Indian J. Dryland Agric. Res. & Dev. 2019 34(2) : 38-50 10.5958/2231-6701.2019.00019.8

Effect of Conjunctive Use of Inorganic and Organic Sources of Nutrients on Soil Quality Parameters, Key Indicators and Soil Quality Indices (SQIs) under Sorghum + Cowpea Intercropping System in Rainfed Vertisol Soils of Southern India

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ABSTRACT: The present study was conducted at Kovilpatti Centre of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) to assess the impact of conjunctive nutrient management practices on soil quality parameters, to identify the key indicators of soil quality, to compute the soil quality indices (SQIs) and to identify the best conjunctive nutrient management practices from the view point of soil quality improvement in sorghum + cowpea intercropping (C1), sorghum sole cropping (C2) and cowpea sole cropping (C3) systems. The treatments were comprised of T1: control, T2: 100% N (inorganic), T3: 25 kg N (compost), T4: 15 kg N (compost) + 20 kg N (inorganic) and T5: 15 kg N (green leaf) + 20 kg N (inorganic). The results of the present study clearly indicated that the conjunctive nutrient treatments significantly influenced organic carbon (OC), available phosphorus (P), sulphur (S), zinc (Zn) and copper (Cu) contents of soil in all the three systems; the potassium (K) and manganese (Mn) were significantly influenced in the C2 and C3 cropping systems. The dehydrogenase activity (DHA) was significantly highest under T3 in sole sorghum system with highest value of 1.41 µg TPF ha^{-1} g^{-1} of soil, which was on par with T4. The microbial biomass carbon (MBC) was significantly influenced by sole cowpea and sole sorghum systems, with highest values of 125.1 and 114.0 µg g^{-1} of soil under T3, respectively. However, the labile carbon (LC) content was significantly influenced in all the three cropping systems, with the highest LC content of 338.3 (T3), 285.2 (T3) µg g^{-1} and 339.64 (T4) of soil under sorghum + cowpea, sole sorghum and sole cowpea systems, respectively. The mean weight diameter of soil aggregates (MWD) was significantly influenced by the treatments in the sole sorghum system with the highest value of 0.50 mm with the T5 treatment. When all the cropping systems were viewed together, the final set of key soil quality indicators for these Vertisol soils emerged were: EC, OC, available P, available S, available Zn, LC, MBC and BD. From the view point of RSQI, the order of superiority of the conjunctive nutrient management treatments was: T3: 25 kg N (compost) (0.95)=T4: 15 kg N (compost) + 20 kg N (inorganic) (0.95) > T5: 15 kg N (green leaf) + 20 kg N (inorganic) (0.84) > T2: 100% N (inorganic) (0.73) > T1: control (0.55).

Key words: Conjunctive nutrient management, cropping systems, principal component analysis, soil quality indices, vertisols

Introduction

Vertisols are also known as black lands and occupy a considerable area of the world. The countries that predominantly have Vertisols or black lands include India (72.9 m ha), Australia (70.5 m ha), Sudan (40 m ha), Chad (16.5 m ha), and Ethiopia (10 m ha) (Dudal 1965; ICRISAT, 1989). In India, these soils are found in Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, and Tamil Nadu (Murthy, 1981). Earlier, Rajput *et al.* (2009) reported that these soils are predominantly developed on base-rich rocks (basalt) or the related colluvium or alluvium. Consequently, these soils are generally alkaline and heavy in texture (clay, clay loam, or silty clay loam). These soils are dominated by a smectite group of clay minerals, leading to expansion and shrinkage on wetting and drying, and are highly erodible.

Millets, especially sorghum and pearl millet, are widely cultivated in Vertisol soils of Kovilpatti region of Southern Tamil Nadu under dryland condition. The productivity of these crops is low as compared to state average due to several constraints *viz.,* uneven distribution of rainfall, inadequate fertilizer schedule, poor fertilization and no or low application of manures, resulting in deterioration of soil health. Since the farmers of this region are not economically capable of fertilizing the crop with commercial fertilizers, alternative strategies are required to enhance the productivity of crops at nominal cost. Further, it is of paramount importance to minimize the dependence on the use of the inorganic fertilizers and to build up soil fertility and improve overall soil quality (physical, chemical and biological). The conjunctive use of inorganic fertilizers and organic manures not only helps in increasing the crop yield but also ensures sustainable soil fertility and productivity. Several researchers have established that the conjunctive use of organic and inorganic sources of nutrients influence nutrient availability i) by addition of nutrients, ii) through mineralization-immobilization patterns, iii) by enhancing energy source for microbial activities, iv) by acting as precursors to soil organic matter (SOM), and v) by reducing P sorption of the soil (Palm *et al.,* 1997). If fertilizer nutrient is supplied along with organic materials, the yield decrement if any, in the initial years can be overcome (Bartholomew, 1971 and Allision, 1973) by enhancing the mineralization of nutrients from fresh organic materials with wide C/N ratios by way of supplementing with slightly higher fertilizer doses (Sreemannarayana *et al.,* 1994). The various feasible mechanisms by which availability of nutrients in soil and the overall soil quality can be improved in drylands, could be i) use of fertilizer in combination with organic manures like farm yard manure or compost in an appropriate proportion, ii) conjunctive use of fertilizer nutrients in combination with leaves + twigs (biomass) of nitrogen fixing trees including legume crops in rotations (Sharma *et al.*, 2002, 2005). When these combinations of conjunctive nutrient management are practiced over long term basis, they show their differential impact on soil quality indicator

