Improvement in soil quality through tillage and residue management in Jute (Corchorus spp.) based cropping systems of Indo-Gangetic plains

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ABSTRACT
The changes in soil quality in terms of carbon accumulation, aggregate stability and enzyme activity were evaluated in Jute based cropping systems (jute-rice-wheat, jute-rice-lentil and jute-rice-mustard) subjected to various tillage systems, i.e. conventional tillage (CT), no tillage (NT) and no tillage with additional crop residue retention (NTR) under tropical climate of Indo-Gangetic plains. The crops were grown with conventional (disc plowing, followed by 2 cultivators) and no tillage (no ploughing) and additional crop residues were applied as Sesbania spp. with a rate of 2 t ha\(^{-1}\). Addition of crop residue under no tillage improved bulk soil organic carbon (SOC), particulate SOC content (PSOC) and aggregate stability, promoting a better soil physico-chemical behavior in all crop-rotations. The SOC contents under No tillage with residue incorporated plots (NTR) are much higher, maximum being in jute-rice-lentil (6.02 and 7.29 g kg\(^{-1}\) in 0–0.15 and 0.15–0.30 m soil depth). The highest SOC density (330.03 g C m\(^{-2}\)) and stock (3.30 Mg C ha\(^{-1}\)) were recorded in the NT R. Soil microbial biomass (SMBC) was significantly higher in NT R (range: 641.84 to 745.97 µg g\(^{-1}\)) followed by NT (631.42 to 678.46 µg g\(^{-1}\)) and CT (490.68 to 634.83 µg g\(^{-1}\)). Jute equivalent yield (JEY) was highest in jute-rice-lentil (J-R-L) under NTR (7.33 t ha\(^{-1}\)). Thus, no tillage with residue incorporation under Jute-rice-lentil system is highly beneficial in maintaining crop productivity and improving soil quality.

KEYWORDS
No tillage and crop residue; jute based cropping systems; soil organic carbon stock and enzyme activity

1. Introduction
The overwhelming effort in increasing agricultural production in India is attributed to several changes facing intensive agriculture like excessive tilling of land, water and fertilizer applications as well as risk in environmental pollution and degradation of soil and water resources [1]. Of late, it has been established that disturbing the soil too much through tillage operations is not actually required to obtain good crop yields [2], and also a major portion of energy (25–30%) in agriculture is utilized for either field preparation or crop establishment [3], where conventional tillage is mostly followed. Moreover, early warning signals of environmental degradation are becoming visible in the form of declining soil fertility, degradation of irrigation water quality, shift in water table, rising salinity and resistance of many pests to pesticides [4]. Thus, conservation agriculture (CA) is becoming attention over the past few decades due to increasing concern of sustainability of agri-production system and food security in near future.

Conservation agriculture is popular worldwide due to its enhanced C sequestration potential and favorable effects on soil fertility and nutrient dynamics [5–8]. Conservation agriculture based on principles of no tillage (NT), residue retention and crop diversification improves physical, chemical and biological properties of the soil [9]. There has been ample number of reports on the effect of various tillage and residue management practices in modifying the soil physical environment [10,11]. No-tillage with crop residue cover is usually reported to have better soil aggregation and higher soil organic matter. Thus in long term, more stable structure under no tillage improved saturated hydraulic conductivity as compared to conventional methods [12]. Similarly, nutrient distribution in soil under CT is more uniform due to mixing of soil along with crop residues, fertilizers and manure [13]. Cropping systems also have a great influence on distribution of plant available nutrients in soil profile which may be affected by nutrient removal, decomposition of crop residues.
retained on the soil surface and nutrient leaching [5]. Diversification in cropping systems can change the quality and quantity of crop residues due to their different C:N ratios and decomposition pattern, which are retained on the soil surface [6, 8]. Thus, the interaction of tillage and cropping systems can ultimately result into nutrient stratification [5]. Emphasis has been laid only on the physical and chemical constituents most often, whereas the biological components which are highly sensitive to disturbance and perturbation and performs multiple functions in soil sustenance has been ignored [14,15]. Since the assessment of soil quality in terms of measurement of rate of change in soil organic matter (SOM) is very difficult and time consuming process, therefore, soil microbial biomass, which has been shown to quickly respond to changes in soil management, is being used [16]. Microbial properties related to total organic carbon content have been considered as the biological indicators of soil quality [17].

