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Effect of Surface Residue Management under Minimum Tillage on Crop yield and Soil Quality Indices after 6 years in Sorghum (*Sorghum bicolor (L.) Moench)* - Cowpea (*Vigna unguiculata*) System in Rainfed Alfisols

K.L Sharma, K. Sammi Reddy, G. Ravindra Chary, A.K. Indoria, K. Srinivas, D. Suma Chandrika, Munna Lal, M. Prabhakar, G. Prathiba, Pravin Thakur, M. Vasavi and P. Haindavi

ICAR- Central Research Institute for Dryland Agriculture, Hyderabad- 500 059, Telangana

Email: kl.sharma@icar.gov.in

ABSTRACT: This experiment was conducted in rainfed semi-arid tropical Alfisol at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture, Hyderabad, India, during the period 2005 to 2010 to study the long-term effect of varying levels of surface residue application under minimum tillage on crop yields and soil quality in sorghum-cowpea system. The experiment was conducted in a randomized block design with minimum tillage (MT) as main block. The experimental treatments comprised of application of four levels of dry sorghum residues (@ 0, 2, 4 and 6 t/ha) as surface application. After 6th year of the experimentation, the pooled mean sorghum grain yield varied from 1607 to 1819 kg/ha across the treatments and was significantly influenced by the residue application. The percent increase in pooled grain yields with residue application @ 2, 4 and 6 t/ha was to the extent of 5, 9 and 13.0% respectively over the control (no residue application). Similarly, the pooled mean cowpea yield varied from 335 to 541 kg/ha across the treatments and was significantly influenced by the residue application. The percent increase in cowpea grain yield with @ 2, 4 and 6 t/ha was to the extent of 28, 61 and 45% respectively no residue application. Significantly higher organic carbon (6.80 g/kg) content was recorded with the application of sorghum stover @ 6 t/ha which was 55.89% higher compared to control (4.36 g/kg). The increase in available N with the application of 6t and 4t crop residue was to the extent of 19.5 and 28% respectively while significantly higher contents of soil available P (10.67 kg/ha) and K (288.8 kg/ha) were observed with application of sorghum residue @ 4 t/ha. Among the biological properties, significantly higher microbial biomass carbon (MBC) and dehydrogenase activity (DHA) were recorded with the application of sorghum stover @ 4 t/ha. Besides reducing the bulk density, the application of residues had a significant influence on the mean weight diameter (MWD) of the soil aggregates. The highest overall soil quality index (SQI: 9.58) was observed with the residue application @ 6 t/ha. A significant positive relationship was observed between SQI and pooled cowpea seed yield (R^2=0.82) and pooled sorghum grain yield (R^2=0.69).

Key words: Alfisol, crop yields, crop residue, minimum tillage, rainfed, soil quality indices, sustainability

Introduction

Red Alfisol (*Pedalfer*) soils which are less intensively weathered than Ultisols represent one of the important soil orders in the semiarid tropical regions. In India, Alfisols covers an area of 42 M ha, and are predominantly located in the heartland of dryland region (Bhattacharyya *et al.,* 2013). Semi-arid regions with low and highly variable rainfall, with shallow soils and low water retention characteristics, high evapo-transpiration rates, with problems of crusting and surface sealing, low soil fertility, imbalanced nutrient use, low soil organic carbon (SOC), low or virtually no crop residue recycling and poor socio-economical factors limit the productivity of rainfed crops in Alfisols (Srinivasarao *et al.,* 2015). These soil constraints exert more pressure on natural resources in rainfed areas. Besides, the climate change and its impact on agricultural production and vulnerability of farmers or population living in such areas are some of the great concerns of rainfed regions. There are many incidences when crops fail due to extreme weather events, adversely affecting the crop production at global (Lesk *et al.,* 2016) and regional levels (Swaminathan and Rengalakshmi, 2016).

Soil quality assessment is widely recognized as a tool for evaluating sustainability of soil and crop management practice (Hussain *et al.*, 1999). Among several soil properties, soil organic matter (SOM) content in soils plays an important role in influencing soil quality and hence, across the world, it is well established and agreed fact that to improve soil tilth, fertility, and productivity, it is essential to maintain a high level of SOM. There are reports that the SOM has declined considerably in both temperate and tropical soils under repeated intensive tillage than under undisturbed soil (Ogle *et al.,* 2005). Regular tillage exacerbates SOM status in soils and affects physical, chemical and biological soil environment (Drinkwater and Snapp, 2007; Thierfelder and Wall, 2010) and thus, decline crop yield (Kang *et al.*, 2005). Soil quality can be improved through proper management systems such as adoption of integrated farming, conjunctive use of organic-inorganic sources of nutrients and other resource conservation practices (Sharma *et al.*, 2013; 2015; 2016).