The use of chemical fertilizers to enhance crop productivity has often negatively affected the complex system of the biogeochemical cycles (Perrott *et al.,* 1992; Steinshamn *et al.*, 2004) due to their continuous long-term use. The overall strategy for increasing crop yields on sustainable basis could be the conjunctive use of organic and inorganic sources of nutrients, along with other complementary measures. Organics are known to have favorable effects on soil structure, texture, and tilth and facilitate quick and greater availability of plant nutrients. Organics thus provide a better environment for root growth and proliferation, thereby creating more absorptive surface for uptake of nutrients (Avnimelech, 1986). Kler and Walia (2006) reported that organic farming treatment supplemented with farmyard manure (FYM) along with crop residue incorporation and green manuring recorded greater growth components in wheat under maize-wheat cropping system. Some researchers have reported that integrated use of organic and inorganic sources of nutrients along with biofertilizers resulted in greater productivity and net returns in soybean (Singh and Rai, 2004; Bhattacharyya *et al.,* 2008). Wu *et al.* (2005) reported that microbial inoculants increased the growth and nutritional assimilation [total nitrogen (N), phosphorus (P), and potassium (K)] of maize and improved soil properties. Singh (2010) found an increase in organic carbon and microbial biomass carbon in the treatments receiving application of organic manures (particularly FYM), green manure, and biofertilizers in conjunction with inorganic fertilizer. More and Hangarge (2003) noticed that grain and fodder yields of sorghum were greater in treatments receiving nutrients only through organics such as FYM, crop residues, and inoculation with azotobacter compared to nutrient supply only through chemical fertilizer. Studying the long-term effect of INM practices in terms of soil quality is of presumable importance in rainfed agriculture. Soil quality assessment has been suggested as a tool for evaluating the sustainability of soil and crop management practices (Hussain *et al.,* 1999; Karlen *et al.,* 1997). Jaenicke and Lengnick (1999) emphasized that the soil quality index is desirable because individual soil properties in isolation may not be sufficient to quantify changing soil conditions. Application of *Gliricidia* loppings proved superior to sorghum stover and no-residue treatments in maintaining greater SQI values in Vertisols (Sharma *et al.,* 2005).

To quantify these impacts precisely, systematic study of soil quality assessment using standard procedures was felt necessary. Some of the studies on conjunctive nutrient management were initiated at Kovilpatti Centre of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and the influence of these treatments on the yield of crops was studied and documented (AICRPDA, 2008). However, the quantitative information on the impact of these long-term INM treatments on soil quality was lacking. Thus, the present study was undertaken i) to study the impact of conjunctive nutrient management treatments on soil chemical, physical and biological soil quality parameters, ii) to identify the key indicators of soil quality and iii) to compute the soil quality indices (SQIs) and to identify the superior most conjunctive nutrient management treatments from the view point of soil quality.

Materials and Methods

Description of experimental site

The experimental location *viz.* Kovilpatti centre of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) is situated amidst the Vertisol belt in the southern zone of Tamil Nadu uplands and leeward flanks of South Sahayadris and Deccan (Karnataka) plateau and lies between 8° 43’ and 9° 20’ North latitude and 77° 4’ and 28° 25’ East longitude at 90 m above MSL. The climate of the region is hot semi-arid with a mean annual rainfall of 743 mm and potential evapotranspiration of 812 mm. The summer and southwest monsoon rains are insufficient to raise any crop because the evapotranspiration is high during this period due to high solar radiation and high wind speed. Thus, the length of growing period extends from October to January only being 90-120 days. The frequency of drought is once in ten years. Water erosion is medium severity with slight loss of topsoil, affecting 26-50% area. The soils are moderately deep, water retentive, slowly permeable, prone to erosion, highly deficient in phosphorus and have high phosphorus fixing capacity, and texture is clayey with varying bulk density. Infiltration rate of the soil is low (0.5-0.9 cm hr^{-1}) with moisture at field capacity to the extent of 30-35% and at permanent wilting point 12-14% (with sunflower as indicator plant). During the summer season, these soils develop deep cracks of more than 1 cm wide and 50 cm deep during the moisture stress due to the abundance of smectitic type of clay minerals noticed in the subsoil (AICRPDA, 2006).

Details of experiment

The experiment was initiated during September 1999 in a randomized block design with nine conjunctive nutrient management treatments in three replications using sorghum (K8) and cowpea (C 152) as test crops with three cropping systems namely sorghum + cowpea (C1), sole sorghum (C2) and sole cowpea (C3) systems. Out of these nine treatments, only five treatments *viz.,* T1: Control, T2: 100% N (inorganic), T3: 25 kg N (compost), T4: 15 kg N (compost) + 20 kg N (inorganic) and T5: 15 kg N (green leaf) + 20 kg N (inorganic) were chosen for the present study to assess the soil quality. Phosphorus was applied to all the treatments at the recommended level and for legume, 30 kg P_2O_5 ha^{-1} was applied and rotated with cereal block every year.

Soil sample collection and analysis

Soil samples were collected from plough layer (0.0-0.15 m depth) after the harvest of the respective crops during the year 2005. Soil samples were partitioned and passed through 8 mm, 4.75 mm, 2 mm, 0.2 mm sieves differently and used for different kind of analysis. Soil samples passed through 8 mm sieve and retained on the 4.75 mm sieve were used for aggregate analysis. Soil samples passed through 2 mm sieve were used for chemical analysis for pH, EC, available N, P and K, exchangeable Ca and Mg, available S, and micronutrients such as Zn, Fe, Cu, Mn and B. While the soil samples passed though 0.2 mm sieve were used for organic carbon and labile carbon. For biological properties like microbial biomass carbon and dehydrogenase assay, 2 mm sieved soil samples were used. The various standard procedures adopted for the estimation of different soil quality parameters were: pH and electrical conductivity (Rhoades, 1982) measured in 1:2 soil water suspension, 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 $NaHCO_3$ method (Olsen *et al.,* 1954), available K (Hanway and Heidal, 1952) and exchangeable Ca and Mg using neutral normal ammonium acetate method (Lanyon and Heald 1982), DTPA extractable Zn, Fe, Cu, Mn by Diethylene Triamine Penta Acetic Acid (DTPA) (0.005 M) + Triethanolamine (TEA) (0.1M) + Calcium chloride ($CaCl_2$. $2H_2O$) (0.01M) reagent (pH 7.3) using Inductively Coupled Plasma Spectrophotometer (ICP-OES, GBC model) (Lindsay and Norvell, 1978), extractable Boron by DTPA-Sorbitol extraction (Miller *et al.,* 2001), bulk density by Keen's box method, aggregate stability using wet sieve technique (Yoder, 1936), mean weight diameter was computed after oven drying (Van Bevel, 1949), microbial biomass carbon by fumigation extraction (Jenkinson and Powlson, 1976), dehydrogenase activity by triphenyl tetrazolium chloride (TTC) method (Lenhard, 1956) and labile carbon by $KMnO_4$ (0.01 M) method (Weil *et al.,* 2003) with slight modification.

