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Long-Term Effects of Soil and Nutrient Management Practices on Soil Properties and Additive Soil Quality Indices in SAT Alfisols

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ABSTRACT: A long term experiment was conducted for 11 years to study the effects of soil and nutrient management practices on soil fertility and additive soil quality indices in rainfed Alfisol, at Hyderabad, India. The treatments were comprised of conventional tillage (CT) and minimum tillage (MT) as main factors, sorghum stover (dry) @ 2 t/ha (SS), fresh gliricidia loppings @ 2 t/ha (GL) and no residue (NR) application on surface as sub-treatments and N levels @ 0, 30, 60 and 90 kg N/ ha as sub- sub treatments in castor-sorghum yearly rotation. The results indicated that after 11 years, MT significantly improved organic carbon (OC), available N, available K, exchangeable Mg, available S, microbial biomass carbon (MBC), dehydrogenase activity (DHA), labile carbon (LC), bulk density (BD) and mean weight diameter (MWD) of soil aggregates. Application of sorghum residue and gliricidia loppings showed significant increase in OC by 6.28% and 3.7%, respectively over NR. Statistical regression functions indicated that soil parameters viz., MBC, LC, MWD, OC, S, Fe and DHA influenced by long term soil management practices significantly influenced the crop yield. The physical (PSQI), physico-chemical (PCSQI), chemical (CSQI), biological (BSQI) and additive SQIs (ASQI) were significantly influenced by management treatments. On an average, the percent contribution of these component soil quality indices towards ASQI was in the order of BSQI (32.1%) > CSQI (26.1%) > PSQI (25.7%) > PCSQI (16.2%). Crop yields were significantly correlated with these indices and thus emphasized their importance in increasing the productivity in these semi arid Alfisol soils.

Key words: Minimum tillage, crop residues, gliricidia loppings, sorghum stover, soil quality and soil quality indices

Semi-arid tropical region (SAT) with a total land area of 21 m km^2 is one of the key agricultural environments. Nearly, 33% of the SAT area is occupied by Alfisol, which are characterized by low inherent soil fertility, soil organic matter, MBC and available water capacity (Palaniappan *et al.,* 2009). The most important physical constraints in these soils are: extreme structural instability, susceptibility to formation of crusts leading to reduction in water infiltration, increase in runoff and erosion and decreased seedling emergence and crop stand (Rao *et al.,* 1998). The deficiencies of nitrogen (N) and phosphorus (P) (El-Swaify *et al.,* 1985) and low levels of secondary and micronutrients (Srinivasa Rao *et al.,* 2011) occur universally in these soils.

Tisdall and Oades, (1982) reported that intensive tillage systems could lead to loss of organic carbon. Several researchers reported that reduced tillage has proven beneficial effects in terms of improving organic carbon (Reicosky *et al.,* 1995), available nitrogen, MBC, available soil P, microbial biomass nitrogen, reducing bulk density and improving aggregate size (Doran and Smith, 1987; Arshad *et al.,* 1999, Madari *et al*., 2005) and ultimately soil structure. Though, the systematic studies on assessing the long-term impacts of soil management practices such as minimum tillage, residue, management etc. on soil quality and influence on crop yield in irrigated agro eco regions and specially under temperate regions have been in vogue since long back, but in rainfed tropics such studies began only in the recent decades. As rainfed tropical lands, especially Alfisols have suffered with higher degree of degradation and soil quality deterioration, more intensive research through long term studies was needed to restore the quality of these soils. Hence, the present study was conducted for 11 years, to quantify the long term effects of soil and nutrient management practices on soil properties and additive soil quality indices and their relationship with crop yield in semi arid tropical Alfisols under castor-sorghum cropping system.

Materials and Methods

Experimental details

The study was conducted at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad, India. Soils of the experimental field belong to Hayathnagar soil series (Typic Haplustalf) and are slightly acidic to neutral in reaction. The experiment was initiated during the year 1995 in a strip split-split plot design with two tillage practices as the main treatments, three residue levels as sub plot treatments and four nitrogen levels as the sub-sub plot treatments with three replications with a sub-sub plot size of 4.52 x 6.0 m^2. Sorghum (*Sorghum vulgare* (L)) and castor (*Ricinus communis* (L)) were grown as the test crops in a two-year rotation. The sorghum (cultivar SPV 462) crop was always grown in the *kharif* season in the first week of June with the onset of monsoon rains and was always harvested in the month of first week of October. Whereas, the castor (cultivar DCS-9) crop was always grown in the *kharif* season in the first week of June and was always harvested in the months November-December through mostly three pickings of the castor capsules. Among the treatments, the strip consisted of two tillage treatments *viz.,* i) conventional tillage (CT) with two ploughings before planting + one plough planting + harrowing + operation for top dressing and ii) minimum tillage (MT) which included seeding with country plough, weeding occasionally with blade harrow. The three residues levels included i) dry sorghum stover (SS) (N content of 5 g/kg and C:N ratio of 72) applied @ 2 t/ha, ii) fresh gliricidia loppings (*Gliricidia maculata*) (GL) (mean N content of 27.6 g/kg (dry weight basis) and C: N ratio of 15) applied @ 2 t/ha (fresh weight) and iii) no residue (NR). The four nitrogen levels were: i) 0 kg N/ha (N_0), ii) 30 kg N/ha (N_{30}), iii) 60 kg N/ha (N_{60}) and iv) 90 kg N/ha (N_{90}) through urea. Nitrogen was applied in two equal splits, one at sowing and another 45 days after sowing while phosphorus was applied basally at the time of sowing of each crop @ 30 kg P_2O_5/ha single super phosphate.

