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Soil Quality under Tillage and Residue Management in Jute (*Corchorus* spp.) based Cropping Systems of Indo-Gangetic Plains

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A B S T R A C T

Conservation agriculture (CA) is based on principles of minimum soil disturbance through zero or minimum tillage operations, residue retention on soil surface and crop diversification which not only improves healthy functioning of soil but also enhances nutrient availability, its biological quality and aggregate formation. On the other hand, conventional tillage (CT) practices characterized by excessive tillage, residue removal and monoculture are often associated with the degradation of soil mainly in terms of depletion of SOC, sub-soil compaction and loss of biodiversity. Therefore, field experiment conducted with zero tillage, zero tillage + residue along with CT (control) under the most predominant cropping systems *i.e.* Jute-Rice-Wheat/lentil/Mustard systems to assess the dynamics of soil quality status in sandy loam soils of Indo-Gangetic plains. Surface soil samples were collected and analyzed for soil physico-chemical properties (pH, Electrical conductivity: EC; Bulk density: BD; Mean weight Diameter: MWD; Soil Organic Carbon: SOC; and Available N, P and K). The results revealed that soil organic carbon (SOC) was significantly and positively correlated with clay content (0.99**), MWD (0.83**) and Av-N (0.68**) but negatively correlated with BD (-0.74**). Evaluation of soil quality using soil quality index (SQI) under different tillage and cropping system showed that soil quality was better in Jute-rice-lentil (range: 0.42-0.62) under zero tillage with residue as compared to the other systems. The higher index values implied that SQ under that management is better as compared to other treatments. This indicated that minimum soil disturbances coupled with residue retention improved and/or optimized soil properties and provided better soil environment for plant growth. The tillage that caused destructive effects on soil quality should be discouraged for long-term cultivation to maintain good soil health for sustainable agricultural production.

Introduction

Climate changes in terms of long term changes in temperature and precipitation are inevitable. So its impact on agricultural production is unavoidable rather it has been experiencing mostly with negative consequences. Accelerated atmospheric CO_2 concentration of 387 ppm and increasing @ 2 ppm/ year results in unprecedented global warming. The surface air temperature has been projected to rise between 1.8 to 4°C in

21st century along with frequent warm spells, heat waves, heavy rainfall events and droughts. These projected changes in climate with extreme events can affect agricultural production with serious implications on food as well as fibre security.

Traditional agriculture, based on tillage and being highly mechanized, has been accused of being responsible for land resources degradation, biodiversity reduction, low energy efficiency and contribution to the global warming problems.

Hence conservation agriculture (CA) is a way to cultivate annual and perennial crops, based on no vertical; perturbation of soil (zero and conservation tillage), with crop residues management and cover crops, in order to offer a permanent soil cover and a natural increase of organic matter content in soil.

Soil quality is defined as the '*capacity of a reference soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation*' (Karlen *et al.*, 1997). Soil quality studies are focused on soil physico-chemical properties (Larson and Pierce, 1994) and recently soil biological properties too have been included as these serve as early and sensitive indicators in response to the change in management practices (Kennedy and Papendick, 1995).

Jute (*Corchorus* spp.) is considered as the golden fibre of India. It is eco-friendly, biodegradable and has much higher CO_2 assimilation rate which is creating an opportunity for the survival and growth of jute industry in the era of environmental concern. The most significant impact of the jute life cycle is carbon sequestration by green jute plants in vegetative stage. Jute crop has a unique physiological characteristic that the leaves automatically fall down in this field itself at matured stage of growth. The daily potential biomass production of jute is 49.7 g/m^2 (Palit, 1993). During the 120 days of jute growing season, 1 ha of jute plant can absorb about 15 MT of CO_2 from the atmosphere and liberate about 11 MT of O_2, the life supporting agent (IJSG, 2013).

Thus jute plantation acts as a sink for carbon. GHG emissions from jute are negative on the account of large carbon sequestration at vegetative stage. Considering these facts, it is obvious that jute crop has tremendous potential for conservation agriculture practice. Withthis backdrop, the present study was aimed to assess the dynamics of soil quality status under conventional and zero tillage with or without crop residue in alluvial soils of Indo-Gangetic plains.