Steps followed for soil quality assessment

The data on chemical, physical and biological soil quality indicators as influenced by conjunctive nutrient use treatments were tested for their level of significance using randomized block design, and the qualified variables were considered for computation of soil quality analysis using principal component analysis (PCA) and linear scoring technique (LST). For identification of key indicators and computation of soil quality indices (SQIs), the following steps were used: i) testing the level of significance for various soil indicators as influenced by various management treatments, ii) fixing or defining the goals, iii) selecting representative minimum data set (MDS) through PCA, iv) correlation analysis among soil variables to reduce spurious grouping among highly weighted variables within each PC, v) multiple regressions using the final MDS components as the independent variables and each goal attribute as a dependent variables, vi) scoring of the MDS indicators based on their performance of soil function, and vii) computation of soil quality indices (SQIs). To identify the MDS, the procedures earlier suggested by Doran and Parkin (1994) and Andrews *et al.* (2002) and followed by Sharma *et al.* (2005, 2008) were used. Subsequent to the test for level of significance, the data were subjected to PCA with an objective to reduce the dimensionality (number of variables) of the dataset and retain most of the original variability in the data. As per the criteria set by Brejda *et al.* (2000a, b), those principal components which received higher eigen values ≥ 1, which 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 MDS. When more than one factor was retained under a single PC, multivariate correlation coefficients were used to determine if the variables could be considered redundant and therefore eliminated from the MDS (Andrews *et al.,* 2002). Among the well-correlated variables (r > 0.70), only one variable was considered for the MDS. However, flexibility criteria were also followed in most of the circumstances depending upon the importance of the variables. If the highly weighted variables were not correlated, each was considered important and was retained in the MDS.

After screening the variables through PCA and correlation for MDS, multiple regressions were performed as a check of how well the MDS represented the management system goals. This was done considering the indicators retained in the MDS as independent variables and the functional goals such as long-term average yields of crops and sustainability yield indices (SYIs) as dependent variables. 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. Subsequent to identification of the indicators to be retained in the MDS, all the observations of each MDS indicator were transformed using a linear scoring method as suggested by Andrews *et al.* (2002). To assign the scores, indicators were arranged in order depending on whether a higher value was considered desirable or undesirable in terms of influencing soil function.

In case of desirable indicator values, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For undesirable indicator values, 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, 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 SQI, the weighted MDS indicator scores for each observation were summed up using the following relation:

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

In this equation, S_i is the score for the subscripted variable and W_i is the weighing factor obtained from the PCA. Here, it was assumed that the higher index scores meant better soil quality or greater performance of soil function. Relative soil quality indices (RSQIs) were also computed by reducing the SQI values to a scale of 0-1 by dividing all the SQI values with the highest SQI value. Further, the percent contributions of each final key indicator were also calculated.

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

Influence on soil quality parameters

Soil reaction was found to be saline-alkali and pH ranged from 8.13 to 8.57 across the cropping sequences. Only the sole cowpea (C3) plots had a significant influence on the soil reaction while sorghum + cowpea (C1) and sole sorghum (C2) plots did not show any effect. Within the sole cowpea plots, application of 25 kg N (compost) resulted in maximum decrease in pH (8.13) compared to control plot (8.47). Similar to soil reaction, only the sole cowpea plots had significant influence on the electrical conductivity and values varied from 0.24 to 0.34 dS m^{-1} across cropping systems. Organic carbon in these soils varied between 3.39 to 6.20 g kg^{-1} across different plots, and the conjunctive nutrient use treatments had a significant influence on it. Among all the treatments, the application of 25 kg N (compost) recorded significantly highest organic carbon content of 6.2 g kg^{-1} under sorghum + cowpea plots, 6.11 g kg^{-1} under sole sorghum plots and 5.42 g kg^{-1} under sole cowpea plots followed by 15 kg N (compost) + 20 kg N (inorganic) treatment.

The conjunctive nutrient use treatments significantly influenced the available N content under sorghum + cowpea plots and sole cowpea plots but not under sole sorghum plots and it ranged from 72.4 to 123.8 kg ha^{-1} across the plots. Among all the treatments, the application of 100% N (inorganic) recorded significantly highest available N content of 123.8 and 110.2 kg ha^{-1} under sorghum + cowpea plots and sole cowpea plots, respectively. However, sole sorghum plots, 15 kg N (compost) + 20 kg N (inorganic) recorded the highest available N content of 115.4 kg ha^{-1}. The nutrient use treatments had a significant influence on the available phosphorus content of the soils under all the three systems and it varied from 6.77 to 17.20 kg ha^{-1} across all the plots. Among all the nutrient use treatments, 15 kg N (green leaf) + 20 kg N (inorganic) recorded the highest available P content of 16.8, 17.2 and 16.2 kg ha^{-1} under sorghum + cowpea, sole sorghum and sole cowpea plots, respectively followed by 15 kg N (compost) + 20 kg N (inorganic). Available potassium content of the soil was significantly influenced by the nutrient use treatments under sole sorghum and sole cowpea plots but not under sorghum + cowpea plots and varied from 453.7 to 623.5 kg ha^{-1} across the plots. It was interesting to observe that, the application of 25 kg N (compost) and 15 kg N (compost) + 20 kg N (inorganic) were observed to be almost at par in recording significantly highest K content under both sole sorghum and sole cowpea plots while the lowest available K was observed under control plots (Table 1).