Soil measurements

After harvesting the 11th year's crop, soil samples were collected from plough layer (0 to 0.20 m depth), air dried, ground, partitioned and passed through standard size sieves prior to further analyses. Soil samples passed through an 8 mm sieve and retained on the 4.75 mm sieve were used for aggregate analysis, while samples passing through a 0.2 mm sieve were saved for estimating organic carbon (OC) and labile carbon (LC). For the remaining soil quality parameters, soil samples that passed through a 2 mm sieve was used for analysis. Soil parameters namely, soil pH (McLean, 1982), electrical conductivity (Rhoades, 1982), organic C (Walkley and Black, 1934), available nitrogen (Subbaiah and Asija, 1956), bicarbonate-extractable P (Olsen *et al.,* 1954), available potassium (K) (ICP-OES, GBC) (Hanway and Heidal, 1952), exchangeable Ca and Mg (GBC 906, Australian Model) (Lanyon and Heald, 1982) and sulphur (Williams and Steinbergs, 1959) were estimated. Micronutrients viz., Zn, Fe, Cu, and Mn (Lindsay and Norvell, 1978) were estimated with Inductively Coupled Plasma Spectrophotometer (ICP), (GBC-Australia) and boron was estimated using DTPA-Sorbitol extraction (Miller *et al.,* 2001).

Bulk density was measured by soil core method (Blake and Hartge, 1986). The distribution of water stable aggregates was determined by wet sieving technique (Yoder, 1936) and mean weight diameter (MWD) was computed after oven drying (Van Bevel, 1949). Dehydrogenase activity (DHA) in the soils was measured by triphenyl tetrazolium chloride method (Lenhard, 1956). Microbial biomass carbon (MBC) was determined using the chloroform fumigation incubation technique (Jenkinson and Powlson, 1976). Microbial biomass carbon was calculated using the following relationship: MBC ($\mu g/g$ 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 (LC) was estimated by using the method suggested by Weil *et al.* (2003) with slight modification. Tukey's test (Tukey, 1953) was used for testing the means at $P \leq 0.05$ using SAS 9.2. Multiple regression equations were fitted and tested with t test at $p \leq 0.05$.

Data screening for assessment of soil quality indices

The data set containing 19 soil quality parameters was statistically analyzed using the split plot design. Parameters that 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 data variation (Wander and Bollero, 1999) and variables which had high factor loading, were considered to be the best representative to the system attributes. Within each PC, only highly weighted factors (having absolute values within 10% of the highest factor loading) were considered for the minimum data set (MDS). Those variables were labeled as the 'key indicators' and were considered for computation of SQI after suitable transformation and scoring. The values of each indicator were transformed using linear scoring technique (Andrews *et al.,* 2002). To assign the scores, indicators were arranged in an order depending on whether a higher value was considered "good" or "bad" in terms of influencing the soil function. For the 'more is better' category of indicators, each observation was divided by the highest observed value such that the highest observed value received a score of 1. For the '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 procedure, 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 'n' observations (no. of indicators qualified from PCA) were summed up according to Equation (2):

$$SQI = \sum_{i=1}^{n} (W_i \times S_i) \quad (2)$$

where S_i is the score for the subscripted variable obtained by linear scoring method and W_i is the weighing factor obtained by dividing the individual percent variance of a given PC with cumulative variability of all the PCs. Physical SQI (PSQI) was obtained by summation of the scores obtained for the physical soil quality indicators (MWD, BD) and physico-chemical SQI (PCSQI) was obtained by summation of the scores of physico-chemical soil quality parameters (OC, pH, EC). Chemical SQI (CSQI) and biological SQI were obtained by summation of soil chemical parameters and biological parameters (DHA, MBC and LC), respectively. Finally additive SQI (ASQI) was obtained by summation of all the indices studied i.e., PSQI, PCSQI, CSQI and BSQI. It was assumed that higher index scores meant for better soil quality or greater performance of soil function.