Jute (Corchorus spp.) is an important commercial fibre crop and has much higher carbon dioxide (CO₂) assimilation rate which is creating an opportunity for the survival and growth of jute industry in the era of environmental concern. About 15 tonnes of green jute leaves per hectare is added through leaf fall during total crop duration and supplements a considerable amount of essential plant nutrients along with increase in soil organic matter for succeeding crops [18]. In the eastern Indo-Gangetic plains (IGP) of India, jute based cropping systems are most predominant due to better adaptability, availability of high yielding varieties and highly productive and energy efficient in irrigated condition. These systems are no longer profitable with higher labor requirement under climate change scenario, i.e. increased temperatures and erratic rainfall pattern. Thus, CA may be sustainable production system under this situation for resource poor farmers of this region. However, no scientific reports are available to support this proposition. Therefore, the present study was undertaken with the objective to evaluate the effects of tillage and residue management on soil physical properties, fertility and microbial activities under predominant jute based cropping systems in alluvial soils of Indo-Gangetic plains.

2. Material and methods

2.1. Experimental site

The long-term on-going field experiment was initiated in April, 2015 at ICAR-Central Research Institute for Jute and Allied Fibres research farm at Barrackpore, Kolkata (22°45’N latitude and 88°26’E longitude), India at an altitude of 9 m above mean sea level. The climate of the area is characterized 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 [19]. About 80% of the rainfall occurs during June to September. The soil of the experimental site was moderately deep, well drained and sandy loam in texture and classified as Typic Eutrochrept. Initial soil pH was neutral to alkaline in reaction (pH: 7.83) with presence of calcium carbonate, low to medium in Walkley and Black oxidizable organic carbon (4.90 g kg⁻¹) medium in available N and K (226.84 kg ha⁻¹ and 122.35 kg ha⁻¹, respectively), and high in available P (45.09 kg ha⁻¹).

2.2. Treatment details

The experiment was laid out in a split-plot design with three tillage systems viz., conventional (CT), no tillage (NT) and no tillage with additional crop residue (NTR), as the main plot treatments and three crop systems viz., Jute-rice-wheat (J-R-W), Jute-rice-lentil (J-R-L) and Jute-rice-mustard (J-R-M) as sub plot treatments in plots of 6 × 4 m size. Each treatment was replicated thrice. The conventional tillage (CT) consisted of deep summer ploughing and 3 to 4 pass tillage operations up to 30–40 cm depth using tine cultivator followed by sowing in kharif and 1 to 2 pass tillage operation followed by sowing in rabi crops. No tillage (NT) consisted of direct sowing of crops in undisturbed soil by opening a narrow slit of sufficient width and depth to place the seed. Around 30% crop residue retained in the field itself for residue retention under tillage treatment. For additional residue incorporation in NTR treatment, brown manuring practice introduced where Sesbania crop, a rich source of organic carbon (8.64 g kg⁻¹) and N, P and K content (2.28, 0.49 and 2.09%, respectively) @ 2 tonnes ha⁻¹ is broadcasted in between the rows of jute crop after few days of jute sowing and allowed to grow for 30 days. Sesbania 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. Jute was grown during April-July, 2015
onward followed by rice (August-November) and wheat/lentil/mustard (November-March). The jute was harvested at maturity and preferably after 96 days of crop growth. After jute harvest in the last week of July, rice was transplanted at the rate of 2–3 seedlings per hill in puddled soil at 0.20 m × 0.15 m spacing in first week of August. Rice seedlings were transplanted under no tillage with the help of dibbler, i.e. with minimum disturbances in soil system. The rice crop was harvested in the last week of October. Immediately after, wheat/lentil/mustard was sown in the second week of November with a spacing of 0.20 m between rows, and harvested in March. Recommended intercultural operations like weeding, thinning, top dressing were followed at regular interval under various crops. Before sowing, the seeds were treated with the fungicides Carbendazim 50 WP with a uniform dose of 2 g kg⁻¹ seed, at least 4 h before sowing. Irrigation was applied at all the critical stages of crop growth during the experimentation and herbicides were applied at recommended rates as and when required.