Exchangeable Ca and Mg were not significantly influenced by the conjunctive nutrient management treatments. However, exchangeable Ca varied from 13.4 to 15.7 cmol kg^{-1}, while exchangeable Mg varied from 3.93 to 4.57 cmol kg^{-1} across the plots. However, a conspicuous influence of the conjunctive nutrient use treatments on available S was observed under all the plots, the range being 29.5 to 76.3 kg ha^{-1} under sorghum + cowpea system, 33.4 to 69.5 kg ha^{-1} under sole sorghum system, and 42.5 to 77.0 kg ha^{-1} under sole cowpea system. Of the conjunctive nutrient treatments, the application of 15 kg N (compost) + 20 kg N (inorganic) recorded significantly highest available S to the extent of 76.3 kg ha^{-1} and 69.5 kg ha^{-1} under sorghum + cowpea system and sole sorghum system, respectively while under sole cowpea system, the application of sole organic sources of nutrients as 25 kg N (compost) recorded significantly highest available S (77.0 kg ha^{-1}).

Among the micronutrients, available Fe and B were not significantly influenced by the conjunctive nutrient use treatments under any of the plots, however, their contents varied from 3.07 to 3.64 and 2.12 to 3.00 µg g^{-1} of soil, respectively. Available Zn varied between 0.54 to 1.35 µg g^{-1} soil, available Cu from 0.80 to 1.50 µg g^{-1} soil and available Mn from 9.49 to 14.17 µg g^{-1} soil across the plots in these soils. It was quite interesting to observe that almost all the treatments, except control, behaved equally in significantly influencing the available Zn, Cu and Mn in soils and the amounts were significantly higher than the control, except the Mn in the sorghum + cowpea system (Table 2).

Bulk density (BD) of these soils varied from 1.20 to 1.35 Mg m^{-3} across the plots and the contents were significantly

Table 1 : Effect of different conjunctive nutrient management treatments on physico-chemical and nutrient (N, P, K and Ca) related soil quality parameters under sorghum-cowpea cropping systems in vertisol soils

Treatment	pH			EC (dSm^{-1})			OC ($g\ kg^{-1}$)			N ($kg\ ha^{-1}$)			P ($kg\ ha^{-1}$)			K ($kg\ ha^{-1}$)			Ca ($cmol\ kg^{-1}$)		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
T1	8.50	8.37	8.47	0.34	0.35	0.34	3.39	3.39	3.49	93.43	94.53	72.41	8.62	7.52	6.77	500.3	453.7	480.2	14.9	15.1	15.2
T2	8.40	8.57	8.40	0.26	0.24	0.25	4.53	4.71	4.48	123.78	110.06	110.23	12.00	11.34	7.64	542.0	547.3	528.8	14.0	14.9	15.7
T3	8.23	8.33	8.13	0.28	0.33	0.29	6.20	6.11	5.42	121.00	114.34	109.13	12.79	7.86	9.81	558.6	552.6	623.5	13.4	15.3	14.0
T4	8.27	8.33	8.27	0.30	0.27	0.26	5.40	5.05	5.10	121.33	115.36	102.85	14.98	14.90	15.01	557.8	552.7	602.4	14.6	15.1	15.5
T5	8.50	8.47	8.20	0.27	0.27	0.30	5.16	4.64	4.65	107.32	104.80	105.62	16.77	17.20	16.23	556.9	534.1	575.1	13.5	15.2	15.6
LSD (P=0.05)	NS	NS	0.19	NS	NS	0.06	0.66	0.55	0.46	16.12	NS	10.61	1.77	3.19	1.87	NS	27.64	53.49	NS	NS	NS

Table 2 : Effect of different conjunctive nutrient management treatments on nutrient related (Mg, S, Zn, Fe, Cu, Mn and B) soil quality parameters under sorghum-cowpea cropping systems in vertisol soils

Treatment	Mg (cmol kg^{-1})			S (kg ha^{-1})			Zn (μg g^{-1})			Fe (μg g^{-1})			Cu (μg g^{-1})			Mn (μg g^{-1})			B (μg g^{-1})		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
T1	4.35	4.54	4.37	29.5	33.4	42.5	0.54	0.55	0.59	3.07	3.64	3.28	0.80	0.97	0.99	10.35	10.43	9.49	2.25	2.36	2.12
T2	4.45	4.52	3.93	43.0	53.1	48.6	0.70	0.71	0.81	3.64	3.52	3.61	1.07	1.09	1.33	11.41	12.06	11.57	2.35	2.71	2.34
T3	4.50	4.46	4.52	59.9	68.8	77.0	0.99	1.15	1.06	3.47	3.48	3.34	1.26	1.24	1.41	13.15	13.80	14.16	2.63	3.00	2.61
T4	4.55	4.36	4.57	76.3	69.5	69.0	1.09	1.35	1.16	3.40	3.38	3.37	1.31	1.24	1.50	12.55	11.92	14.17	2.31	2.71	2.39
T5	4.56	4.53	4.55	48.2	49.4	56.5	0.95	1.13	1.00	3.34	3.38	3.42	1.30	1.27	1.48	13.67	11.96	12.98	2.36	2.42	2.39
LSD (P=0.05)	NS	NS	NS	7.09	10.1	18.0	0.18	0.19	0.18	NS	NS	NS	0.29	0.19	0.32	NS	1.74	1.93	NS	NS	NS

Treatments - T1: Control; T2: 100% N inorganic; T3: 25 kg N (compost); T4: 15 kg N (compost) + 20 kg N (inorganic); T5: 15 kg N (green leaf) + 20 kg N (inorganic); Cropping pattern - C1- Sorghum + Cowpea; C2- Sole Sorghum; C3- Sole cowpea

Table 3 : Effect of different conjunctive nutrient management treatments on physical and biological soil quality parameters under sorghum-cowpea cropping systems in vertisol soils