Conservation agriculture (CA), is a set of agricultural practices which is emerging as a effective technology and helps in protection of soil from erosion, reduction of nutrients loss, enhancement of soil fertility, improving agronomic sustainability and maintenance of overall soil quality in the tropics (Campbell *et al.*, 1998; Eck and Stewart, 1998). CA implies three important interlinked principles viz., minimum tillage, permanent residue cover and crop diversification (*http://www.fao.org/ag/ca/1a.html*). Crop residues contain large amount of nutrient concentrations which can be available for plant growth. Moreover, long-term agro-ecosystem requires maintenance of carbon inputs through residue recycling for coarse textured soils (Chivenge *et al.,* 2007). It has been reported that retention of crop residues coupled with minimum tillage have enhanced soil fertility, improved soil hydrology, and biological properties (Sharma *et al*., 2013; 2014). Increased SOC improves soil aggregation (Moussadek *et al.,* 2011) and help to stabilize SOM through physical protection in micro and macroaggregates (Dai *et al.,* 2017). It has also been reported that adopting CA practices improve nutrient use efficiency (Sehrawat *et al.,* 2015). This is attributed to the reason that contrary to incorporation, the surface application of crop residue in CA practices is less likely to cause N immobilization which is a common problem in soil where tonnes of crop residues with high C:N ratios are incorporated in to the soil. Beside these, surface application of crop residue has been proved effective in improving *in-situ* soil water conservation and suppression of weeds (Sharma and Prasad, 2008) and ultimately in enhancing the grain production per unit of nutrient used i.e., Nutrient Use Efficiency (NUE).

Keeping in view these past research developments, a long term study was initiated on soil quality improvement and assessment in sorghum (*Sorghum bicolor* (L.) – cowpea (Vigna unguiculata (L.) Walp system with conservation agricultural practices comprising of minimum tillage and different levels of surface residue application in rainfed red chalka soil (Alfisols). The main objectives of the study were (i) to assess the effect of minimum tillage and surface residue application on crop yield, sustainability yield index (SYI) and soil quality parameters, (ii) to identify the key soil quality indicators under a given system and (iii) to compute the integrated soil quality Index and to establish its quantitative relationship with the crop yield.

Materials and Methods

A field experiment was conducted during 2005 to 2010 at Hayathnagar Research Farm of ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, India. The farm represents a semi-arid tropical region with hot to very hot summers and mild winters with mean annual temperature of 25.7^{o} C. In this region, about 70% of the total precipitation is received during the southwest monsoon season (June to September). Soils in the experimental field belong to Hayathnagar soil series (Typic Haplustalf). These soils have a sandy surface layer, with increasing clay content in the sub soil. Sorghum (CSH-9) and cowpea (C152) were grown as the test crops in yearly rotation. The crop was grown every year with minimum tillage employing tractor drawn seed planter or by using a non-inversion type plough depending upon the situation. The experimental treatments were comprised of control (no surface residue application) - (T1), surface application of dry sorghum crop residue @ 2 t/ha (T2), 4 t/ha (T3), and 6 t/ha (T4) which were replicated thrice in a randomized block design (RBD). The residue levels were surface applied after 25-30 Days After Sowing (DAS). Sorghum and cowpea crops received N every year @ 60 and 30 kg N/ha. Phosphorus was applied every year uniformly to all the plots and to both the crops @ 30 kg P_2O_5 /ha through single super phosphate respectively. During the experimental period, in all, (2005 to 2010), sorghum (2005, 2007, 2009) and cowpea crops (2006, 2008, 2010 could be grown for three years each. In order to leave the anchored residue in the field, at the time of the harvest of crop, the stubbles were retained at 30 cm height in case of sorghum and full biomass was retained after the harvest of the pods in case of cowpea. The weeds were controlled by use of pre emergence herbicides such as pendimethalin (for legume), atrazine (for sorghum) and mechanical methods of weed control as and when required. The summer sprays of broad spectrum herbicide such as glyphosate were also made, whenever required.