2.3. Soil sampling and analysis

Soil samples from different depths (0–0.15 and 0.15–0.30 m) were collected randomly from 2 to 3 locations from the plots at the end of 3rd crop cycles, i.e. after harvest of wheat/lentil/mustard crops. Half of soil samples were kept in freezer (4 °C) to determine the microbial properties and enzymatic activities, and remaining half soil samples were air dried and ground to pass through a 2 mm sieve after removing large plant material and analyzed for physico-chemical properties. Soil pH was measured by soil water suspension (1:2.5 soil:water) through pH meter. Bulk density (BD) values of the soil samples were determined after packing soil samples into 0.05 m diameter and 0.10 m height of cylinders with proper compaction effect so as to get the representative samples like in field condition. The aggregate size distribution was determined using the wet sieving method [20] and the mean weight diameter (MWD) values were calculated after oven-drying [21]. Walkley and Black oxidizable carbon content was measured by wet digestion method [22] and particulate soil organic carbon (K MnO₄-C) was determined as per the procedure given by [23]. Soil organic carbon density was calculated by multiplying the SOC content (g kg⁻¹), soil thickness (0.30 m) and bulk density (Mg m⁻³) and the results were presented in g m⁻² [24]. The organic carbon density thus obtained was then multiplied by the area, to produce an estimate of the organic carbon stock in a furrow slice ha⁻¹ of soil [24]. SOC stock change in the top 0.30 m soil depth was used to evaluate the SOC change after 4th year of continuous imposition the treatments [25]. Each observation of SOC stock change for j site was calculated with formula:

\[ \Delta C = C_t - C_i \]

where \( \Delta C \) is changes in SOC stock, \( C_t \) is the SOC stock in treatment plots and \( C_i \) is the initial SOC stock before imposing the particular treatment. Mean annual absolute rate of change in SOC stock has been calculated using formula given by [26]:

\[ \text{Mean annual absolute rate of change in SOC stock} = \frac{\Delta C}{\text{total year of experimentation}} \]

The primary nutrient contents of soil were determined by standard procedures viz., potassium permanganate oxidizable soil N (K MnO₄-N) [27], available phosphorus [28], available potassium [29]. Soil microbial biomass C (SMBC) was estimated by the method of Vance et al. [30]. The enzyme activities of soil viz., Dehydrogenase activity (DHA) and β-glucosidase activity was estimated by reducing 2,3,5-triphenyltetrazolium chloride [31] and by determining the amount of p-nitropheno l released after 1 h of incubation with p-nitrophenyl-b-D-glucopyranoside [32], respectively.

The respective crops were harvested manually at maturity from net plot area 6 × 4 m at regular interval for the consecutive 4 year of experimentation and the yield data were recorded in terms of jute equivalent yield (t ha⁻¹). Means were compared using least significant difference (LSD) where the analysis of variance (F-test) was performed to determine the significant differences (\( p = 0.05 \)) among the tillage practices and cropping systems [33]. All the data sets were processed and analyzed using SAS 9.1 software (SAS Institute, Cary, NC).

3. Results and discussion

3.1. Soil physico-chemical properties

Soil pH was similar across the treatments irrespective of either tillage treatments or cropping systems (Table 1). Soil pH, however, increased non-significantly with respect to increase in soil depth. In general, soil bulk density (BD) decreased in deeper layer of the soil irrespective of the treatments (Table 1). Among the tillage treatments, NTR had...
the lowest BD values as compared to other treatments. However, the differences in BD under NTR as compared to other tillage treatments are statistically non-significant (p = 0.05). Among the cropping systems, there were no significant differences in bulk density between the treatments across the soil depths. The lower bulk density under NTR treatment indicated the effect of residue incorporation in reducing the bulk density because of higher organic carbon accumulation which has also been widely reported by Monneveux et al. [34].