Treatment	BD (Mg m^{-3})			MWD (mm)			DHA (μg TPF hr^{-1}g^{-1})			MBC (μg g^{-1} of soil)			LC (μg g^{-1})		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
T1	1.29	1.35	1.23	0.39	0.40	0.39	0.72	0.79	0.64	94.38	82.83	77.94	160.06	159.04	155.82
T2	1.22	1.26	1.22	0.44	0.44	0.48	0.88	0.81	0.75	110.95	95.72	94.85	224.15	250.18	261.83
T3	1.23	1.24	1.20	0.52	0.46	0.43	0.94	1.41	0.90	109.75	114.00	125.14	338.33	285.16	287.77
T4	1.24	1.25	1.23	0.49	0.45	0.43	0.98	1.31	1.00	111.79	92.38	86.79	329.70	275.41	339.64
T5	1.21	1.25	1.23	0.46	0.50	0.40	0.95	0.82	0.84	95.58	89.21	85.48	320.60	261.88	255.16
LSD (P=0.05)	0.05	0.06	NS	NS	0.05	NS	NS	0.22	NS	NS	17.68	6.83	32.22	39.24	46.70

Treatments - T1: Control; T2: 100% N inorganic; T3: 25 kg N (compost); T4: 15 kg N (compost) + 20 kg N (inorganic); T5: 15 kg N (green leaf) + 20 kg N (inorganic); Cropping pattern - C1- Sorghum + Cowpea; C2- Sole Sorghum; C3- Sole cowpea influenced by the management treatments under sorghum + cowpea plots and sole sorghum plots only. In sorghum + cowpea plots, 15 kg N (green leaf) + 20 kg N (inorganic) treatment recorded significantly lowest BD of 1.21 Mg m^{-3}, while in sole sorghum plots, it was lowest under 25 kg N (compost) (1.24 Mg m^{-3}). Nutrient management treatments showed a significant influence on the mean weight diameter (MWD) of the soil aggregates only under sole sorghum plots but not under sorghum + cowpea and sole cowpea plots. However, MWD of these soils ranged from 0.39 to 0.52 mm across the plots irrespective of the level of significance. Under sole sorghum plots, highest MWD was recorded under 15 kg N (green leaf) + 20 kg N (inorganic) (0.50 mm) treatment followed by 25 kg N (compost) (0.46 mm).

Dehydrogenase activity (DHA) in these soils varied from 0.64 to 1.41 µg TPF h^{-1} g^{-1} soil across the treatments and was significantly influenced by the conjunctive nutrient management treatments only under sole sorghum plots. Significantly highest DHA was observed under 25 kg N (compost) (1.41 µg TPF h^{-1} g^{-1} of soil) under sole sorghum plots which was at par with 15 kg N (compost) + 20 kg N (inorganic) (1.31 µg TPF h^{-1} g^{-1} of soil). The nutrient use treatments had significant influence on the microbial biomass carbon (MBC) content only under sole sorghum and sole cowpea plots but not under sorghum + cowpea plots and varied from 77.9 to 125.1 µg g^{-1} of soil across the plots. Significantly highest MBC was recorded under 25 kg N (compost) under both sole sorghum (114.0 µg g^{-1} of soil) and sole cowpea (125.1 µg g^{-1} of soil) plots. Labile carbon (LC) in these soils varied from 155.8 to 339.6 µg g^{-1} of soil and was significantly influenced by the nutrient use treatments under all the three systems. Even in case of LC content, application of 25 kg N (compost) proved superior and recorded significantly highest LC content of 338.3 and 285.2 µg g^{-1} of soil under sorghum + cowpea plots and sole sorghum plots, respectively, while it was highest in 15 kg N (compost) + 20 kg N (inorganic) (339.6 µg g^{-1} of soil) under sole cowpea plots (Table 3).

Key soil quality indicators and soil quality indices (SQIs)

The results of the principal component analysis (PCA) for the sorghum + cowpea system, sole sorghum system and sole cowpea system are presented in Table 4. In the sorghum + cowpea system, at Kovilpatti, among the 19 variables chosen for the soil quality assessment studies, only nine variables were found to be significantly influenced by different conjunctive nutrient management treatments while the rest of the ten variables *viz.,* pH, EC, Ca, Mg, Fe, Mn, B, DHA, MBC and MWD were found to be non-significant and hence were dropped from PCA. In the PCA of 9 variables, only two PCs had eigen values > 1 which explained a variance of 80.8% within the data set (Table 4). The highly weighted variables in PC1 included OC, available S, Cu and LC. The correlation matrix run for these parameters (Table 5) under PC1 also revealed significant positive correlations between each other, inspite of which only Cu which had the lowest correlation sum was dropped while the other three variables *viz.,* OC, S and LC were retained for the MDS depending upon their importance in these soils.

Table 4 : Principal component analysis of soil quality parameters as influenced by different conjunctive nutrient management treatments under sorghum-cowpea cropping system in vertisols at Kovilpatti

Cropping systems	Sorghum + cowpea		Sole sorghum		Sole cowpea		
	PC1	PC2	PC1	PC2	PC1	PC2	PC3
Total eigen values	6.079	1.193	7.260	1.948	7.779	1.320	1.173
% of Variance	67.548	13.260	60.502	16.233	64.828	10.998	9.773
Cumulative %	67.548	80.807	60.502	76.735	64.828	75.826	85.599
Eigen vectors							
pH	-	-	-	-	-0.773	-0.088	-0.430
EC	-	-	-	-	-0.541	0.167	0.704
OC	0.907	0.164	0.897	0.344	0.945	0.160	-0.029
N	0.608	0.295			0.802	0.018	-0.473
P	0.820	0.068	0.366	-0.889	0.622	-0.679	0.262
K	0.768	-0.517	0.905	-0.053	0.878	0.135	0.082
S	0.865	0.245	0.887	0.210	0.864	0.225	0.256
Zn	0.837	0.411	0.852	-0.253	0.920	-0.205	0.045
Cu	0.881	-0.298	0.814	-0.346	0.832	-0.236	0.052
Mn	-	-	0.726	0.224	0.936	0.016	0.199
DHA	-	-	0.681	0.450	-	-	-
MBC	-	-	0.595	0.577	0.585	0.781	-0.071
LC	0.948	0.204	0.926	0.014	0.832	-0.144	-0.277
BD	-0.708	0.670	-0.848	0.215	-	-	-
MWD	-	-	0.635	-0.420	-	-	-

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

Variables under PCs				
PC1	OC	S	Cu	LC
OC	1.00	0.783**	0.740**	0.939**
S	0.783**	1.00	0.708**	0.833**
Cu	0.740**	0.708**	1.00	0.801**
LC	0.939**	0.833**	0.801**	1.00
Correlation sum	3.462	3.324	3.249	3.573

**Correlation is significant at 0.01 level

While in PC2, only BD was the highly weighted variable and was retained for MDS. Hence, the final MDS consisted of OC, available S, LC and BD as the key soil quality indicators for sorghum + cowpea system at Kovilpatti. The final indicators retained in the MDS, when regressed with average yield, sustainable yield index (SYI) and mean equivalent yields as management goals (Table 6), it was observed that available S and BD were found to be significantly influenced (Table 7).