Soil sampling and analysis

Soil samples were collected during the year 2010 after the harvest of cowpea crop from plough layer (0.0-0.15 m depth). 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 20 soil quality parameters were as follows: Soil pH and electrical conductivity (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).

Studies were also conducted to see the effect of different levels of residues under minimum tillage on soil water retention characteristics such as field capacity (FC), permanent wilting point (PWP) and available water capacity (AWC) using pressure plate membrane apparatus (Model: Moisture Equipment Corporation, USA).

Soil quality assessment: Theory and quantification

In order to assess soil quality, the data obtained for 20 chemical, physical and biological soil quality parameters were statistically tested for their level of significance using the randomized block design. After the statistical analysis, two variables viz., EC and Zn were found non significant. Hence, we considered all the 20 variables for Principal Component Analysis (PCA) (Andrews *et al.,* 2002a, b; Doran and Parkin, 1994) 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.,* 2000 a, 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 labeled 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. 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, Si is the score for the subscripted variable and Wi 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.

Statistical analyses

Analysis of variance (ANOVA) was performed using SPSS 12.0 version. Randomized block design was used and the differences were compared by Least Significant Difference Test (LSD) to a significance level of $p < 0.05$ (Snedecor *et al.,* 1989). Principal component analysis was performed using SPSS 12 version.

Sustainability yield index

Sustainability yield index (SYI) was calculated for each treatment as suggested by (Singh *et al.,* 1990).

$$\text{Sustainability yield index (SYI)} = \frac{\beta - SD}{Ymax}$$

where β = average yield over the years for a particular treatment, SD = standard deviation for the treatment and Y_{max} = maximum yield (average) obtained in any of the treatments over 6 year

Results and Discussion

Effect of graded levels of crop residue application on pooled yield of sorghum

The pooled sorghum grain yield varied from 1607 to 1819 kg/ha across the treatments and was significantly influenced by the residue application (Table 1). Application of sorghum stover @ 6 t/ha in combination with N @ 60 kg N/ha recorded significantly higher sorghum grain yield (1819) when compared to residue application @ 4 t/ha in combination with N @ 60 kg/ha (1757 kg/ha). The percent increase in grain yields with residue application @ 2, 4 and 6 t/ha was to the extent of 5, 9 and 13.0 % respectively over the control (no residue application).

Retention of crop residues on soil surface coupled with minimum/no-tillage practices play an important role to sustain soil fertility, improving water use efficiency, physical conditions of soils and enhance crop productivity. These results are in confirmation with those earlier reported by (Sainju *et al.,* 2008; Mohammad *et al.,* 2003).

Effect of graded levels of residue application on pooled yield of cowpea

The pooled cowpea yield as influenced by different levels of crop residue application varied from 335 to 541 kg/ha across the treatments and was significantly influenced by the residue application (Table 1). Application of sorghum stover @ 4 t/ha in combination with N @ 30 kg/ha recorded significantly higher cowpea yields when compared to residue application @ 6 t/ha in combination with N @ 30 kg/ha which showed yields only up to 487 kg/ha. The percent increase in grain yields with residue application @ 2, 4 and 6 t/ha was to the tune of 28, 61 and 45 % respectively over the control (no residue application).

Table 1 : Effect of increasing levels of crop residue on pooled grain yield and sustainability yield indices (SYI) of sorghum and cowpea under minimum tillage

Treatments	Sorghum grain yield (kg/ha)	Sustainability yield index	Cowpea grain yield (kg/ha)	Sustainability yield index
T1 - Control	1607±76.5	0.69±0.034	335±25.3	0.15±0.007
T2 - 2 t/ha of sorghum residue	1690±84.4	0.80±0.040	430±35.0	0.09±0.004
T3 - 4 t/ha of sorghum residue	1757±89.2	0.77±0.038	541±40.5	0.13±0.006
T4 - 6 t/ha of sorghum residue	1819±92.7	0.63±0.032	488±37.9	0.12±0.006
LSD (p =0.05 level)	114.9	--	40.2	--

Effect of long term application of graded levels of crop residue under minimum tillage on physical, chemical and soil biological properties

In the present study, soil quality assessment was carried out to quantify the effect of long term application of graded levels of crop residue under minimum tillage. Surface soil samples (0-15 cm) were collected from the treated plots after the harvest of cowpea crop in the year 2010.