### 3.2. Soil fertility status

Available N, P and K content in soil was higher under surface soil (0–0.15 m) and decreased gradually with soil depths in NT and NTR treatments, whereas the trend is just reverse in case of CT treatment (Table 2). Highest available N content was recorded in NT R (289.16 and 319.41 kg ha$^{-1}$) followed by NT and CT among the tillage practices (p = 0.05). The recycling of the higher amount of biomass either through previous crops residue or additional residue in the form of *sesbania* spp. in NT and NTR treatments, respectively lead to addition of more nutrients in NT and NTR practices compared to CT. On the other hand, the stover/straw was incorporated in deep soil layers under CT and leads to rapid decomposition and might also lead to leaching of mineralized nutrients in much deeper soil layers which in turn reduces content of plant available nutrients in CT [6, 13].

### Table 1. Changes in soil physico-chemical properties under different tillage practices and cropping systems.

| Treatments     | Soil pH | Bulk density (Mg m$^{-3}$) | Clay content (%) |
|----------------|---------|-----------------------------|------------------|
|                | 0–0.15 m | 0.15–0.30 m | 0–0.15 m | 0.15–0.30 m | 0–0.15 m | 0.15–0.30 m |
| Tillage practices* |         |                 |                  |               |              |              |
| CT             | 7.34     | 7.38             | 1.64             | 1.61          | 17.66       | 17.44        |
| NT             | 7.40     | 7.43             | 1.62             | 1.59          | 18.09       | 17.06        |
| NTR            | 7.42     | 7.41             | 1.59             | 1.52          | 19.73       | 18.08        |
| LSD (p = 0.05) | NS       | NS              | NS               | NS            | 0.67        | 0.45         |
| Cropping systems* |       |                 |                  |               |              |              |
| J-R-W          | 7.33     | 7.44             | 1.62             | 1.63          | 17.61       | 16.32        |
| J-R-L          | 7.33     | 7.48             | 1.61             | 1.55          | 19.37       | 18.07        |
| J-R-M          | 7.38     | 7.41             | 1.60             | 1.58          | 18.33       | 17.85        |
| LSD (p = 0.05) | NS$^4$   | 0.03            | NS               | NS            | 0.59        | 0.42         |
| Interaction LSD (p = 0.05) | NS       | NS              | NS               | NS            | NS          | NS           |

*CT: Conventional tillage; NT: No tillage and NTR: No tillage + residue

$^4$: J-R-W: Jute-Rice-Wheat; J-R-M: Jute-Rice-Mustard and J-R-L: Jute-Rice-Lentil

(NS: Not significant)
organisms and exposed to sunlight, thereby increasing N-mineralization from active and physically protected pools [6]. The interaction effects of systems (NT and NTR) and cropping systems (J-R-L) are statistically \( (p = 0.05) \) significant.

The NT and NTR treatments significantly increased \( (p = 0.05) \) available P in soil depths compared to CT. There is a sharp decline in P content across the soil depths, about 11.4% in NT and 12.3% in NTR treatments from 0–0.15 to 0.15–0.30 m soil layers. However, it is just reverse in case of CT. Among cropping systems, available P in all depths was in the order: J-R-L > J-R-W > J-R-M (Table 2). However, the differences in available P content among the cropping systems were statistically insignificant \( (p = 0.05) \). Available K content in NT and NTR treatments was significantly higher than CT in surface soil. The similar findings for enhancing K in soils due to no tillage practices reported widely by several workers while working in different agro-climatic conditions throughout the world [5, 13]. Among all the cropping systems, the available K content in the surface soil under J-R-L cropping system was 7.3 to 15.07% higher than J-R-W and J-R-M cropping systems. The similar enhancement in available nutrients due to CA practices in soil were also reported by Dey et al. [6] for N, Kumawat et al. [7] for P and Raghavendra et al. [36] for K.