Results and Discussion

Effect on soil physico-chemical and chemical properties

The results revealed that the application of residues significantly influenced the soil pH. Electrical conductivity (EC) was also significantly influenced only by residues and N levels. Significantly higher OC (6.4 g/kg) was observed under SS followed by GL (6.2 g/kg) (Table 1). Nitrogen application at 90 kg/ha recorded higher OC (6.58 g/kg) followed by N 60 kg/ha

Table 1 : Influence of tillage, residues and N levels on physical chemical and chemical soil quality parameters

Treatments	pH	EC	OC	Ava. N	Ava. P	Ava. K	Exch.Ca	Exch.Mg	Avail.S
		dS/m	g/kg		kg/ha		c mol/kg		kg/ha
Tillage									
CT	5.29a	0.089a	6.05b	209.87b	38.12a	178.56b	3.45a	0.96b	17.98a
MT	6.11a	0.091a	6.38a	222.41a	39.24a	188.80a	3.41a	1.13a	15.95b
Residue									
SS	5.88b	0.093b	6.42a	222.66a	39.45a	193.31a	3.88a	1.01a	18.35a
GL	6.13a	0.095a	6.24b	222.16a	39.60a	183.97a	3.41a	1.04a	17.65b
NR	6.04b	0.083c	6.01c	204.13b	37.04b	174.38a	3.22a	0.97a	14.96c
N levels									
N0	6.19a	0.081b	5.60c	188.07c	34.41c	162.52c	3.10a	1.01a	13.63c
N30	5.86b	0.083ab	6.19b	211.52b	38.05b	181.07b	3.43a	1.04a	16.41b
N60	5.92b	0.093a	6.47a	228.21a	40.91a	193.40a	3.59a	1.06a	18.32a
N90	6.12a	0.102a	6.58a	235.55a	41.13a	196.84a	3.85a	1.07a	19.33a

In a column, means followed by a common letter are not significantly different from each other at the 0.05 level by Tukey's test. CT- Conventional tillage, MT- Minimum tillage, SS- Sorghum Stover @ 2t/ ha, GL - fresh Gliricidia loppings @ 2t/ha and NR- No residue and 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg/ha of nitrogen.

(6.47 g/kg). Tillage in combination with residues (T x R) and N levels (T x N) have also significantly influenced the organic carbon content (Table 2). Significantly higher OC (6.55 g/kg) was recorded with SS under MT. Application of SS along with 90 kg N/ha under MT recorded the highest amount of OC (7.1 g/kg).

On an average, a significant increase of 5.6% in OC was observed with MT over CT after 11 years of experimentation. This increase in OC could be attributed to relatively less mixing of surface soil and residue applied and reduction in soil temperature resulting in slower decomposition of organic residue and relatively less losses due to water erosion under MT compared to CT. Residue application in combination with N levels showed a significant increase in SOC. Nitrogen applied @ 60 and 90 kg/ha increased OC by 15.3% and 17.3%, respectively over no nitrogen. This increase in OC due to increasing N levels might be due to better crop growth and higher root biomass contribution to the soil which is also in conformity with earlier findings of Zhengchao *et al.* (2013).

In this study, we observed that, available nitrogen was significantly influenced by tillage, residues and N levels. The MT plots recorded significantly higher (222.4 kg/ha) available nitrogen compared to CT (209.8 kg/ha). In case of GL application, available N in soil (222.1 kg/ha) was almost on par with that recorded under SS (222.6 kg/ha) application (Table 1). The application of 90 kg N/ha recorded the highest soil available N content of 235.5 kg/ha. The interaction effects of the treatments (T x R, T x N and T x R x N) on soil available N were also found to be significant (Table 2). These findings are in confirmation with those earlier reported by Mathew *et al.* (2012). Application of SS was on par with GL and resulted in an increase of available N by 8.4% over NR. This increase is attributed to the contribution of N through mineralization from organic sources applied, which releases N slowly and persistently over a period of time.

Residues application played significant role in influencing available P. Application of SS and GL significantly influenced available P and were on par with each other. Available P was found significantly higher with application of SS by 6.92% over NR. It is important to mention here that P @ 30 kg P_2O_5/ha was uniformly applied to all the plots. Irrespective of fertilizer P application, residue significantly enhanced available P over NR. Earlier reports have indicated that organic residues can reduce P sorption and increase P availability to plants as organic acids produced during mineralization of organic matter compete with phosphate anions for binding sites in the soil (Iyamuremye *et al.,* 1996a). Available K was significantly higher under MT (188.8 kg/ha) compared to CT (178.5 kg/ha). The interaction effects (T x R and T x N) were found to be significant on soil available K (Table 2). The increase in soil potassium in this study might be due to non mixing of the surface soil under minimum tillage. Tillage practices, residues and N levels revealed significant effect on available S. Significantly higher available S was recorded with CT (17.9 kg/ha) compared to MT (15.9 kg/ha). The application of SS recorded the highest available S (18.3 kg/ha) followed by GL (17.6 kg/ha). The interactive effects (T x R, T x N) were also found significant (Tables 2 and 3).

Higher available S under CT might be due to higher rates of decomposition of residue leading to mineralization of nutrients including sulphur. Among the residues, SS and GL resulted in increase in available sulphur by 21% and 18%, respectively over NR. This can also be attributed to release of sulphur from decomposing residue during the process of mineralization.