Materials and Methods

A field experiment was initiated in 2015 with zero tillage (ZT), zero tillage + residue (ZT+R) along with conventional tillage (CT) under the most predominant cropping systems *i.e.* Jute-Rice-Wheat/lentil/Mustard systems to assess the dynamics of soil quality status under contrasting tillage and cropping systems in Indo-Gangetic plains in Eastern India. The experiment conducted at ICAR-Central Research Institute for Jute and Allied Fibres research farm at Barrackpore, Kolkata (22°45′N and 88°26′E) at an altitude of 9 m above mean sea level.

The climate of the area is characterised as tropical, with mean maximum and minimum air temperatures and mean annual rainfall are 31.2°C, 20.5°C and 1383.2 mm, respectively (Barman *et al.*, 2012). About 80 % of the rainfall occurs during the rainy season, i.e. June to September. Soil of the experimental site was characterized as sandy loam in texture, neutral in reaction (pH: 7.83), low to medium in Walkley and Black oxidizable organic carbon (4.9 g/kg), medium in available N and K (226.84 kg/ha and 122.35 kg/ha, respectively), and high in available P (45.09 kg/ha).

The experiment was laid out in a split-plot design with three tillage systems *viz.*, conventional, zero tillage and zero tillage with additional crop residue, as the main treatments and three crop systems *viz*., Jute-rice-wheat, Jute-rice-lentil and Jute-rice-mustard as sub-treatments in plots of 6 x 4 maize. Each treatment was replicated thrice. The conventional tillage (CT) consisted of deep summer ploughing and 3 to 4 pass tillage operations using tine cultivator followed by sowing in *kharif* and 1 to 2 pass tillage operation followed by sowing in *rabi* crops. Zero tillage consisted of direct sowing of crops in undisturbed soil by opening a narrow slit of sufficient width and depth to place the seed. The residue retention under tillage treatment was >30% on soil surface. For additional residue incorporation in the field, brown manuring practice introduced where *Sesbania* crop @ 20 kg/ha is broadcasted in between the rows of jute crop after few days of jute sowing and allowed to grow for 30 days. Then, the crop was incorporated in the plot for additional organic matter in the soil.

The crops *viz.* Jute (*cv.* JRO 204/ *Suren*), rice (*cv.*IET 4094/ *Khitish*), wheat (*cv.* PBW 343), lentil (*cv.*Usha) and mustard (*cv.* B-9/ *Binoy*) were grown as per recommended agronomic practices with prescribed dose of fertilizers and intercultural operations. Surface soil samples (0-15 cm) were collected randomly from 2-3 locations from the plots at the end of 3rd crop cycles. These samples were composited, processed, sieved through a 2-mm sieve after removing large plant material and analyzed for physico-chemical properties. The indicators of soil quality were selected based on the performance of considered soil functions. The selected soil properties were Bulk density: BD; Mean weight Diameter: MWD as physical indicators and pH, Electrical conductivity: EC; Available N, P and K: Av-N, Av-P and Av-K and Soil Organic Carbon: SOC as chemical indicators. Soil samples were analysed for their bulk density as described by Black (1965). The aggregate size distribution was determined using the wet sieving method (Yoder, 1936) and the mean eight diameter (MWD) values were calculated after oven-drying (van Bavel, 1949). The soil pH and EC were measured in 1:2.5 soil-water suspensions at room temperature. Soil organic carbon was determined by wet digestion method (Walkley and Black, 1934), Av.-N by using alkaline permanganate method (Subbiah and Asija, 1956), Av.-P by Olsen's extraction method (Olsen *et al.,* 1954) and Av.-K by neutral normal ammonium acetate extract, using flame photometric method (Jackson, 1967).