### 3.3. SOC status

In general, SOC content increases with soil depth irrespective of the treatments (Figure 2). A significant difference in SOC (range: 5.45–7.07 g kg\(^{-1}\) at 0–0.30 m soil depth) was observed due to different tillage and residue management practices. In 0–0.15 m soil depth, SOC content in NTR (6.84 g

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**Table 2. Changes in soil fertility status under different tillage practices and cropping systems.**

| Treatments       | Available N (kg ha\(^{-1}\)) | Available P (kg ha\(^{-1}\)) | Available K (kg ha\(^{-1}\)) |
|------------------|-----------------------------|-----------------------------|-----------------------------|
|                  | 0–0.15 m  | 0.15–0.30 m | 0–0.15 m  | 0.15–0.30 m | 0–0.15 m  | 0.15–0.30 m |
| Tillage practices* |                |                |                |                |                |                |
| CT               | 265.07   | 265.43       | 31.64         | 32.93         | 134.20     | 142.5        |
| NT               | 308.87   | 270.69       | 36.61         | 32.43         | 150.44     | 140.56       |
| NTR              | 319.41   | 289.16       | 35.27         | 30.94         | 149.18     | 135.16       |
| LSD (\(p = 0.05\)) | 10.47   | 4.07         | NS            | NS            | NS         | NS           |
| Cropping systems* |                |                |                |                |                |                |
| J-R-W            | 291.55   | 271.74       | 34.30         | 32.35         | 147.60     | 131.19       |
| J-R-L            | 316.74   | 289.60       | 36.56         | 32.48         | 159.29     | 135.32       |
| J-R-M            | 285.07   | 263.95       | 33.95         | 30.17         | 135.28     | 143.41       |
| LSD (\(p = 0.05\)) | 7.82    | 6.55         | NS            | NS            | 9.22       | 3.86         |
| Interaction LSD (\(p = 0.05\)) | 5.36    | 3.40         | NS            | NS            | NS         | NS           |

*CT: Conventional tillage; NT: No tillage and NTR: No tillage + residue
*J-R-W: Jute-Rice-Wheat; J-R-M: Jute-Rice-Mustard and J-R-L: Jute-Rice-Lentil
NS: Not significant
kg$^{-1}$) was significantly higher ($p = 0.05$) compared to NT and CT. In 0.15–0.30 m soil depth, SOC content varied in between 5.70 and 7.29 g kg$^{-1}$, highest being in NTR. The increase in SOC under NTR treatment is significantly higher ($p = 0.05$) than NT (8.2–10.3%) and CT (21.9–22.1%) across the soil depth. This higher amount of SOC in NTR plots could be attributed to continuous retention of additional crop residue in the form of Sesbania spp. on soil surface and the minimum disturbance of soil layers due to tillage practices. This was more evidenced by the difference in particulate soil organic carbon (PSOC) contents in CT treatments (Figure 2), which was much low (0.46–0.59 g kg$^{-1}$) as compared to NT (0.49–0.71 g kg$^{-1}$) and NTR plots (0.53–0.75 g kg$^{-1}$). PSOC content in NTR treatment was 18.2% higher than CT and 7.6% over NT treatments. The significant difference of PSOC content between CT with either NT or NTR ($p = 0.05$) treatments also indicated that the effect of tillage got better manifestation with residue management practices. Cropping systems had insignificant effect on SOC contents in soil ($p = 0.05$). Among the cropping systems, J-R-L contributed highest SOC (mean: 6.33 g kg$^{-1}$) followed by J-R-W (mean: 5.86 g kg$^{-1}$) and J-R-M (mean: 5.78 g kg$^{-1}$). The cumulative effects of tillage and cropping systems had positive impact on SOC contents as it is evidenced from much higher SOC under NTR, maximum being in jute-rice-lentil (6.02 and 7.29 g kg$^{-1}$, respectively in 0–0.15 and 0.15–0.30 m soil depth) followed by jute-rice-wheat (5.68 and 6.23 g kg$^{-1}$, respectively) and jute-rice-mustard (5.32 and 5.90 g kg$^{-1}$, respectively). Higher addition of roots, plants biomass, contribution of leguminous crop and leaf litter falls of jute and biological activities in surface layer might have improved its status [37].