The soil pH in these soils varied from 6.75 to 7.12 across the treatments. The pH in the soil was significantly higher with control (7.12) followed by application of sorghum stover @ 2 t/ha (6.92) while the significantly lowest pH was observed with application of sorghum stover @ 6 t/ha (6.75) (Table 2). The organic carbon in these soils varied from 4.36 to 6.80 g/kg across the treatments. Significantly higher organic carbon (6.80 g/kg) content was recorded with the application of sorghum stover @ 6 t/ha followed by @ 4 t/ha (5.48 g/kg) compared to control (4.36 g/kg). An increase in organic carbon to the extent of 55.89% was observed with the application of sorghum stover @ 6 t/ha compared to control.

The available nitrogen in these soils varied from 131 kg/ha to 170.9 kg/ha across the treatments (Table 2). Significantly higher amount of N was observed with application of sorghum stover @ 4 t/ha which was 30.45% higher compared to control. Application of 2 t and 6 t/ha of sorghum stover also recorded an increase in available N to the extent of 19.5 and 28%, respectively. The available P in these soils varied from 9.1 to 10.67 kg/ha across the treatments and significantly higher available P (10.67 kg/ha) was observed with the application of sorghum residue @ 4 t/ha followed by application of sorghum stover @ 2 t/ha (9.56 kg/ha). Available of K in these soils varied from 188.8 kg/ha to 288.8 kg/ha across the treatments. Significantly higher available K in these soils was observed with the application of sorghum stover @ 4 t/ha (288.8 kg/ha) compared to control.

Earlier studies also reported the significant increase in the status of soil available NPK with soil management practices adopted on long term basis (Sharma *et al.,* 2013). Pandey *et al.* (2006) reported that application of manures, irrespective of sources and rates recorded significantly higher soil organic carbon, N, P_2O_5 and K_2O compared to control.

Table 2 : Effect of increasing levels of crop residue on soil properties and primary nutrient status under minimum tillage in Sorghum-cowpea rotation after 6 years of experimentation

Treatments	pH	EC	OC	N	P	K
		(dSm^{-1})	(g/kg)	(kg/ha)		
T_1 - Control	7.12	0.05	4.36	131.03	9.10	188.81
T_2 - 2 t/ha of sorghum residue	6.92	0.05	5.15	156.56	9.56	227.18
T_3 - 4 t/ha of sorghum residue	6.81	0.07	5.48	170.91	10.67	288.98
T_4 - 6 t/ha of sorghum residue	6.75	0.08	6.80	167.43	9.44	226.96
LSD (p =0.05 level)	0.14	NS	0.95	8.52	0.67	5.63

Exchangeable calcium in these soils varied from 5.54 cmol/kg to 8.79 cmol/kg (Table 3). Significantly higher exchangeable calcium (8.79 cmol/kg) was observed with application of sorghum stover @ 6 t/ha followed by @ 4 t/ha (7.44 cmol/kg). Similarly, significantly higher exchangeable magnesium (2.82 cmol/kg) was observed with application of sorghum stover @ 6 t/ha followed by application @ 4 t/ha (2.68 cmol/kg). Significantly higher available sulphur (61.6 kg/ha) was recorded with application of sorghum stover @ 6 t/ha compared to that applied @ 4 t/ha (50.4 kg/ha). It was observed that the soil available micronutrients contents except Zinc were significantly influenced by residue treatments (Table 4).

Table 3 : Effect of increasing levels of crop residue on soil available secondary nutrients under minimum tillage in sorghum-cowpea rotation after 6 years of experimentation

Treatments	Ca	Mg	S
	(cmol/kg)		(kg/ha)
T_1 - Control	5.54	1.87	11.34
T_2 - 2 t/ha of sorghum residue	6.32	2.27	33.3
T_3 - 4 t/ha of sorghum residue	7.44	2.68	50.4
T_4 - 6 t/ha of sorghum residue	8.79	2.82	61.6
LSD (p =0.05 level)	0.20	0.15	4.45

In the present study, among the biological properties, significantly higher microbial biomass carbon (MBC) and dehydrogense activity (DHA) was observed in soil with application of sorghum stover @ 4 t/ha (Table 5). The MBC content in these soils varied from 52.4 mg kg^{-1} to 78.6 mg kg^{-1} across the treatments. Significantly higher MBC content (78.66 mg kg^{-1}) was observed with application of sorghum stover @ 4 t/ha followed by 6 t/ha (72.8 mg kg^{-1}) compared to control. The MBC content was found to be higher to the extent of 50% compared to control. Sommer *et al.* (2014) observed higher contents of soil organic matter and microbial biomass contents, increased levels of extractable phosphate, soil infiltration capacity and soil water retention with conservation tillage and residue retention in the Mediterranean region of North Syria.

