1.46				0.23			
Sub treatments	0.07				0.84				0.13			
Main treatments x sub treatments	NS				NS				0.45			

Table 5 : Effect of cropping sequences and nutrient management treatments on micronutrient status in Rajkot in Vertisol soils at Targhadia, Rajkot

Treatments	Manganese (µg g^{-1})				Boron (µg g^{-1})			
	Control	RDF	INM	Organic	Control	RDF	INM	Organic
Sesamum-cotton	3.51	4.65	3.92	3.79	0.28	0.31	0.37	0.43
Sesamum-sesamum	3.66	7.55	5.79	4.98	0.36	0.41	0.52	0.52
Sesamum-groundnut	3.32	5.85	4.89	6.53	0.27	0.30	0.30	0.40
Bajra-groundnut	3.84	7.11	7.66	6.20	0.38	0.45	0.44	0.61
Bajra-bajra	4.47	4.91	4.82	4.68	0.39	0.46	0.43	0.65
Bajra-cotton	4.96	6.81	5.39	5.73	0.29	0.37	0.43	0.65
Castor-cotton	4.01	4.29	8.22	8.96	0.33	0.37	0.42	0.56
Castor-castor	4.93	8.54	7.61	10.43	0.33	0.44	0.50	0.57
Castor-groundnut	4.13	4.55	4.69	9.10	0.23	0.31	0.39	0.51
Cotton-groundnut	4.33	5.14	6.85	9.78	0.41	0.43	0.45	0.69
Cotton-cotton	5.03	5.42	8.74	9.69	0.21	0.54	0.71	0.61
Groundnut-groundnut	5.04	5.16	5.77	6.98	0.30	0.51	0.35	0.40
Main treatments	0.69				0.04			
Sub treatments	0.40				0.03			
Main treatments x sub treatments	1.39				0.09			

In the present study, the biological soil quality parameters *viz.,* DHA, MBC and labile carbon were found to be significantly influenced by the cropping sequences, nutrient management treatments and their interaction effects. DHA in these soils ranged from 0.05 to 0.56 µg TPF g^{-1} of soil, MBC from 77.4 to 170.2 µg g^{-1} of soil and labile carbon from 226.1 to 365.7 µg g^{-1} of soil across the treatments. Among the cropping sequences followed, on an average, sesamum-sesamum sequence recorded significantly highest DHA of 0.34 µg TPF g^{-1}, sesamum-cotton had highest MBC(139.4 µg g^{-1} of soil) and castor-castor system recorded highest labile carbon content of 340.7 µg g^{-1} of soil. Among the nutrient management practices, on an average, the application of sole organic sources of nutrients recorded significantly highest DHA (0.32 µg TPF g^{-1} of soil), microbial biomass carbon (142.8 µg g^{-1} of soil) and labile carbon (338.2 µg g^{-1} of soil) followed by INM treatment (Table 6).

Table 6 : Effect of cropping sequences and nutrient management treatments on biological soil quality parameters in Vertisol soils at Targhadia, Rajkot