Table 2 : Interaction effects of tillage with residues and N levels on soil chemical properties

Treatments	OC g/kg	Ava. N kg/ha	Ava. K kg/ha	Exch.Ca (Cmol/kg)	Exch. Mg (Cmol/kg)	Available S kg/ha
Conventional tillage						
SS	6.23b	215.3a	183.9b	3.82a	1.03b	20.36a
GL	6.01bc	214.9a	181.3bc	3.21bc	0.94cb	17.97b
NR	5.90c	197.8b	169.2d	3.31b	0.90c	15.18b
Minimum tillage						
SS	6.55a	227.4a	200.3a	3.90a	1.20a	15.89b
GL	6.47a	229.3a	186.5b	3.60ab	1.14a	17.32b
NR	6.12b	210.4ab	179.5c	3.13c	1.05b	14.75c
Conventional tillage						
N0	5.48d	184.4d	158.2e	3.14c	0.93cb	13.51a
N30	6.07c	208.1cb	178.9cd	3.43b	0.95bc	17.83ab
N60	6.30b	219.5b	185.3bc	3.51ab	0.95c	19.23a
N90	6.34b	225.2b	190.2b	3.71a	0.99b	20.78a
Minimum tillage						
N0	5.74d	192.1c	167.1d	3.07c	1.06ab	13.66a
N30	6.31b	214.8b	183.1c	3.44b	1.14a	14.99c
N60	6.65a	236.8ab	201.5b	3.67a	1.18a	17.40b
N90	6.83a	245.8a	203.4a	3.99a	1.15a	17.89ab

In a column, means followed by a common letter are not significantly different from each other at the 0.05 level by Tukey's test. SS- Sorghum Stover @ 2t/ha, GL - fresh Gliricidia loppings @ 2t /ha and NR- No residue and 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg/ha of nitrogen

Table 3 : Influence of tillage, residues and N levels on soil micronutrients (µg/g) and biological and physical parameters

Treatments	Fe	Cu	Zn	Mn	B	MBC (µg/g of soil)	DHA (µg TPF /h/g)	Labile carbon (mg/kg)	MWD (mm)	BD (Mg m^{-3})
Tillage										
CT	12.05a	0.72a	0.74a	17.92a	0.24a	207.05b	3.08b	242.13b	0.26b	1.70b
MT	12.22a	0.74a	0.79a	18.03a	0.25a	215.37a	3.54a	259.4a	0.29a	1.66a
Residue										
SS	12.65a	0.75a	0.78a	18.12a	0.26a	213.5b	3.75a	260.68b	0.29a	1.66a
GL	12.31a	0.76a	0.82a	17.26a	0.25b	224.12a	3.47b	262.85a	0.28b	1.67a
NR	11.46a	0.68b	0.70a	18.56a	0.22c	196.28c	2.73c	229.53c	0.26c	1.72b
N levels										
N0	10.13b	0.63d	0.62d	16.08b	0.22c	170.27c	2.31d	194.94d	0.22d	1.73c
N30	12.37a	0.71c	0.72c	18.63a	0.24b	200.51b	2.80c	253.47c	0.26c	1.70b
N60	12.82a	0.76b	0.81b	18.27a	0.24b	232.64a	3.71b	271.75b	0.30b	1.65a
N90	13.10a	0.81a	0.90a	18.82a	0.28a	239.39a	4.35a	280.27a	0.33a	1.64a

In a column, means followed by a common letter are not significantly different from each other at the 0.05 level by Tukey's test.
CT- Conventional tillage, MT- Minimum tillage, SS - Sorghum stover @ 2t/ha, GL - fresh Gliricidia loppings @ 2t/ha and NR - No residue, and 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg/ha of nitrogen

Biological properties

Tillage, residues and N levels showed a significant effect on MBC. The MT recorded significantly higher MBC (215.3 µg/g of soil) compared to CT (207 µg/g of soil). The application of GL and SS recorded significantly higher amount of MBC (224 µg/g and 213.5 µg/g, respectively) over NR (196.2 µg/g). Nitrogen applied @ 90 kg/ha recorded the highest amount of MBC (239.3 µg/g). The interaction effects of T x R and T x N were also found to be significant. Of all the treatments, MBC was found to be highest with application of GL + N @ 90 kg/ha under MT ($MTGLN_{90}$) (270 µg/g). The MT maintained significantly higher MBC by 4.6% over CT. Application of GL maintained significantly higher MBC content (14.1%) followed by SS (7.6%) over NR. Earlier, Balota *et al.* (2004) reported that residue retention under no tillage increased soil microbial biomass by 83% compared with traditional tillage in Brazil. Further, the increase in N levels showed a significant increase in MBC. With the application of N@ 90 kg/ha, MBC increased by 41% over N0 level.

Residues and N levels significantly influenced DHA. Application of SS recorded significantly higher DHA (3.75 µg TPF/g/hr) compared to GL (3.5 µg TPF/g/hr). The application of nitrogen @ 90 kg/ha also recorded significantly higher DHA (4.4 µg TPF/g/hr) (Table 3). Use of SS under MT showed significantly higher DHA (4.11µg TPF/g/hr) (Table 4). The increase in DHA with N application @ 90 kg/ha was 88% over N0 level. Similarly, significantly higher labile carbon (270.7 mg/kg) was recorded with GL under MT and also with application of N at 90 kg/ha under MT (287.2 mg/kg). Earlier studies revealed that more labile C existed in no-tillage systems than in conventional systems (Balota *et al.,* 2003 and Lewis *et al.,* 2011).