Table 4 : Effect of increasing levels of crop residue on soil available micronutrients under minimum tillage in sorghum-cowpea rotation after 6 years of experimentation

Treatments	DTPA extractable micronutrients (ug/g)				
	Fe	Cu	Zn	Mn	B
T_1 - Control	3.55	1.29	0.64	34.19	0.39
T_2 - 2t/ha of sorghum residue	4.81	1.37	0.65	35.63	0.56
T_3 - 4 t/ha of sorghum residue	4.95	1.37	0.67	35.14	0.74
T_4 - 6 t/ha of sorghum residue	5.04	1.51	0.71	35.70	0.83
LSD (p =0.05 level)	0.12	0.06	NS	0.58	0.05

The labile carbon content in these soils varied from 256.9 to 326.7 mg kg^{-1} of soil across the treatments. Significantly higher labile carbon content (326.7 mg kg^{-1}) was recorded with application of sorghum stover @ 6 t/ha followed by @ 4 t/ha (283.67 mg kg^{-1}). The dehydrogenase activity in these soils varied from 0.56 to 1.55 ug TPF/hr/g significantly higher DHA activity (1.55 ug TPF/hr/g) was recorded with application of sorghum stover @ 4 t/ha (Table 5).

Among the physical properties, significantly lower bulk density (1.10 Mg m^{-3}) was observed with application of sorghum stover @ 6 t/ha which was on par with application of sorghum stover @ 4 t/ha (1.13 Mg m^{-3}) compared to control (1.20 Mg m^{-3}) (Table 5). Application of residues had a significant influence on the mean weight diameter of the soil aggregates and it varied from 0.15 to 0.32 mm. The MWD was significantly higher with application of sorghum stover @ 6 t/ha (0.32mm) compared to control (0.15mm). Meena *et al.* (2015) observed that soil properties such as soil bulk density, hydraulic conductivity and aggregation at 0–15 cm layer were significantly affected both by tillage and cropping systems.

Effect of different levels of crop residues application under minimum tillage on soil moisture characteristics

After six years of amending the soil by application of the crop residue on surface, soil moisture at field capacity (1/3 bars) and permanent wilting point (15 bars) was measured using

Table 5 : Effect of increasing levels of crop residue on biological and physical properties under minimum tillage in sorghum-cowpea rotation after 6 years of experimentation

Treatments	MBC (mg kg^{-1})	LC (mg kg^{-1}) of soil	DHA (ug TPF/hr/g)	BD (Mg m^{-3})	MWD (mm)
T_1 - Control	52.43	256.97	0.56	1.20	0.15
T_2 - 2 t/ha of sorghum residue	63.76	263.63	0.65	1.26	0.15
T_3 - 4 t/ha of sorghum residue	78.66	283.67	1.55	1.13	0.25
T_4 - 6 t/ha of sorghum residue	72.87	326.71	0.75	1.10	0.32
LSD (p =0.05 level)	1.74	5.41	0.036	0.03	0.02

Table 6 : Effect of increasing levels of residue on soil water availability under minimum tillage in sorghum- cowpea rotation after 6 years of experimentation

Treatments	Field capacity	Permanent wilting point	Available water capacity
T1 - Control	10.11±0.50	6.90±0.34	3.21±0.16
T2 - 2 t/ha of sorghum residue	10.78±0.53	7.27±0.36	3.51±0.17
T3 - 4 t/ha of sorghum residue	11.25±0.56	7.40±0.37	3.85±0.19
T4 - 6 t/ha of sorghum residue	12.94±0.64	7.45±0.37	5.49±0.27
LSD (p =0.05 level)	0.28	0.59	0.59

pressure plate apparatus. It was observed that soil moisture at field capacity was significantly influenced by residue treatments and it varied from 10.11 to12.94 cm m^{-1} (Table 6). Significantly higher field capacity (12.94 cm m^{-1}) was observed with the application of sorghum stover @ 6 t/ha followed by residue application at 4 t/ha (11.25 cm m^{-1}). Similarly, soil moisture at permanent wilting point varied from 6.90 to 7.45 cm m^{-1}. The available water content increased with the increase in the increasing residue levels and it varied from 3.21 to 5.49 cm m^{-1}. Significantly higher available water capacity (5.49 cm m^{-1}) was observed with the application of sorghum stover @ 6 t/ha followed by residue application at 4 t/ha (3.85 cm m^{-1}). The increase in available water content with higher doses of surface residue could be attributed to higher organic C, improved soil structure and consequently more water retention.