Treatments	Dehydrogenase Assay (µg TPF g^{-1} of soil)				Microbial biomass carbon (µg g^{-1} of soil)				Labile Carbon (µg g^{-1} of soil)			
	Control	RDF	INM	Organic	Control	RDF	INM	Organic	Control	RDF	INM	Organic
Sesamum-cotton	0.14	0.37	0.25	0.43	125.9	128.8	132.9	170.2	307.2	311.4	322.0	340.9
Sesamum-sesamum	0.10	0.17	0.54	0.56	95.7	111.3	117.4	132.8	226.1	246.1	312.5	332.7
Sesamum-groundnut	0.13	0.29	0.25	0.41	82.0	96.7	139.5	147.3	256.4	296.6	301.2	317.1
Bajra - groundnut	0.18	0.30	0.20	0.32	77.4	110.9	134.4	138.2	303.3	306.2	312.4	327.5
Bajra-bajra	0.08	0.14	0.12	0.24	102.2	114.5	131.7	140.1	308.8	310.3	334.7	337.8
Bajra-cotton	0.09	0.15	0.12	0.22	87.2	119.2	125.4	127.2	310.0	327.7	329.4	346.2
Castor-cotton	0.05	0.14	0.14	0.17	94.3	110.7	138.8	149.9	280.3	293.5	323.9	338.2
Castor-castor	0.09	0.17	0.26	0.31	99.0	115.9	128.3	146.2	316.9	338.2	342.2	365.7
Castor-groundnut	0.12	0.19	0.21	0.24	90.2	111.3	119.3	143.5	299.7	308.2	318.6	335.9
Cotton - groundnut	0.08	0.13	0.24	0.42	94.1	99.2	128.7	137.4	295.4	326.5	328.4	346.1
Cotton-cotton	0.15	0.21	0.23	0.27	97.6	106.0	121.1	139.8	289.8	300.1	348.4	349.9
Groundnut-groundnut	0.08	0.22	0.23	0.31	104.2	108.6	124.7	141.7	296.2	298.1	290.8	320.9
Main treatments	0.04				12.56				14.65			
Sub treatments	0.02				7.25				8.46			
Main treatments x sub treatments	0.07				NS				29.31			

The cropping sequences and the nutrient management treatments showed significant influence on the bulk density and mean weight diameter of the soils aggregates, while their interaction effects did not show any influence. Bulk density of the soils across the treatments varied between 1.10 to 1.37 Mg m^{-3}. Among the cropping sequences, cotton-groundnut system recorded significantly lowest bulk density of 1.16 Mg m^{-3} while sesamum-groundnut recorded the highest (1.24 Mg m^{-3}). Among the nutrient management treatments, on an average, application of sole organic nutrient sources aided in significantly lowering the bulk density (1.15 Mg m^{-3}) compared to control (1.26 Mg m^{-3}). Mean weight diameter of the soil aggregates varied between 0.19 to 0.68 mm across the treatments. Among all the cropping sequences, bajra-cotton sequence recorded significantly highest mean weight diameter of 0.44 mm while under the nutrient management treatments. Again, the sole organic nutrient treatments favored in significant increase in mean weight diameter (0.38 mm) compared to control (0.24 mm) (Table 7).

Table 7 : Effect of cropping sequences and nutrient management treatments on physical soil quality parameters in of Vertisol soils at Targhadia, Rajkot

Treatments	Bulk density (Mg m^{-3})				Mean weight diameter (mm)			
	Control	RDF	INM	Organic	Control	RDF	INM	Organic
Sesamum-cotton	1.29	1.23	1.19	1.18	0.30	0.34	0.34	0.36
Sesamum-sesamum	1.31	1.17	1.23	1.10	0.22	0.22	0.24	0.26
Sesamum-groundnut	1.29	1.27	1.23	1.15	0.26	0.27	0.28	0.30
Bajra - groundnut	1.24	1.20	1.19	1.16	0.23	0.23	0.40	0.68
Bajra-bajra	1.24	1.17	1.15	1.15	0.24	0.29	0.39	0.41
Bajra-cotton	1.37	1.23	1.21	1.18	0.30	0.38	0.49	0.59
Castor-cotton	1.24	1.24	1.18	1.15	0.28	0.30	0.30	0.34
Castor-castor	1.22	1.21	1.20	1.15	0.25	0.25	0.29	0.34
Castor-groundnut	1.22	1.19	1.18	1.14	0.19	0.22	0.27	0.31
Cotton - groundnut	1.18	1.17	1.15	1.13	0.20	0.23	0.29	0.30
Cotton-cotton	1.25	1.18	1.15	1.15	0.23	0.25	0.27	0.29
Groundnut-groundnut	1.26	1.15	1.15	1.14	0.22	0.22	0.33	0.35
Main treatments	0.08				0.04			
Sub treatments	0.05				0.02			
Main treatments x sub treatments	NS				NS			