Soil quality assessment

Soil quality assessment tools need to be flexible in terms of selection of soil functions to be assessed and indicators to be measured to ensure that assessments are appropriate for specific management goals. For developing a soil quality index (SQI), first the raw data of soil quality indicators were transformed into normalized numerical linear scores ranging from 0 to 1 because different indicators are expressed by different numerical scales. The transformation of an indicator value to a score was achieved with the help of a scoring function. According to Karlen and Stott (1994), the sum of weights for all soil functions must equal 1.0. Using the non-linear scoring curve equation, three types of standardized scoring functions typically used for soil quality assessments were generated: (1): More is better"; (2) "Less is better"; and (3) "Optimum" as per earlier studies. The equation defines a "More is better" scoring upper asymptotic sigmoid curve for positive slopes, a "Less is better" lower asymptotic sigmoid curve for negative slopes, and an "Optimum" Gaussian function curve is defined by the combination of both positive and negative slopes (Andrews *et al.*, 2002). The weights of each parameter were assigned based on principal component analysis (PCA) using SPSS for physical, chemical soil indicators. The objective of PCA is to reduce the dimension of data while minimising the loss of information. Principal components (PCs) with eigenvalues ≥ 1 were selected as PC with eigenvalues with ≤ 1 accounts for less variation than generated by a single variable. Multivariate correlation coefficients were used to check for redundancy and correlation between variables/indicators (Andrews *et al.*, 2002). After determining the weight of each determinant of soil quality, SQI was calculated by the following equation:

$$SQI = \frac{1}{n}\sum_{i=1}^{n} W_i * S_i$$

Where, n = number of indicators included in index, S_i = linear or non-linear score of i^{th} indicator, W_i = weight assigned to i^{th} indicator.

Results and Discussion

Relationship among soil physico-chemical properties

Correlation analysis of the soil attributes representing soil physico-chemical parameters resulted in a significant correlation at 1% ($P < 0.01$) and 5% ($P < 0.05$) of various soil attribute pairs (Table 1). Soil organic carbon (SOC) was significantly and positively correlated with clay content (0.99**), MWD (0.83**), and Av-N (0.68**) but negatively correlated BD (-0.74**). High correlation relationship between SOC and MWD showed increase in aggregation with SOC. A good aggregation promotes plant growth by improving water retention and transmission, oxygen availability and nutrient adsorption and desorption to the roots. Similar result has been observed by Sakin (2012) for BD and Mohanty *et al.*, (2013) for MWD. Negative and significant correlation between BD and SOC may be because of humic and fulvic acid formation due to organic matter decomposition. In present investigation, soil pH is negatively and significantly correlated with Av-N (-0.79**) and Av-K (-0.60**). It indicated that, at higher pH, these nutrients are less available to crop. Wright *et al.*, (2012) have critically reviewed the availability of plant nutrient under varying pH and suggested that, nutrients in soils are strongly affected by soil pH due to reacting with soil colloids and other nutrients. Thus, availability of many nutrients has been determined as a function of soil pH.

Principal Component Analysis (PCA)

Principal component analysis (PCA) is a widely accepted method for data reduction which simplified the procedure of indicator selection. The soil quality analysis PCA (multivariate statistical approach) has effectively been used to select minimum data set for soil quality assessment.

It uses linear combination of soil properties to determine maximum variance within a data set consisting of a large number of soil properties. The results (Table 2) obtained from PCA indicated 4 PCs with eigenvalues > 1 and soil variables/indicators from each PC were considered for further analysis.

The cumulative variance explained by the selected PCs was 79.02. The soil parameters selected from PC1 were pH, clay content, bulk density, SOC and avail.-P whereas EC and MWD were contributed from PC2, avail-N from PC3 and avail.-P from PC4.

Table.1 Correlation matrix of soil quality parameters (n=27)

Parameters	pH	EC (dS/m)	Clay (%)	BD (g/cm^3)	SOC (%)	MWD (mm)	Avail N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)
pH	1.00								
EC (ds/m)	0.44*	1.00							
Clay (%)	-0.41*	-0.78*	1.00						
BD (g/cm^3)	0.80**	0.89**	-0.98**	1.00					
SOC (%)	-0.36*	-0.41*	0.99**	-0.74**	1.00				
MWD (mm)	-0.89**	-0.80**	0.99**	-0.99**	0.83**	1.00			
Avail N (kg/ha)	-0.79**	-0.90	0.98**	-0.99*	0.68**	0.98*	1.00		
Avail. P (kg/ha)	0.14	0.82**	-0.29	0.48*	0.40*	-0.32	-0.49*	1.00	
Avail. K (kg/ha)	-0.60**	-0.98**	0.88**	-0.96**	0.58*	0.90**	0.96**	-0.71**	1.00