Relationship between soil available moisture and crop yield

In order to establish a relationship between crop yield and volumetric moisture, a simple linear regression equation was developed with yield as functional goal and soil moisture as independent variable. It was observed that the relationship between sorghum grain yield and soil moisture was significant (p=0.01). The coefficient of regression (R^2= 0.55) denotes that sorghum yield could be explained by volumetric soil moisture content as follows:

$$Y_{\text{Sorghum yield}} = 1053.2 + 222.2\ (\text{Volumetric Soil Moisture}) \ldots\ldots\ldots (R^2 = 0.55)^{**}$$

Long term effect of graded levels of residue application on soil quality indicators and soil quality index

In the present study, principal component analysis of soil quality parameters was carried out to identify the predominant soil quality indicators affecting soil quality.

Results of principal component analysis

Data pertaining to the influence of graded levels of residue application under minimum tillage in Alfisols of Hyderabad on 20 soil quality indices has been statistically analyzed and it was observed that after 6th year of the experimentation, out of 20 soil quality parameters, viz., EC, and available Zn were found non significant. But we considered all the parameters from PCA. In the PCA of 20 variables, three PCs had eigen values >1 and explained 93% variance in the data set (Table 7). In PC1, N, P, K, Ca, Mg, S, LC, Fe, B, MBC, BD, MWD were highly weighted variables. In PC2 available water content (AWC) and labile carbon (LC) and in PC3, EC were the highly weighted variables. Sharma *et al.,* (2008) selected significant indicators from the MDS, as influenced by management treatments.

Effect on soil quality indices

Soil quality indices were computed using fourteen key soil quality indicators viz., EC, N, P, K, Ca, Mg, S, Fe, B, LC, MBC, BD, MWD, AWC. The soil quality indices varied from 6.6 to 9.58 across the residue management treatments (Table 8). Application of sorghum stover @ 6 t/ha recorded significantly higher soil quality index of 9.58 which was on par with (4 t/ha) T_3 treatment (9.28). The relative soil quality indices (RSQI), varied between 0.69 to1.00. From the data (Table 8), it was observed that increased levels of residue application had a significant influence in maintaining relatively higher soil quality Index in all the treatments, however, the application of 6 t/ha of sorghum residue recorded highest relative soil quality index (1.00) followed by 4 t/ha (0.97). Sharma *et al.* (2005) recorded higher soil quality index with INM treatments compared to control. Similarly, (Langeroodi, 2015) observed greater soil quality and crop productivity with zero tillage + residue treatment compared to conventional tillage + residue treatment.

Table 7 : Principal component analysis of soil quality parameters as influenced by long term application of increasing levels of crop residue under minimum tillage in sorghum-cowpea system

	Component		
	PC1	**PC2**	**PC3**
Eigen values	15.54	1.79	1.29
% of variance	77.71	8.98	6.47
Cumulative %	77.71	86.70	93.17
pH	-.948	.103	.075
EC	-.618	.263	**.557**
OC	.876	.290	.013
N	.977	.088	-.003
P	.956	.044	.106
K	.974	-.157	.141
S	.928	-.265	-.169
Ca	.980	-.086	.154
Mg	.989	-.086	.075
LC	.894	.412	.138
Fe	.898	-.271	-.277
Cu	.876	.381	-.109
Mn	.647	-.059	-.648
Zn	.806	.373	.176
B	.990	-.016	.094
MBC	.894	-.404	.170
DHA	.479	-.752	.421
BD	-.974	.101	.049
MWD	.899	.223	.318
AWC	.819	.441	-.108