The soil organic carbon (SOC) density and SOC stock, indices for estimating the SOC accumulation/status in the soil system varied significantly (Table 3) under various treatments from an initial SOC density (0–0.30 m soil depth) of 234.24 g m$^{-2}$. Among the tillage treatments, SOC density varied in between 242.17–330.03 g m$^{-2}$ whereas it is ranging from 273.92 to 303.43 g m$^{-2}$ under cropping systems treatments, after fourth year of experimentation. Thus, the SOC density increased up to 59.40 and 95.79 g m$^{-2}$ in NT and NTR plots, respectively over the years lowest being in CT (7.93 g m$^{-2}$). Among the cropping systems, the SOC density increased by 39.68 to 69.19 g m$^{-2}$ over the initial SOC density, highest being the J-R-L system, might be because of higher crop biomass and better decomposition rate in the system [17]. A similar trend was observed for SOC stock. NTR contributed the highest SOC stock (3.30 Mg C ha$^{-1}$) followed by NT (2.94 Mg C ha$^{-1}$), and CT.
(2.42 Mg C ha\(^{-1}\)). Among the cropping systems, the SOC stock followed the order of: J-R-L > J-R-W > J-R-M. The maximum increase in SOC stock was observed under NTR treatment, which is 41.03% over the initial SOC stock (2.34 Mg C ha\(^{-1}\)) followed by NT (25.21%), lowest being in CT (3.42%). The significant increase in SOC stock \((p = 0.05)\) under NTR and NT may be ascribed by mean annual absolute rate of change in SOC stock \((\text{Table 3})\) which is much higher \((0.15–0.24 \text{ Mg C ha}^{-1} \text{ year}^{-1})\) as compared to CT \((0.2 \text{ Mg C ha}^{-1} \text{ year}^{-1})\). No tillage had an effect of the capacity of the soil for storing SOC, moisture, and nutrient supply and the increased biomass which have favorable effects on the physical and biological properties of soil [38].

### 3.4. Soil microbial and enzymatic activities

Soil microbial biomass carbon (SMBC) ranged from 531.47–719.59 µg C g\(^{-1}\) soil in NT and NTR treatments as compared to 398.75–585.81 µg C g\(^{-1}\) of soil in CT across the soil depths \((\text{Table 4})\). Higher SMBC across the soil depth were observed in NTR treatment \((18.59–40.15\%)\) followed by NT \((16.51–33.28\%)\) than CT. This finding is in conformity with the study of Mondal et al., [39]. NT and NTR systems in which crop residues got mixed and integrated within surface soils showed an increase in soil microbial biomass carbon (SMBC) as compared to CT. The changes in microbial biomass can be accredited to fluctuations in crop residue availability, soil moisture, and temperature and rhizosphere effects. As the crop season progressed, standing stubble decomposed, resulting in higher SMBC in NT and NTR treatments than the CT \((p = 0.05)\). The increase in SMBC values in both the systems clearly depicted the differences in the availability of the substrate and the efficiency of its conversion into SMBC. The results are in corroboration with the finding of Doran [40] where it showed 54% higher microbial biomass in the surface layer of no tillage, than the ploughed soils showing a close association of the microbial biomass with soil organic carbon and moisture content as influenced by the tillage practices. No tillage also increased the amount of microorganisms in soil [41]. The greater stratification of SMBC under the NT is in consistent with the results reported by Salinas-Garcia et al., [42]. The SMBC values among the cropping systems depict significant effect of crop biomass/residues as it is reflected that J-R-L \((533.46–686.42 \mu\text{g C g}^{-1})\) had the highest SMBC followed by J-R-W \((459.05–659.37 \mu\text{g C g}^{-1})\) and J-R-M \((496.58–642.19 \mu\text{g C g}^{-1})\).