Physical responses

The long term effects of the tillage, residue and N levels on bulk density were statistically significant. BD was significantly lower under MT (1.66 Mg m^{-3}) than CT (1.7 Mg m^{-3}). The MT helped in reducing the BD by 2.5% over CT. The residues applied reduced the BD of the soil by 3.0% over NR (Table 4). The MWD was significantly higher under MT (0.29 mm) compared to CT (0.26 mm). Among the residues, application of SS proved superior most in improving the MWD (0.29 mm) (Table 3). The MWD of the soil aggregates was also found significantly higher (0.30 mm) with SS under MT (Table 4). The MT significantly improved the size of soil aggregates by 10.4% and BD by 2.5% over CT. Application of SS and GL improved the bulk density of the soils by 3.0% and 2.7%, respectively over NR. This could be possible due to improvement in OC owing to residue application under MT that decreased the BD by diluting the soil matrix with organic matter as well as by increasing aggregation and pore volume (Sur *et al.,* 1993). The MWD of soil aggregates increased with N levels and was improved by 46.0% and 33.2%

Table 4 : Interaction effects of tillage with residues and N levels on soil available micronutrients, biological and physical soil properties

Treatments	Cu	Zn	Mn	B	MBC (µg/g of soil)	DHA (µg TPF /h/g)	Labile carbon (mg/kg)	MWD (mm)	BD (Mg m^{-3})
	µg/g								
Conventional tillage									
SS	0.75a	0.76c	18.35a	0.28a	209.9d	3.27b	245.7c	0.28b	1.68b
GL	0.75a	0.75cd	17.81b	0.25ab	215.0b	3.26b	254.9e	0.26c	1.69ab
NR	0.69a	0.71d	18.04a	0.21b	192.4e	2.63c	220.7d	0.24c	1.74a
Minimum tillage									
SS	0.74a	0.78b	17.66b	0.25a	212.7b	4.11a	269.0a	0.30a	1.65bc
GL	0.78a	0.89a	17.34b	0.25a	233.1a	3.67a	270.7a	0.29ab	1.64c
NR	0.70a	0.69d	19.09a	0.24a	200.1c	2.82cb	238.3d	0.28b	1.70a
Conventional tillage									
N0	0.57c	0.58c	15.67a	0.22b	169.1d	2.25e	184.7d	0.22c	1.75a
N30	0.72a	0.70b	18.64a	0.25b	195.1c	2.61d	244.1b	0.24b	1.72a
N60	0.75a	0.79a	18.32a	0.24b	230.0ab	3.33c	259.7b	0.28b	1.68b
N90	0.84a	0.88a	18.79a	0.27a	228.8ab	4.03b	273.3a	0.31a	1.66bc
Minimum tillage									
N0	0.70b	0.66b	16.43a	0.22b	170.4d	2.37ed	203.8c	0.23bc	1.72a
N30	0.70b	0.74ab	18.61a	0.24b	205.8c	3.00c	262.7ab	0.28b	1.68b
N60	0.77a	0.83a	18.23a	0.23b	235.2a	4.09b	283.7a	0.32a	1.63c
N90	0.79a	0.92a	18.85a	0.30a	249.9a	4.68a	287.2a	0.34a	1.62c

In a column, means followed by a common letter are not significantly different from each other at the 0.05 level by Tukey's test.

SS- Sorghum stover @ 2t/ha, GL - fresh Gliricidia loppings @ 2t/ha and NR, and 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg/ha of nitrogen at N applied @ 90 kg/ha and 60 kg/ha, respectively. The increase in MWD by application of SS and GL by 11.8% and 6.6%, respectively over NR is attributed to the favourable effect of decomposing constituents of Gliricidia residue on binding and aggregation of primary particles.

Key indicators of soil quality-principal component analysis

Data pertaining to 19 soil quality indices was statistically analyzed and it was observed that out of 19 soil quality parameters, available P, Ca, Mg, S, Zn, Fe, Cu, Mn were insignificant and hence were dropped from further PCA analysis. Following a strict criteria, only significant variables were considered for PCA analysis. In the PCA of 11 variables, three PCs had eigen values >1 and explained 70.7% variance in the data set. In PC1, eight variables namely, organic carbon, available N, available K, dehydrogenase activity, MBC, BD, MWD and LC were qualified as the highly weighted variables and were retained for the final MDS. In PC2, only one variable namely pH was qualified as highly weighted variable. In PC3, electrical conductivity and available B were found highly weighted hence were retained in the final MDS. Finally, the variables retained in MDS were *viz.,* pH, electrical conductivity, organic carbon, available N, available K, available B, DHA, MBC, BD, MWD and LC and were termed as the key indicators of soil quality. These indicators further used for computing component soil quality indices.

Soil quality indices

The data on physical (PSQI), physico-chemical (PCSQI), chemical (CSQI) and biological soil quality (BSQI) are presented in Table 6. Across the treatments, the PSQI varied from 1.2 to 1.46. Significantly highest PSQI (1.46) was observed with MTSSN90 (Table 6).The values for PCSQI and CSQI varied from 0.74 to 0.95 and 1.12 to 1.62, respectively.