Linear regression relationship between crop yield and SQI

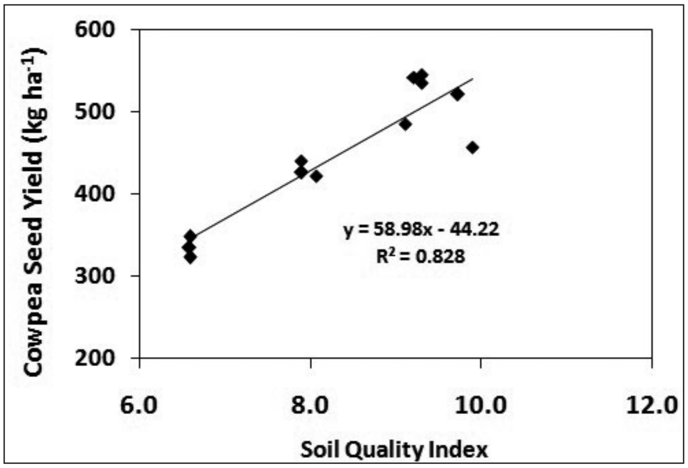

Fig. 1 : Relationship between cowpea seed yield (kg/ha) with soil quality index (SQI)

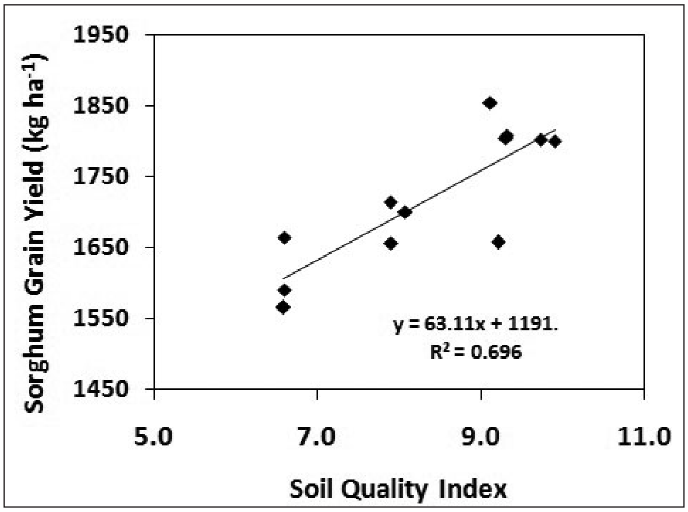

Fig. 2 : Relationship between sorghum grain yield (kg/ha) with soil quality index (SQI)

The linear regression relationship between crop yield and SQI was computed to study the quantitative effect of soil quality on pooled cowpea and sorghum yield under rotation (Figure 1 & 2). From the results, it was observed that a significant positive relationship exists between SQI and Cow pea crop yield (R^2=0.82) and Sorghum crop yield (R^2=0.69).

Y_{Cowpea} = - 44.2+ 58.98 (SQI)……………….(R^2 = 0.82)

$Y_{Sorghum}$ = 1191.29 +63.1 (SQI)……………….(R^2 = 0.69).

In the present study, the soil reaction across the treatments was significantly (p=0.05) reduced over control with the higher levels of application of crop residue treatment (Table 2). There are different reviews and reports on changes in soil pH under CA practices (Sithole *et al.,* 2017). Long term application of crop residue could increase SOM level and it has been recognized that the SOM is important for buffering the soil reaction and hence, there was slight increase in the pH over the initial value. There are also reports that the retention of crop residues in soils is associated with an increase in SOC concentration in short term (6 year) (Xue *et al.,* 2015) and could continue in long term (>35 year) experiment (Jacobs, Rauber, and Ludwig 2009). In the present study, significantly (p=0.05) higher SOC content was recorded with the application of sorghum stover @ 6 t/ha followed by @ 4 t/ha than control. Increase in SOC content to the extent of 55.96% was registered with the application of sorghum stover @ 6 t/ha compared to control. It was quite interesting to record the increasing trend in SOC with the increase in crop residue application. Based on the earlier studies, the application of sorghum crop residue has been reported to have high C sequestration potential in soils as its wide C:N ratio helps in increasing the C mean residence time (Kushwah *et al.,* 2014). Considerable build up of SOC (19.9%) has been reported due to residue incorporation under CA practices in hot and sub humid climate of Orissa (Mohanty *et al.,* 2015). In general, improvement of SOM in soils is related to input and output of C balance and its mean increases in residence time. It has also been reported that the rate of decomposition of crop residues depends not only on its quantity, but also on soil properties, quality of the residues and the climate conditions (Dikgwatlhe *et al.,* 2014).