Key indicators and soil quality assessment

Results of principal component analysis

As the selected soil quality variables tested significant with the cropping sequences as well as the nutrient management treatments, all the variables were subjected to PCA. In the PCA of 19 variables, five PCs had eigen values > 1 and explained 60.6% variation in the data set (Table 8). In PC$_1$, the highly weighted variables were Fe and B, which were also significantly correlated (Table 9), but both were retained for MDS. In PC$_2$, exchangeable Ca and Mg were highly weighted and were also significantly correlated. Considering their importance in these soils, both the variables were retained for the final MDS. However, in PC$_3$, PC$_4$ and PC$_5$, the highly weighted variables were only EC, MWD and pH respectively and hence were retained for the MDS. Hence, the final MDS consisted of pH, EC, exchangeable Ca, Mg, available Fe, B and MWD as the final key soil quality indicators for different cropping sequences and nutrient management treatments followed at Rajkot.

Soil quality indices

Soil quality indices for the various cropping sequences and various nutrient management treatments were computed using seven key indicators *viz.,* pH, EC, exchangeable Ca, exchangeable Mg, available Fe, available B and MWD which were qualified through PCA. Soil quality indices as influenced by cropping sequences and nutrient management treatments varied from 0.74 to 1.22 (Table 10). Different cropping sequences practiced showed a conspicuous influence in improving the soil

Table 8 : Principal component analysis of the soil quality variables of different management treatments at Targhadia, Rajkot

	PC1	PC2	PC3	PC4	PC5
Total Eigen values	6.038	1.657	1.464	1.285	1.070
% of Variance	31.778	8.723	7.706	6.761	5.633
Cumulative %	31.778	40.501	48.207	54.968	60.600
Eigen Vectors					
pH	-0.197	-0.064	0.332	0.544	-0.552
EC	-0.189	0.066	0.583	0.298	0.283
OC	0.576	-0.056	-0.006	0.129	-0.166
N	0.556	0.287	-0.285	0.245	0.229
P	0.392	-0.472	0.430	-0.075	0.340
K	0.604	-0.030	0.227	-0.288	-0.259
Ca	0.471	0.581	0.062	0.082	0.222
Mg	0.272	0.588	0.454	-0.171	0.106
S	0.637	0.258	0.248	-0.078	-0.170
Zn	0.585	-0.080	-0.369	0.132	-0.087
Fe	0.783	-0.086	-0.117	0.066	-0.229
Cu	0.587	-0.420	0.415	0.024	-0.064
Mn	0.702	-0.313	0.123	-0.164	-0.104
B	0.745	-0.165	-0.120	0.039	-0.050
DHA	0.607	0.435	0.029	-0.245	0.131
MBC	0.692	0.153	0.013	0.176	0.275
LC	0.639	-0.216	-0.110	0.065	0.360
BD	-0.628	0.107	0.238	0.144	0.085
MWD	0.320	0.056	-0.062	0.726	0.160

Table 9 : Pearson's correlation matrix for highly weighted variables under PC's with high factor loading

Variables under PCs		
PC1	Fe	B
Fe	1.00	0.556**
B	0.556**	1.00
Correlation sum	1.556	1.556
PC2	Ca	Mg
Ca	1.00	0.450**
Mg	0.450**	1.00
Correlation sum	1.450	1.450

Table 10 : Soil quality indices as influenced by cropping sequences and nutrient management treatments at Targhadia, Rajkot