Table 6 : Data of management goals (yield and SYI) under sorghum + cowpea system used for regression analysis

Name of the treatments	Sorghum 5 years mean yield (kg ha^{-1})*	SYI*	Average sorghum equivalent yield of 8 years (kg ha^{-1})
T1: Control	1462	0.35	1168
T2: 100% N inorganic	2058	0.54	2390
T3: 25 kg N (compost)	1919	0.50	2104
T4: 15 kg N (compost) + 20 kg N (inorganic)	2203	0.59	2516
T5: 15 kg N (green leaf) + 20 kg N (inorganic)	2091	0.55	2445

Source: AICRPDA, *2006, 2008

Table 7 : Results of multiple regressions of the minimum data set (MDS) components using management goal attributes at different probability (*P*) levels

Goal or Function	R^2 **	Most significant MDS variables	P
Sorghum 5 years mean yield	0.743	BD	> 0.031
SYI	0.784	S, BD	> 0.073, > 0.039
Average sorghum equivalent yield of 8 years	0.774	S, BD	> 0.087, > 0.037

**Significant at P = 0.01 level

In sole sorghum system, of the 19 variables chosen for soil quality assessment studies, 7 variables *viz.,* pH, EC, N, Ca, Mg, Fe and B were not significantly influenced by any of the management treatments and hence were dropped from PCA. In the PCA of 12 variables, only two PCs had eigen value >1 which explained about 76.7% variance in the data set. The highly weighted variables in PC1 included OC, available K, S, Zn, LC and BD. Correlation matrix run for these variables (Table 8) revealed a significant relation between each other, but among these only K was dropped while the rest of the variables were retained for the final MDS. However, in PC2, as available P was the only indicator qualified, it was retained for the MDS. Hence, the final MDS included OC, available P, S, Zn, LC and BD as the key soil quality indicators for sole sorghum system at Kovilpatti. The final key indicators when regressed as independent variables with management goals as dependent variables (Table 9), available P, S, Zn and LC were found to be significantly influenced (Table 10).

In sole cowpea system, among the 19 variables chosen for soil quality assessment studies, 7 variables *viz.,* exchangeable Ca, Mg, available Fe, B, DHA, BD, and MWD were not significantly influenced by the management practices and were dropped

Table 8 : Pearson's correlation matrix for highly weighted variables under PCs with high factor loading under sole sorghum system

Variables under PCs						
PC1	**OC**	**K**	**S**	**Zn**	**LC**	**BD**
OC	1.00	0.782**	0.830**	0.663**	0.858**	-0.685**
K	0.782**	1.00	0.856**	0.670**	0.882**	-0.772**
S	0.830**	0.856**	1.00	0.746**	0.801**	-0.596**
Zn	0.663**	0.670**	0.746**	1.00	0.744**	-0.698**
LC	0.858**	0.882**	0.801**	0.744**	1.00	-0.799**
BD	-0.685**	-0.777**	-0.596*	-0.698**	-0.799**	1.00
Correlation sum	4.818	4.967	4.829	4.521	5.084	4.555

** Correlation is significant at 0.01 level

Table 9 : Data of management goals (yield and SYI) under sole sorghum system used for regression analysis

Name of the treatments	Sorghum 5 years mean yield (Kg ha^{-1})*	SYI*	Average sorghum equivalent yield of 8 years (kg ha^{-1})
T1: Control	1127	0.34	978
T2: 100% N inorganic	1862	0.61	2061
T3: 25 kg N (compost)	1660	0.54	1836
T4: 15 kg N (compost) + 20 kg N (inorganic)	2019	0.67	2190
T5: 15 kg N (green leaf) + 20 kg N (inorganic)	1868	0.62	2113

Source: AICRPDA *2006, 2008

Table 10 : Results of multiple regressions of the minimum data set (MDS) components using management goal attributes at different probability (*P*) levels

Goal or Function	R^2 **	Most significant MDS variables	P
Sorghum 5 years mean yield	0.926	P, S, LC	> 0.005, > 0.026, > 0.076
SYI	0.931	P, S, LC	> 0.004, > 0.027, > 0.066
Average sorghum equivalent yield of 8 years	0.934	P, S, Zn, LC	> 0.003, > 0.047, > 0.059, > 0.065

** Significant at P = 0.01 level

from PCA. Finally, in the PCA of 12 variables, three PCs had eigen value > 1 and explained 85.6% variance in the data set (Table 11). In PC1, the highly weighted variables included OC, available K, S, Zn and Mn (Table 11). Of these variables, considering their importance in these soils, only OC, available S and Zn were retained for the final MDS while available K and Mn were eliminated. However, in PC2 and PC3, MBC and EC were the two highly weighted variables, respectively and were retained for the MDS. Hence, the final MDS consisted of EC, OC, available S, Zn and MBC were considered as the key soil quality indicators for sole cowpea system at Kovilpatti. When the key soil quality indicators retained in the MDS were regressed as independent variables with average sorghum equivalent yields as dependant variable (Table 12), EC and OC were found to be significantly influenced by the management goal (Table 13).