Among the treatments, the highest values for PCSQI (0.95) and CSQI (1.62) were observed in MTSSN90 which was on par with MTSSN60 and MTGLN90 treatments. The BSQI was found to be significantly higher with MTGLN90 (2.22) which was on par with MTSSN90, MTSSN60 and MTGLN60 treatments. Further, additive SQI (ASQI) was found to be significantly higher with MTSSN90 which was on par with MTGLN90 and MTGLN60 treatments. Based on the quantum of ASQI, the order of the best five soil and nutrient management treatments were found to be MTSSN90 (6.17) > MTGLN90 (6.11) > MTSSN60 (5.94) > MTGLN60 (5.79) > CTSSN90 (5.75).

On an average, the percent contribution of these component soil quality indices towards ASQI was in the order of BSQI (32.06%) > CSQI (26.07%) > PSQI (25.68%) > PCSQI (16.2%). It was quite interesting to note that BSQI played an important role in influencing the overall soil quality. From these results, it was clearly understood that in majority of the cases, MT in combination with crop residues and higher level of nitrogen

Table 5 : Relationship of soil properties with castor and sorghum crop yield

Dependent variable	Regression equation	R^2	Significant soil properties
Sorghum crop			
$Y_{CT\ Sorghum}$	-6199.5 + 196.4 (OC) + 0.05 (N) + 0.54 (K) -38.4 (Mg) -8.36 (S) + 3.7 (MBC)* + 4 (LC)** + 133.5 (DHA) + 1204 (MWD)* + 2216 (BD)	0.91**	MBC, LC, MWD
$Y_{MT\ Sorghum}$	-1645.3 (OC) + 1.47 (N) -0.02 (K) -230.0 (Mg) + 4.27 (S) + 2.40 (MBC)* + 1.15 (LC) -66.9 (DHA)* + 1971.9 (MWD) + 168.7 (BD)	0.91**	MBC, DHA
$Y_{SS\ Sorghum}$	-10922-155.4 (OC) + 4.36 (N) + 18.58 (P) + 49.2 (S)** -25.2 (Fe) + 1128.8 (B) + 4.03 (MBC) + 0.738 (LC) -45.4 (DHA) + 2373.4 (MWD) + 4788.2 (BD)	0.90**	S
$Y_{GL\ Sorghum}$	7400.5-1254.7 (OC)** + 1.27 (N) 31.5 (P)* + 6.30 (S) + 66.5 (Fe)**- 282.0 (B) + 2.82 (MBC) + 5.06 (LC)** + 107.8 (DHA) + 2034.7 (MWD) - 2220.75 (BD)	0.93**	OC, P, Fe, LC
$Y_{NR\ Sorghum}$	-7101.57 + 62.7 (OC) -1.80 (N) + 15.88 (P) + 13.1 (S) + 19.9 (Fe) -1599 (B) + + 2.74 (MBC) + 1.54 (LC) + 395.3 (DHA)* -1773.1 (MWD) + 3488.6 (BD)	0.79**	DHA
Castor crop			
$Y_{CT\ Castor}$	-2491.7 + 98.4 (OC) + 0.72 (N) + 0.53 (K) -5.5 (Mg) -11.07 (S) + 2.59 (MBC)** + 2.24 (LC)** + 53.87 (DHA) + 13.24 (MWD) + 841.3 (BD)	0.90**	MBC, LC
$Y_{MT\ Castor}$	-18.33 + 78.8 (OC) + 0.23 (N) -0.02 (K)-157.7 (Mg) + 7.05 (S) + 1.55 (MBC)** -8.91 (DHA) -0.36 (LC) + 1091.1 (MWD)** – 283.5 (BD)	0.90**	MBC, MWD
$Y_{SS\ Castor}$	-5236.5 - 109.8 (OC) + 5.02 (N) + 2.17 (P) + 39.3 (S)* -23.2 (Fe) + 159.3 (B) + 2.46 (MBC) + 0.738 (LC) -60.8 (DHA) + 1398.4 (MWD) + 2424 (BD)	0.89**	S
$Y_{GL\ Castor}$	6985.8-1108.6 (OC)** + 3.86 (N) + 21.83 (P) + 5.25 (S) + 41.26 (Fe)* + 781.9 (B) + 1.93 (MBC) + 3.97 (LC) + 82.1 (DHA) - 467.5 (MWD) -2089.1 (BD)	0.85**	OC, Fe
$Y_{NR\ Castor}$	-6988.99 + 100.1 (OC) -2.88 (N) -1.44 (P) -14.33 (S) + 15.03 (Fe) -1626.4 (B) + 3.96 (MBC) -0.28 (LC) + 370.8 (DHA)* -1419.5 (MWD) + 3913.4 (BD)	0.69	DHA

Level of significance * p=0.05; **p=0.01

CT- Conventional tillage, MT- Minimum tillage, SS- Sorghum stover @ 2t/ha, GL - fresh Gliricidia loppings @ 2t/ha and NR- No residue maintained significantly higher ASQI. Earlier research reports indicating that reduced tillage in combination with appropriate residue management improved soil quality (Reicosky *et al.,* 1995, Sharma *et al.,* 2008, Lal, 2009).