Treatments	SQI				
	Control	RDF	INM	Organic	Mean
Sesamum-cotton	0.80	0.86	0.92	0.99	0.89
Sesamum-sesamum	0.86	0.94	1.02	1.09	0.98
Sesamum-groundnut	0.78	0.83	0.95	1.01	0.89
Bajra-groundnut	0.83	0.99	1.01	1.22	1.01
Bajra-bajra	0.78	0.95	0.97	1.09	0.95
Bajra-cotton	0.79	0.91	0.99	1.21	0.98
Castor-cotton	0.81	0.93	1.04	1.19	0.99
Castor-castor	0.80	0.97	1.01	1.12	0.98
Castor-groundnut	0.74	0.84	0.90	1.12	0.90
Cotton-groundnut	0.83	0.92	0.96	1.22	0.98
Cotton-cotton	0.76	1.06	1.22	1.19	1.06
Groundnut-groundnut	0.79	1.05	0.95	1.02	0.95
Mean	0.99	0.94	1.12	0.80	-
LSD (P=0.05)	0.05				
Main treatments (Cropping sequence)					
Sub treatments (Nutrient management)	0.03				
Main treatments x sub treatments	0.10				

quality in these soils. Among the cropping sequences, Cotton - Cotton sequence could significantly aggrade the soil quality (SQI 1.06), which was almost at par with Bajra- Groundnut sequence (SQI 1.01) (Figure 1). Castor – Cotton sequence with a SQI of 1.00, followed this, which was at par with Cotton-groundnut sequence (SQI 0.99). Of all the cropping sequences , Sesamum-cotton sequence showed the lowest value of soil quality index. (SQI 0.89). Among the cropping sequences, the relative order of performance in aggrading the soil quality was: Cotton-cotton (1.06) > Bajra-groundnut (1.01) > Castor-cotton (1.00) = Cotton-groundnut (0.99) = Sesamum-sesamum (0.98) = Castor-castor (0.98) = Bajra-cotton (0.98) = Groundnut-groundnut (0.95) = Bajra-bajra (0.95) > Castor-groundnut (0.90) = Sesamum-cotton (0.89) = Sesamum-groundnut (0.89). Among the nutrient management treatments, the application of sole organic sources of nutrients performed significantly well in aggrading or improving the soil quality (SQI 1.12) which was followed by the integrated nutrient management treatment (SQI 0.99) and sole inorganic treatments (SQI 0.94), while the control plots aggraded soil quality to the lower extent (Figure 2). Among the cropping sequences and the integrated management treatments, the application of sole organic treatment in cotton-groundnut sequence significantly aggraded the soil quality with the highest SQI of 1.22. The average percent contribution of the key indicators towards soil quality indices was: pH (9%), EC (7%), exchangeable Ca (9%), exchangeable Mg (8%), available Fe (34%), available B (30%) and MWD (3%) (Figure 3). It was observed that, of the key indicators, available Fe followed by available B influenced soil quality to a greater extent compared to other key indicators. Available Fe in these soils was found to be in high range.

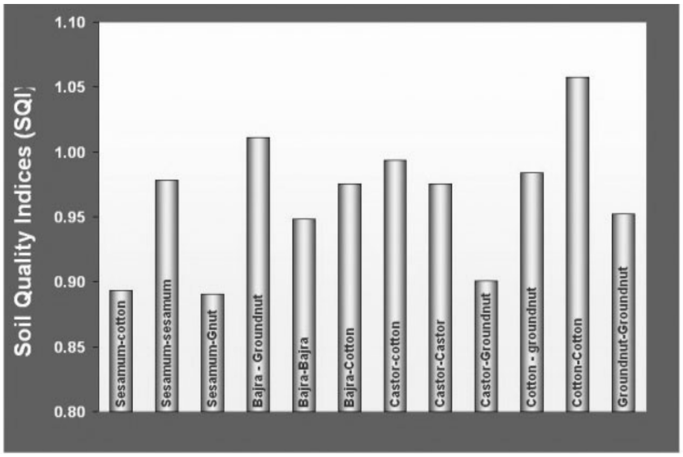

Fig. 1 : Soil quality indices as influenced by cropping sequences (average over nutrient management practices) in Vertisol soils at Targhadia, Rajkot