Table 12 : Data of management goals (yield) under sole cowpea system used for regression analysis

Name of the treatments	Average sorghum equivalent yield of 8 years (kg ha^{-1})
T1: Control	1035
T2: 100% N inorganic	1739
T3: 25 kg N (compost)	1639
T4: 15 kg N (compost) + 20 kg N (inorganic)	1904
T5: 15 kg N (green leaf) + 20 kg N(inorganic)	1816

Source: AICRPDA, 2008

Table 13 : Results of multiple regressions of the minimum data set (MDS) components using management goal attributes at different probability (*P*) levels

Goal or Function	R^2 **	Most significant MDS variables	P
Average sorghum equivalent yield of 8 years	0.868	EC, OC	> 0.057, > 0.026

** Significant at P = 0.01 level

Table 11 : Pearson's correlation matrix for highly weighted variables under PCs with high factor loading under sole cowpea system

Variables under PCs					
PC1	OC	K	S	Zn	Mn
OC	1.00	0.866**	0.814**	0.814**	0.913**
K	0.866**	1.00	0.755**	0.717**	0.869**
S	0.814**	0.755**	1.00	0.802**	0.824**
Zn	0.814**	0.717**	0.802**	1.00	0.811**
Mn	0.913**	0.869**	0.824**	0.811**	1.00
Correlation sum	4.407	4.207	4.195	4.144	4.417

** Correlation is significant at 0.01 levels

Soil quality indices (SQIs)

The data on soil quality indices (SQIs) and relative soil quality indices (RSQIs) as influenced by different conjunctive nutrient management treatments under sorghum/ cowpea intercropping system in Vertisols of Kovilpatti is given in Table 14 and Figure 1 (a) and (b). Under sorghum + cowpea intercropping system, the SQI varied from 1.23 to 2.40 across the treatments. In sole sorghum and sole cowpea system, the SQIs varied from 2.24 to 3.69 and 1.39 to 2.27, respectively. It was observed that, of all the treatments, integrated application of 15 kg N (compost) + 20 kg N (inorganic) was identified significantly best treatment in aggrading the soil quality in both sorghum + cowpea system (SQI 2.40) and sole sorghum system (SQI 3.69) which was followed by sole organic treatment *viz.,* 25 kg N (compost) (Table 15). But in sole cowpea system, application of 25 kg N (compost) with SQI of 2.27 proved to be the best in improving the soil quality followed by 15 kg N (compost) + 20 kg N (inorganic) (SQI 2.17). The SQIs for the sorghum + cowpea system were computed using four key indicators *viz.,* OC, available S, LC and BD and their average percent contribution towards SQIs was: OC (32%), available S (27%), LC (33%) and BD (8%) (Figure 2). For the sole sorghum system, the SQIs were computed using six qualified indicators in PCA *viz.,* OC, available P, S, Zn, LC and BD and their average percent contribution towards the soil quality indices was: OC (18%), available P (4%), S (18%), Zn (16%), LC (20%) and BD (24%) (Figure 3). For sole cowpea system, the soil quality indices were computed using five key indicators qualified in PCA *viz.,* EC, OC, available S, Zn and MBC and their average percent contribution towards soil quality indices was: EC (5%), OC (31%), available S (29%), Zn (30%), and MBC (5%) (Figure 4).

Table 14 : Summary of soil quality indices and relative soil quality indices as influenced by different conjunctive nutrient management practices under different cropping systems in vertisols of Kovilpatti

Treatments details	SQI	RSQI
Conjunctive nutrient management in sorghum + cowpea intercropping system		
Sorghum + cowpea system		
T1: Control	1.23	0.49
T2: 100% N inorganic	1.70	0.68
T3: 25 kg N (compost)	2.36	0.94
T4: 15 kg N (compost) + 20 kg N (inorganic)	2.40	0.96
T5: 15 kg N (green leaf) + 20 kg N (inorganic)	2.07	0.83
Sole sorghum system		
T1: Control	2.24	0.58
T2: 100% N inorganic	3.03	0.78
T3: 25 kg N (compost)	3.66	0.95
T4: 15 kg N (compost) + 20 kg N (inorganic)	3.69	0.96
T5: 15 kg N (green leaf) + 20 kg N (inorganic)	3.31	0.86
Sole cowpea system		
T1: Control	1.39	0.59
T2: 100% N inorganic	1.69	0.73
T3: 25 kg N (compost)	2.27	0.97
T4: 15 kg N (compost) + 20 kg N (inorganic)	2.17	0.93
T5: 15 kg N (green leaf) + 20 kg N (inorganic)	1.91	0.82

(Treatments: T1: Control, T2: 100% N (inorganic), T3: 25 kg N (compost), T4: 15 kg N (compost) + 20 kg N (inorganic) and T5: 15 kg N (green leaf) + 20 kg N (inorganic); Cropping systems: C1: Sorghum + cowpea, C2: Sole sorghum, C3: Sole cowpea)

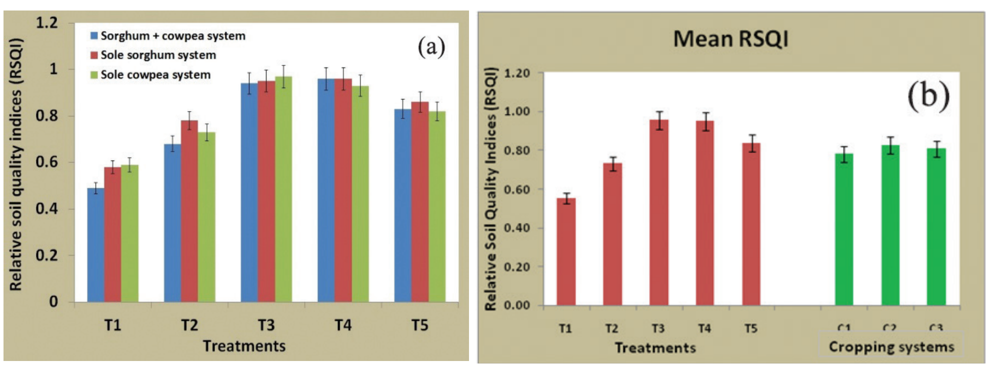

Fig. 1 (a) & (b) : Long term effect of conjunctive nutrient management on relative soil quality indices (RSQIs) under different cropping systems