In general, surface soil had higher enzymatic activities than the subsurface soil \((\text{Table 4})\). Surface accumulation of crop residues and subsurface supply of organic materials through root biomass could contribute to enhanced enzymatic activities in NT and NTR treatments. Dehydrogenase activity (DHA) varied from 0.69 to 2.23 µg TPF g\(^{-1}\) h\(^{-1}\) \((\text{Table 4})\) under various tillage treatments and was significantly higher in NTR \((p = 0.05)\) as compared to other treatments. NTR soils had 43.8 and 20.3% higher DHA than tilled soils (CT) when averaged across both surface \((0–0.15 \text{ m})\) and subsurface \((0.15–0.30 \text{ m})\) soil depths, respectively. Similarly, NT treatments had 36.1 and 15.9% higher DHA than tilled soils (CT) when under surface \((0–0.15 \text{ m})\) and subsurface \((0.15–0.30 \text{ m})\) soil depths, respectively. Higher DHA at the surface soil due to the alteration in the soil microclimate following the residue addition might have influenced the microbial metabolism led to significantly higher surface soil DHA activity. Nannipieri [43] also concluded that more dehydrogenase activity in no-till soil was due to larger proportions of microbial biomass and carbohydrate-C per unit of organic C.

### Table 3. Changes in soil organic carbon (SOC) density and SOC stock under different tillage practices and cropping systems.

| Treatments | SOC density (g C m\(^{-2}\)) | SOC stock (Mg C ha\(^{-1}\)) | Mean annual absolute rate of change in SOC stock (Mg C ha\(^{-1}\) year\(^{-1}\)) |
|------------|--------------------------|-----------------------------|--------------------------------------|
|            | Status (2019) | Gain (2015–19) | Status (2019) | Gain (2015–19) |                  |
| CT         | 242.17         | 7.93           | 2.42       | 0.08           | 0.02             |
| NT         | 259.64         | 59.40          | 3.00       | 0.59           | 0.15             |
| NTR        | 330.03         | 95.79          | 2.74       | 0.94           | 0.24             |
| LSD \((p = 0.05)\) | 27.56 | –               | 0.27       | –              | –                |
| Cropping systems \(*\) |                |                |            |                |                  |
| J-R-W      | 298.07         | 63.83          | 2.98       | 0.64           | 0.16             |
| J-R-L      | 303.43         | 69.19          | 3.03       | 0.69           | 0.17             |
| J-R-M      | 273.92         | 39.68          | 2.74       | 0.40           | 0.09             |
| LSD \((p = 0.05)\) | 15.82 | –               | 0.22       | 3.06           | –                |
| Interaction LSD \((p = 0.05)\) | 18.07 | –               | 0.19       | –              | –                |

*CT: Conventional tillage; NT: No tillage and NTR: No tillage + residue

\(*\)J-R-W: Jute-Rice-Wheat; J-R-M: Jute-Rice-Mustard and J-R-L: Jute-Rice-Lentil
Table 6. System productivity (t ha⁻¹) under different tillage practices and cropping systems.

| Cropping systems | Summer  | Rainy  | Winter | JEF (t ha⁻¹) |
|------------------|---------|--------|--------|--------------|
|                  | CT | NT | NTR | CT | NT | NTR | CT | NT | NTR |
| J-R-W            | 3.03 | 3.09 | 3.12 | 3.62 (2.35)* | 3.66 (2.37) | 3.74 (2.43) | 3.44 (1.58) | 3.49 (1.60) | 3.56 (1.64) | 6.96 | 7.07 | 7.19 |
| J-R-L            | 3.28 | 3.31 | 3.35 | 3.68 (2.39) | 3.73 (2.41) | 3.80 (2.47) | 1.06 (1.43) | 1.08 (1.44) | 1.12 (1.51) | 7.10 | 7.22 | 7.33 |
| J-R-M            | 3.02 | 3.03 | 3.05 | 3.55 (2.31) | 3.62 (2.34) | 3.70 (2.41) | 1.16 (1.26) | 1.18 (1.28) | 1.20 (1.30) | 6.59 | 6.64 | 6.76 |

*The actual yield of the respective crops are presented in parenthesis.