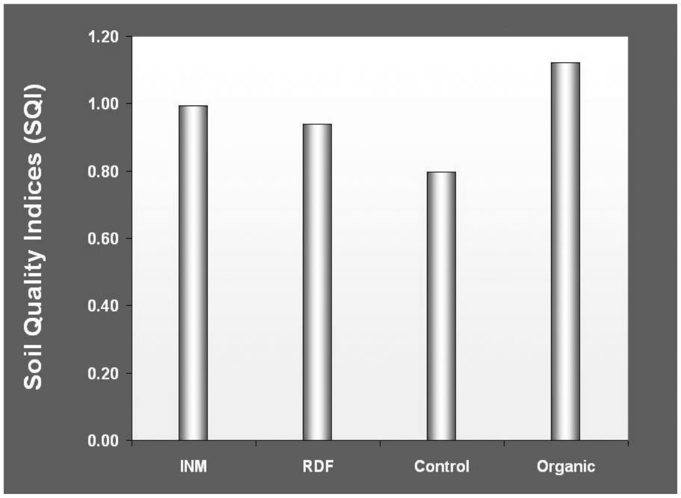

Fig. 2 : Soil quality indices as influenced by nutrient management treatments (average over cropping sequences) in Vertisol soils at Targhadia, Rajkot

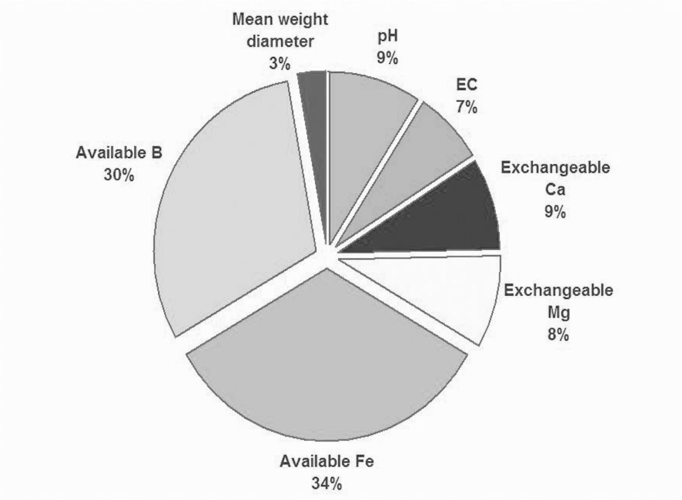

Fig. 3 : Percent contribution of key soil quality indicators towards soil quality indices as influenced by nutrient management treatments in Vertisol soils at Targhadia, Rajkot

Conclusion

This study clearly established the influence of cropping sequences and nutrient management treatments on soil quality indices. The average percent contribution of the key indicators towards soil quality indices at Rajkot was: pH (9%), EC (7%), exchangeable Ca (9%), exchangeable Mg (8%), available Fe (34%), available B (30%) and MWD (3%). Different cropping sequences practiced showed a conspicuous influence in improving the soil quality in these soils. The relative order of performance of the cropping sequences in aggrading the soil quality was: Cotton-cotton (1.06) > Bajra-groundnut (1.01) > Castor-cotton (1.00) = Cotton-groundnut (0.99) = Sesamum-sesamum (0.98) = Castor-castor (0.98) = Bajra-cotton (0.98) = Groundnut-groundnut (0.95) = Bajra-bajra (0.95) > Castor-groundnut (0.90) = Sesamum-cotton (0.89) = Sesamum-groundnut (0.89). Among the nutrient management treatments, application of sole organic sources of nutrients performed significantly in aggrading or improving the soil quality (SQI 1.12) which was followed by the integrated nutrient management treatment (SQI 0.99) and sole inorganic treatments (SQI 0.94), while the control plots maintained the lowest. Thus, it can be concluded that cropping sequence and nutrient management practices are important in influencing the soil quality indices in soil. The methodology adopted and the results of this study will be highly useful in assessing and maintaining the soil quality for ensuring higher productivity in rainfed Vertisols and in other identical situations.

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