Relationship of crop yield and soil properties

In order to study the effect of soil properties on crop yield, multiple regressions were fitted. The multiple coefficients of correlation (R^2) (Table 5) values were found to be significant and varied from 0.69 to 0.93 across the treatments. Soil properties such as MBC, LC, MWD, DHA were found to be the most significant predictors R^2=0.91 for sorghum and castor yield in both the tillage systems. Soil properties such as OC, available P, available Fe and LC explained the yield of sorghum treated with Gliricidia loppings (R^2 = 0.93) while DHA significantly explained castor yield in residue treated plots (R^2= 0.69).

In this study, the significant partial regression coefficients observed in the regression functions of MBC, LC and MWD indicated their importance in influencing the sorghum and castor yield under MT and CT. Soil microorganisms are the driving force behind mineralization and immobilization of organic constituents which are the basis of residue decomposition, soil aggregation, and nutrient availability which in turn help in raising a good crop to achieve higher yield. This could be the possible reason for significant positive relationship between crop yield and MBC. Similarly, labile carbon influences both, the activity and the mass of micro-organisms (microbial biomass) in soil. The degree of soil compaction and size of the aggregates (MWD) in soil are important for aeration to the root system, besides improving micro-porosity and soil moisture retention. Probably, it is because of this reason, MWD has shown significant association with crop yield in this study. Similarly, positive significant changes in OC, available S, available Fe and DHA could influence the crop yield of sorghum and castor under residue application (Sharma *et al.,* 2008).

Table 6 : Long term effect of tillage, residues and N levels on PSQI, PCSQI, CSQI, BSQI and ASQI

Treatments	PSQI	PCSQI	CSQI	BSQI	ASQI
CTSSN 0	1.25b	0.76c	1.19d	1.25e	4.5b
CTSSN 30	1.29a	0.84bc	1.33cd	1.51d	5.0b
CTSSN 60	1.39a	0.87b	1.44bc	1.81c	5.5b
CTSSN 90	1.41a	0.87b	1.46b	2.00ab	5.7a
CTGLN 0	1.20b	0.75d	1.18d	1.28ed	4.4c
CTGLN 30	1.27b	0.81c	1.35cd	1.62c	5.0b
CTGLN 60	1.36a	0.86b	1.39c	1.83c	5.4b
CTGLN 90	1.40a	0.87b	1.44b	1.99b	5.7a
CTNRN 0	1.26b	0.74d	1.12e	1.19e	4.3c
CTNRN 30	1.28a	0.78c	1.24d	1.40de	4.7b
CTNRN 60	1.25b	0.81b	1.27dcd	1.58d	4.9b
CTNRN 90	1.34a	0.84b	1.31d	1.61cd	5.1b
MTSSN 0	1.27b	0.79c	1.23d	1.38d	4.7b
MTSSN 30	1.32a	0.85b	1.39cd	1.67c	5.2b
MTSSN 60	1.42a	0.91a	1.53a	2.09ab	5.9a
MTSSN 90	1.46a	0.95a	1.62a	2.15ab	6.2a
MTGLN 0	1.22b	0.80c	1.25d	1.33e	4.6b
MTGLN 30	1.31a	0.86b	1.33c	1.76c	5.3b
MTGLN 60	1.40a	0.91a	1.49b	2.00ab	5.8a
MTGLN 90	1.44a	0.91a	1.53a	2.22a	6.1a
MTNRN 0	1.23b	0.77c	1.16d	1.21ed	4.4c
MTNRN 30	1.33a	0.83bc	1.30c	1.49dc	5.0b
MTNRN 60	1.34a	0.85b	1.40b	1.67cd	5.3b
MTNRN 90	1.43a	0.88b	1.41b	1.78cd	5.5b

In a column, means followed by a common letter are not significantly different from each other at the 0.05 level by Tukey's test.

CT- Conventional tillage, MT- Minimum tillage, SS- Sorghum stover @ 2t/ha, GL - fresh Gliricidia loppings @ 2t/ha and NR, and 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg/ha of nitrogen

Relationship of crop yield with component and additive SQIs

The relationships of crop yield as dependent variable were studied with component and additive SQIs individually as independent variables. The results indicated that sorghum and castor yields had significant relationships with component and additive SQIs (Table 7) and the R^2 values varied from 0.12 to 0.47. It is interesting to note that the highest R^2 value (0.47) was observed between sorghum yield and BSQI, thus indicated the importance of biological soil functions in influencing the yield (Fig. 1). The relationship of sorghum and castor yield with PSQI, PCSQI, CSQI, BSQI revealed that soil quality had significant role in influencing crop yield. In the present study, it was observed that PCSQI had significant positive effect on sorghum yield (p=0.05). Additive ASQI significantly influenced (p=0.05) sorghum (R^2 = 0.44) and castor yield (R^2=0.22) (p=0.05) (Fig.2). Earlier Fuentes *et al.* (2009) also found that the practice of zero tillage and residue application for 14 years resulted in better SQI and higher yields compared to conventional tillage. Karlen *et al.* (2003) also reported significant influence of SQI on yield and profitability of corn-soybean rotation on long term basis.