**indicates significant at the P <0.01 level, * indicates is significant at the P <0.05 level.

Table.2 Principal components, eigenvalues and component matrix variables under PCA analysis

Principal components	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Eigenvalues	3.22	2.51	1.70	1.38	0.96	0.87	0.63	0.48	0.26
% variance	38.25	18.58	13.62	8.57	6.40	5.09	4.57	3.41	2.51
% Cumulative variance	38.25	56.83	70.45	79.02	85.42	90.51	94.08	97.49	100.00
pH	**0.48***	0.32	0.28	0.23	0.20	0.15	0.09	0.07	0.05
EC (ds/m)	-0.41	**-0.59**	-0.31	-0.25	0.21	0.18	0.14	0.09	0.06
Clay (%)	**0.66**	0.54	-0.32	0.39	0.30	0.23	0.19	0.17	0.17
BD (g/cm^3)	**0.49**	0.44	0.32	-0.17	0.25	0.24	0.18	0.09	0.07
SOC (%)	**0.69**	0.54	0.49	0.41	-0.32	0.36	0.27	0.18	0.11
MWD (mm)	0.44	**0.62**	0.53	0.44	-0.36	0.32	0.24	0.19	0.12
Avail N (kg/ha)	0.11	0.23	**0.77**	0.56	0.43	0.30	0.22	-0.11	-0.08
Avail. P (kg/ha)	-0.13	0.33	0.42	**0.63**	0.57	0.48	0.44	0.28	0.19
Avail. K (kg/ha)	**0.71**	-0.11	0.59	0.47	0.36	0.30	0.22	0.18	0.11

*Boldface factors loading are consider highly weighted, PC = principle component of soil quality indicators
Soil reaction (pH), electrical conductivity (EC), Soil organic carbon content (SOC), bulk density (BD), mean weight diameter (MWD), available nitrogen (Avail. N), available phosphorus (Avail. P) and available potassium (Avail. K)

Fig.1 Soil quality under various tiilage, residue management and cropping systems

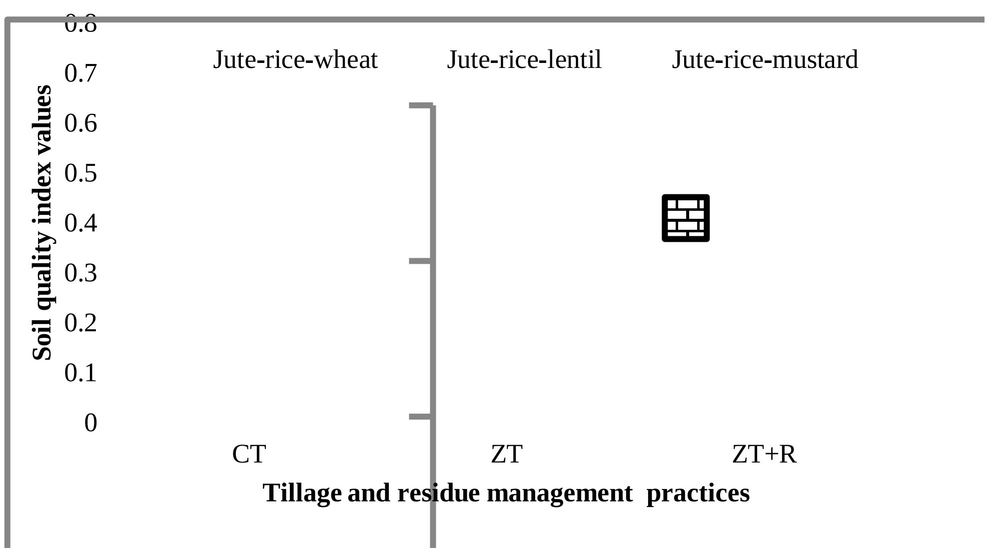
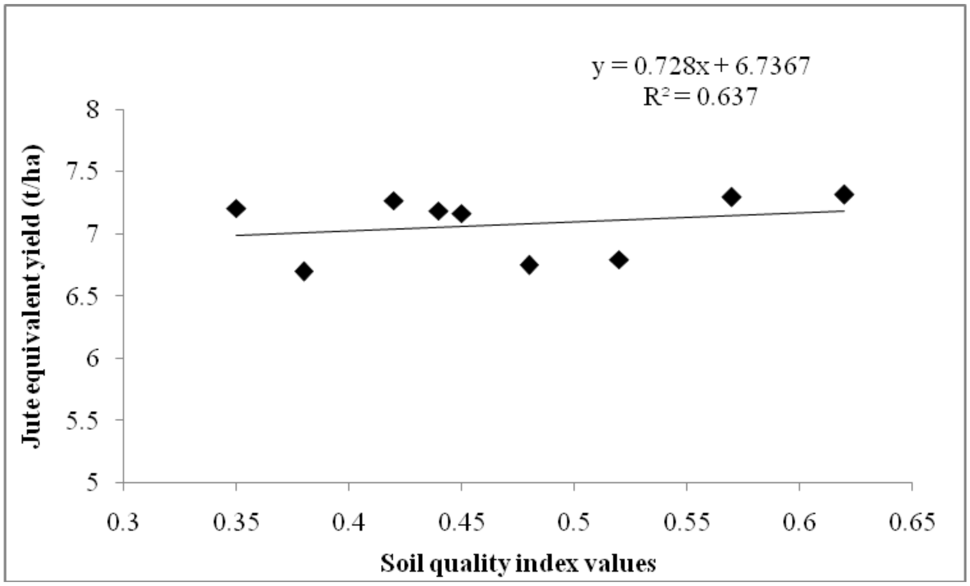