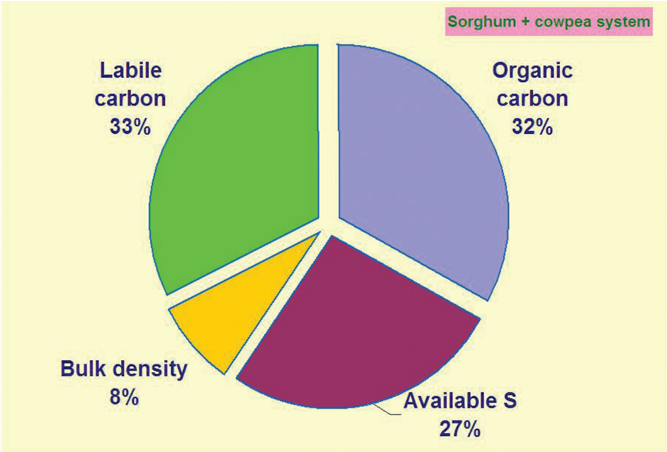

Fig. 2 : Percent contribution of key soil quality indicators towards soil quality indices as influenced by different conjunctive nutrient management treatments under sorghum + cowpea intercropping system in vertisols of Kovilpatti

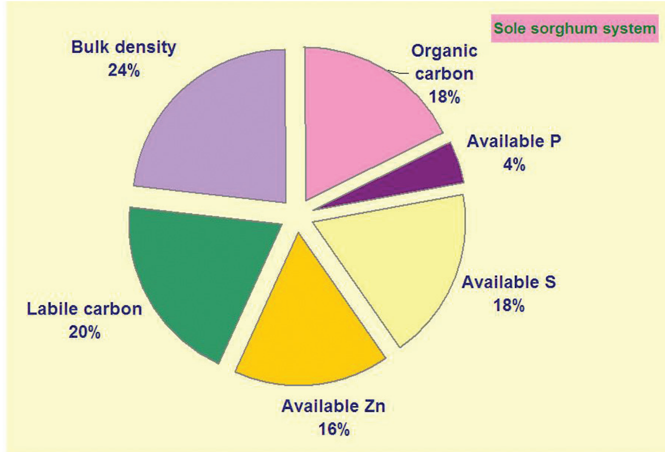

Fig. 3 : Percent contribution of key soil quality indicators towards soil quality indices as influenced by different conjunctive nutrient management treatments under sole sorghum system in vertisols of Kovilpatti

Table 15 : Key soil quality indicators, soil quality indices and efficient management practices under different cropping systems practiced in Vertisols of Kovilpatti

Cropping system	Key soil quality indicators and their % contri-bution	SQI	RSQI	Best management-practices with higher SQI
Sorghum + cowpea system	• Organic carbon (32%) • Available S (27%) • Labile carbon (33%) • Bulk density (8%).	1.23 - 2.40	0.49 -0.96	1. Application of 15 kg N (compost) + 20 kg N (inorganic) (2.40)
Sole sorghum system	• Organic car-bon(18%) • Available P (4%) • Available S (18%) • Available Zn (16%) • Labile carbon (20%) • Bulk density (24%)	2.24 - 3.69	0.58 – 0.96	1. Application of 15 kg N (compost) + 20 kg N (inorganic) (3.69)
Sole cowpea system	• Electrical con-ductivity (5%) • Organic carbon (31%) • Available S (29%) • Available Zn (30%) • Microbial bio-mass carbon (5%)	1.39 - 2.27	0.59 -0.97	1. Application of 25 kg N (compost) (2.27) 2. Application of 15 kg N (compost) + 20 kg N (inorganic) (2.17).

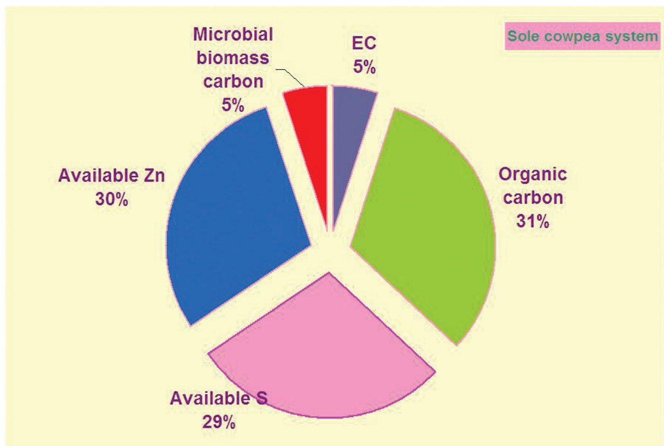

Fig. 4 : Percent contribution of key soil quality indicators towards soil quality indices as influenced by different conjunctive nutrient management treatments under sole cowpea system in vertisols of Kovilpatti

Conclusion

The results of the present study clearly indicated the importance of conjunctive nutrient management practices in influencing soil quality indicators and indices under three different cropping systems. The indicators identified in the present study can be used for periodical assessment of soil quality. Appropriate conjunctive nutrient management strategies can be adopted to improve these indicators and overall soil quality indices of the soil. Among the set of treatments evaluated, the important treatments having higher soil quality index can be used for the future studies and recommended to the farmers for adoption. Hence, the findings of the present study can be effectively utilized for improving soil quality for achieving higher sustained productivity.

Acknowledgement

The authors are thankful to Indian Council of Agricultural Research for funding the study under AP Cess Fund Programme. Authors are also thankful to Director, CRIDA and Head, DRM, for providing necessary support to conduct the research. Thanks are also due to Coordinator of AICRPDA and Chief Scientist and Scientist of Kovilpatti centre for facilitating sample collection for this study. Further, we are thankful to Dr. M. Prabhakar, PI, NICRA for providing contractual man power and other support under NICRA project.

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Received: May 2019; Accepted: November 2019