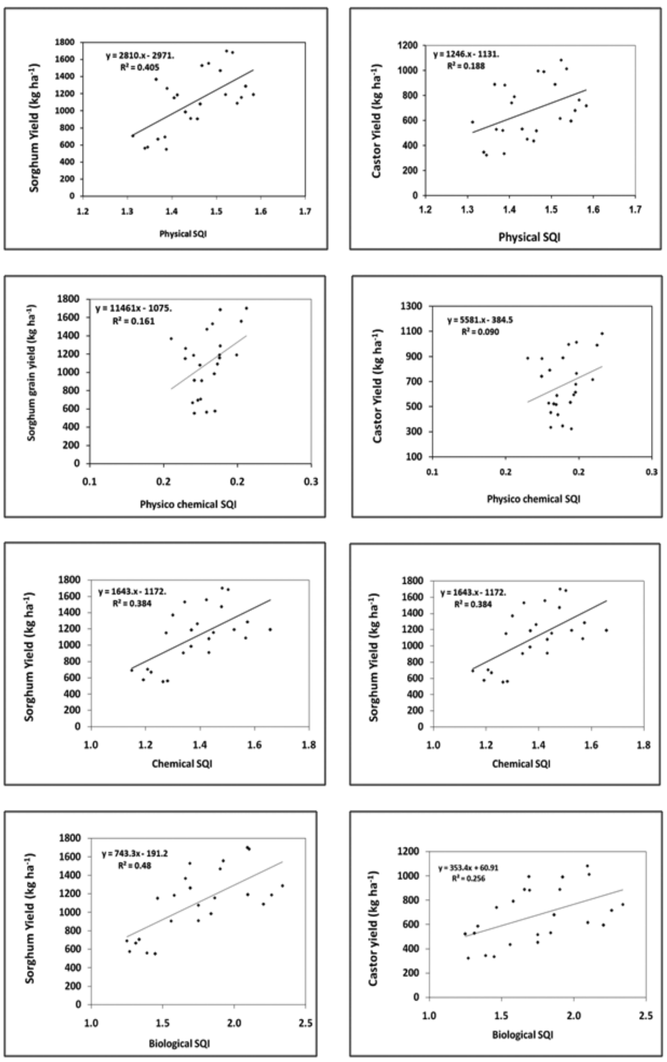

Fig. 1 : Regression relationship between sorghum and castor yield with physical, physico chemical, chemical and biological SQI

Table 7 : Relationship of physical, chemical and biological SQI with castor and sorghum crop yield

Dependent variable	Regression equation	F value	R^2
$Y_{Sorghum}$	-2037.69 + 2364.4 (PSQI)	34.24**	0.33
$Y_{Sorghum}$	-1763.7 + 3421.7 (PCSQI)	31.26**	0.30
$Y_{Sorghum}$	-931.7 + 1508.6 (CSQI)	35.07**	0.33
$Y_{Sorghum}$	-177.2 + 771.8 (BSQI)	61.24**	0.47
$Y_{Sorghum}$	-1047.08 + 415.6 (ASQI)	54.66**	0.44
Y_{Castor}	-660.92 + 1006.79 (PSQI)	11.44**	0.14
Y_{Castor}	-492.57 + 1395.27 (PCSQI)	9.64*	0.12
Y_{Castor}	-231.05 + 672.85 (CSQI)	13.00**	0.16
Y_{Castor}	69.38 + 365.99 (BSQI)	23.03**	0.25
Y_{Castor}	-304.66 + 189.6 (ASQI)	19.21**	0.22

Level of significance * p=0.05; **p=0.01, PSQI- Physical soil quality index, PCSQI- Physico chemical soil quality index, CSQI- Chemical soil quality index, BSQI-Biological soil quality index, ASQI-Biological soil quality index

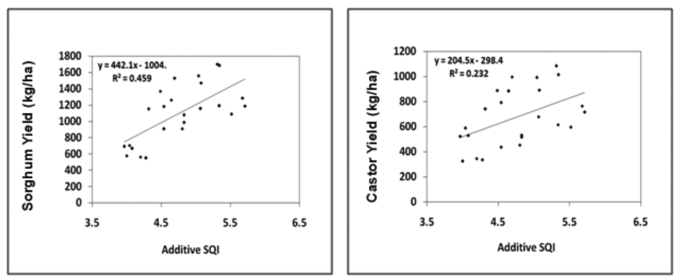

Fig. 2 : Linear regression relationship between sorghum and castor yield with additive SQI

Conclusions

The present study has clearly established that long term soil and nutrient management practices evaluated had significantly influenced predominant soil parameters *viz.,* MBC, LC, MWD, OC, S, Fe and DHA which in turn, significantly enhanced the crop yield. The influence of long term soil management practices on significant improvement of physical, physico-chemical, chemical and biological soil quality was clearly evident in this study. Significant linear relationships between soil quality indices (physical, physico-chemical, chemical and biological) and crop yield (sorghum and castor) were observed. Therefore, to improve the soil quality and crop yield on long term basis, practices *viz.,* minimum tillage, residue application and adequate amount of nitrogen could be of much significance and importance in these soils.

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