Fig.2 Correlation between soil quality index values and jute equivalent yield



Soil quality index under tillage and residue management

Soil quality index (SQI) values were calculated in different tillage and residue management practices under the predominant cropping systems (Jute-rice-wheat, Jute-rice-lentil and Jute-rice-mustard) in present study with the help of PCA. The higher index values implied that SQ under that management is better as compared to other treatments. The higher value of index implied that SQ under that treatment is better compared to other. Result (Fig. 1) indicated that SQI values under ZT + R (range: 0.45-0.62) and ZT (range: 0.44-0.57) are better than CT (range: 0.35-0.42). This result corroborates with findings of study conducted by Kumar *et al.,* (2017). This indicated that minimum soil disturbances coupled with residue retention improved and optimized soil properties and provided better soil environment for plant growth. Hati *et al.,* (2004) and Bandyopadhyay *et al.,* (2010) reported significant positive correlation between the MWD and SOC and %WMSA and SOC, respectively. Removal of residues from the surface and exposing the surface soil through tillage for accelerated decomposition might be responsible for reduced aggregate stability in CT. Among the cropping systems, jute-rice-lentil gave the higher SQI values (range: 0.42-0.62), whereas the other two cropping systems of jute-rice-wheat (range: 0.35-0.45) and jute-rice-mustard (range: 0.38-0.52) were statistically at par with each other. Overall, higher SQI values were observed in jute-rice-lentil cropping system under ZT +R (0.62) followed by ZT (0.57) depicting the significant cumulative effect of lentil crop along with ZT and residue incorporation on soil quality. Gallaher and Ferrer (1987) also reported that the soil under no-tillage contains 20-43% more nitrogen than CT at 0-5 cm soil depth. Crop yield is one of the reliable ways to assess soil quality. In this study, a significant correlation was observed between SQI values and jute equivalent yield: JEY (Fig. 2). A positive correlation (R^2 = 0.64) between SQI values and JEY implied that the index may have practical utility in quantifying the soil quality under various tillage and residue management practices.

The assessment of SQ indicators under different jute based cropping systems in sandy loam soil showed that, the physico-chemical properties of soil are significantly influenced by tillage and residue management practices. The study revealed that zero tillage along with residue management improved the soil physical environment particularly soil aggregation, bulk density due to minimum soil disturbances which are actually reflected by the higher SQI values under this practices. It is evident that crop productivity is one of the reliable ways to evaluate soil quality as SQI values are positively and significantly correlated with jute equivalent yield various tillage and residue management practices.

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