Among the cropping systems, J-R-L system had highest (1.10–2.91 μg TPF g⁻¹ h⁻¹) DHA followed by J-R-W (0.92–2.14 μg TPF g⁻¹ h⁻¹) and J-R-M (0.67–0.84 μg TPF g⁻¹ h⁻¹) across the soil depths depicting significant effect of crop biomass/residues. β-glucosidase activity also followed a similar pattern, varying from 9.31 to 17.0 μg pNP g⁻¹ h⁻¹ among the tillage treatments and 7.07 to 15.20 μg pNP g⁻¹ h⁻¹ among the cropping systems (Table 4). NTR (10.98–17.00 μg pNP g⁻¹ h⁻¹) resulted highest β-glucosidase activity in both surface and sub-surface soil layers, which is 54.8 and 17.9% higher as compared to β-glucosidase activity under CT (9.31–10.98 μg pNP g⁻¹ h⁻¹). The differential accumulation of organic C, N, and inorganic nutrients in top soils under different tillage practices as well as accumulation of inorganic nutrients tends to increase soil enzymatic activities [16].

Among the cropping systems, β-glucosidase activity were in the order of: J-R-L (10.41–15.20 μg pNP g⁻¹ h⁻¹) > J-R-W (9.74–14.13 μg pNP g⁻¹ h⁻¹) > J-R-M (7.07–12.18 μg pNP g⁻¹ h⁻¹).

3.5. 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 5). Soil organic carbon (SOC) was significantly and positively correlated with clay content (0.99**), MWD (0.83**), Av-N (0.68**), SMBC (0.94**) and DHA (0.86**) but negatively correlated BD (−0.74**) . High correlation relationship between SOC and MWD showed increase in aggregation...
with SOC [44]. Similar result has been observed by Mohanty et al., [45]. Negative and significant correlation between BD and SOC may be because of humic and fulvic acid formation due to organic matter decomposition [44]. In present investigation, SOC is significantly correlated with SMBC (0.94**) and DHA (0.86**). It indicated that, at higher SOC level, enzymatic and microbial activities in the soil increases with higher content of SMBC and DHA, better and conducive for crop growth.

3.6. System productivity

System productivity (Table 6) in terms of jute equivalent yield (JEY) was significantly higher ($p = 0.05$) in J-R-L system (7.33, 7.22 and 7.10 t ha$^{-1}$, under NTR, NT and CT, respectively) followed by J-R-W (7.19, 7.07 and 6.96 t ha$^{-1}$, under NTR, NT and CT, respectively) and J-R-M (6.75, 6.64 and 6.59 t ha$^{-1}$, under NTR, NT and CT, respectively). This is in accordance with the finding of Kumar et al. [46]. Wheat and mustard are known to be more nutrient exhaustive crops than leguminous crops like lentil. Leguminous crops have deep root system which recycle the nutrients, improve the soil structure, add nutrient and other nutrients by biological nitrogen fixation and/or by leaf fall, and they show better overall nutrient use efficiency, hence, improves system productivity [47]. The effects of residue incorporation in later stage improved soil health by enhancing nutrients status, soil organic carbon, microbial biomass carbon [48].

4. Conclusion

Study showed significant improvement in soil properties including soil microbial and enzyme activities in no tillage with additional residue management (NTR) treatment compared with conventional tillage (CT) by facilitating continuous retention of additional crop residue in the form of Sesbania spp. on soil surface and minimizing the disturbance of soil layers. Therefore, it is concluded that no-till system with residue application, can contribute in maintaining profitability and improving soil physico-chemical and soil biological properties in jute-rice-lentil cropping system under Indo-Gangetic plains.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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