Similarly, in our study, the amount of available N, P and K was found to be significantly higher (p=0.05) with the application of sorghum stover @ 4 t/ha compared to control, the increase in the amount of these nutrients being 30.53, 17.25, and 52.91..%, respectively. It has been well established that the SOM plays important role is in regulating the cycles of C, N, P and S in soils. Changes in soil physical properties such as moisture, temperature due to minimum tillage and crop residue management affect the nutrient cycling processes related to nutrient supply and loss (Schoenau and Campbell, 1996). Earlier studies have revealed that available N, P and K (Jat *et al.*, 2017) and exchangeable Ca, Mg, and K were significantly (p=0.05) higher in the surface soil under no tillage (NT) with the residue application compared to the ploughed soil (Rahman *et al.,* 2008).

The minimum tillage coupled with the increasing levels of surface application of crop residue over years enhanced the water capacity (AWC) of soil. In semi-arid climates, soil water content close to the soil surface usually reaches a consistent minimum value (approaching air-dry) due to the hot and dry conditions. Groundwater levels are depleting fast, and most rural rainfed areas are facing general water scarcity (Rockstrom *et al.,* 2007). It is usually expected that Alfisols being realtively sandy in texture have higher saturated hydraulic conductivity. The Alfisols have non - stable soil structure, which enhances the soil's tendency to develop surface seals that reduce infiltration and profile recharge even under moderate or mild rains. The surface seal hardens into crusts during intermittent dry periods which further influence the runoff behaviour of the Alfisols. Also because of low structural stability, the smoothing of the soil surface roughness following rain fall events was found to much quicker in the Alfisols. This contributes to fast decline in the surface water storage, resulting in a relatively higher runoff. But the management practices such as reducing the intensity of tillage and applying crop residue worked better in the present study and improved the AWC of the soil, hence these practices have great relevance.

The set of soil attributes which emerged as key soil quality indicators in the present study included EC, N, P, K, Ca, Mg, S, Fe, B, LC, MBC, BD, MWD and AWC. These indicators may directly monitor the soil, or monitor the outcomes that are influenced by the soil, such as increases in biomass, improved water use efficiency, and aeration. The selections of the indicators is very important for assessing long-term soil and crop management effects on soil quality. In the past, many experts have suggested which indicators influence most the quality of soil in the past (Parr *et al.,* 1992; Karlen *et al.,* 1992) and in the present (Chaudhury *et al.,* 2005; Shukla *et al.,* 2006). Based on their importance in crop productivity and availability of nutrients for crop growth, including physical, chemical and biological parameters were chosen to assess the soil quality in the present study (Table 7). It was clearly noted that the higher weighted variables indicate the positive impact of crop residue incorporation on semi-arid Alfisols (Table 7). The properties representing the soil fertility status, carbon content and soil substrate and moisture availability have emerged as highly weighted variables and key indicators and hence, helped to explain the sorghum crop yield up to 70 % ($R^2 = 0.696\%$ and cowpea yield up to 83% ($R^2 = 0.828$) and (Figure 1 & 2) and yield sustainability. It was observed that the increased levels of residue application had a significant influence in maintaining relatively higher soil quality Index in all the treatments.

Table 8 : Soil quality indices as influenced by long term use of increasing levels of crop residue in Alfisols of Hyderabad in sorghum-cowpea system

Treatments	SQI	RSQI
T_1 - Control	6.60	0.69
T_2 - 2 t/ha of sorghum residue	7.96	0.83
T_3 - 4 t/ha of sorghum residue	9.28	0.97
T_4 - 6 t/ha of sorghum residue	9.58	1.00
LSD (p =0.05 level)	0.46	

Conclusion

In conclusion, after 6 years of experimentation the increase in organic carbon, available Nitrogen and phosphorus were found to be significantly higher with the increase in the amount of residues applied. Among the biological properties, significantly higher MBC and DHA were observed in soil with the application of sorghum stover @ 4 t/ha. Physical properties such as BD and MWD were significantly influenced by residue application under minimum tillage. The important soil parameters *viz.,* EC, N, P, K, Ca, Mg, S, Fe, B, LC, MBC, BD, MWD, AWC were identified as the key indicators of soil quality the highest soil quality index (9.58) was observed with the residue application @ 6 t/ha compared to other residue treatments. The findings of the study clearly established that the minimum tillage in combination with the surface residue application on long term basis can play an important role in improving physical, chemical and biological soil quality parameters, crop yields sustainability yield indices and soil quality indices. Land managers, farmers and other stake holders can consistently adopt these practices to restore and maintain the quality of their soils for ensuring higher productivity on sustainable basis.

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