Crop yields and soil organic matter pools in zero-till direct-seeded rice-based cropping systems as influenced by fertigation levels in the Indo-Gangetic plains in India

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ABSTRACT
Fertigation in rice-based cropping systems is catching up the attention of farmers for producing high yield of crops and improved fertilizer use efficiency. As fertigation with different combinations of irrigation and nitrogen (N) levels can interact with depth of rooting system of different crops as well as soil tillage, this study was carried out in 2017 in the fourth year of an on-going long-term experiment initiated in the summer (Kharif) season of 2014 to understand the effect of fertigation on soil organic carbon pools and yield in zero-till direct-seeded rice-based cropping systems. The experiment was laid out in a split plot design with three levels of fertigation as main plots: N0 (20 kg ha−1) in rice through fertigation followed by 200 mm irrigation in post rice crops (W1), N1 (40 kg ha−1) in rice through fertigation followed by 300 mm irrigation in post rice crops (W2), N2 (60 kg ha−1) in rice through fertigation followed by 400 mm irrigation in post rice crops (W3). The sub-plot treatments consisted of zero till direct seeded durum wheat, barley, chickpea, linseed, lentil and lathyrus crops after rice. The rice crop was also under zero till direct seeded cultivation system. The highest grain yield of rice was observed in the rice-lathyrus cropping system with treatment W3 where N was applied in three equal splits, first being basal application and the two subsequent applications through surface inline drip irrigation. Both in surface and sub-surface soil layers, soil carbon stock, carbon pools and aggregate associated carbon were found to be more in the legume based cropping systems and with W3 fertigation regime than in other cereal based cropping systems. The grain yield was found negatively and highly significantly correlated with less labile pool (r=−0.63**) whereas very labile pool was positively significantly correlated with labile (r=0.89**), less labile (r=0.53**) and non-labile (r=0.91**) pools of carbon. Overall, fertigation levels influenced the crop yield and soil organic matter in zero-till direct-seeded rice-based cropping systems.

Introduction
The Indo-Gangetic alluvial plains (IGP) of India are an environmentally sensitive region where landscape, hydrology and fertility are threatened by climate change and human population pressure [1]. Rice-wheat cropping system is the most followed cropping system in IGP, In the Indian part of the IGP it is grown on 10 Mha [2–4] to produce about 50% of the total food consumed in the country [5,6]. Western part of the IGP which is under upper IGP (lying in the states of Punjab and Haryana) is one of the India’s most productive regions while eastern part (in the states of Bihar and Uttar Pradesh) which is under middle IGP is one of its least productive regions and lies mostly in rainfed area [7–9]. Uneven distribution of rainfall coupled with lack of irrigation, results in the major areas of rainfed areas becoming mono-cropped with low cropping intensity and farm productivity [10]. Such conditions can be overcome if the farmers of middle IGP regions are able to cultivate crops just after harvesting the main rice crop and use the residual soil moisture optimally. Traditionally, farmers in these conditions cultivate oil-seeds such as linseed and pulses such as lathyrus, chickpea and lentil after growing rice as puddled transplanted crop. Due to abnormal conditions of soil formed by growing rice crop in puddled soil, yields of crops grown after rice are generally low [11]. As compared to puddled transplanting of rice, zero till direct-seeded rice could conserve more soil...
residual moisture and thus better support the crops grown after rice crop and thus enhance the crops productivity. This conservation tillage method can also maintain the optimum level of soil organic carbon (SOC) and improve the soil quality as compared to puddled transplanting [12].

Soil organic carbon is one of the crucial factors for realizing higher yield of rice crop in humid and sub-humid areas [13]. Paddy soils store SOC to a greater extent in comparison to upland soils [14]. Cultivation of rice can enrich the soil with carbon at faster rate than the other arable ecosystems [15,16]. Strategic enhancement of SOC in soil can only be achieved through sustainable management practices that sequester more atmospheric carbon dioxide. Injudicious fertilizer management may adversely impact nutrient use efficiency and crop yield [17,18]. Balancing fertilizer application especially N in rice considering biologically N-fixing leguminous crops that supplies N to rice crop may reduce dependence on nitrogenous fertilizer. Thus fertigation under rice-based cropping systems under rice ecology should not only lead to high yields but also high N use efficiency and increased profits for the farmers. Fertilizer management and irrigation affect the mechanisms by which SOC is lost or stabilized in the soil and influence the lability of carbon. Labile carbon pools are used as important soil quality indicators because these are likely to be more sensitive to management practices than SOC [13,19–23]. Considering the importance of long-term fertigation experiment in zero-till direct-seeded rice-based cropping systems, we took up this study and hypothesized that (1) Continuous application of fertigation under rice-based cropping systems may increase the SOC and its stock status that may improve soil health; (2) Continuous application of fertigation under rice-based cropping systems may improve soil aggregation as well as aggregate associated carbon; and (3) Legume based cropping systems may be more sustainable than cereal based cropping systems in terms of soil quality and yield. In view of the above hypothesis, the present study was initiated to assess the effect of fertigation in rice based cropping systems on soil organic carbon pools and yield of different crops in six cropping sequences followed in the middle Indo-Gangetic plains.

Materials and methods

Experimental site

This study was a part of an on-going experiment of fertigation on the growth and productivity in rainfed rice based cropping systems. It was initiated in June, 2014. The present investigation was conducted during the fourth rice crop in the system kharif (May-October) 2017. The experiment is located at the research farm of Bihar Agricultural College, Sabour, Bhagalpur, Bihar in the Middle Gangetic plain region (24° 13′ 45″ N latitude, 87° 02′ 48″ E longitudes, 25 m above mean sea level) in the sub-humid climate zone and texture is sandy loam alluvium for both surface and sub-surface layers. The study area is located in sub-tropical climatic conditions commonly associated with hot humid summer during the kharif season, cold during rabi season (November to April) and normal rainfall. The maximum temperature of 35–39°C is observed in kharif season and the minimum temperature varies from 5 to 10°C in the rabi season. The average annual rainfall is 1231 mm and is mostly received as South West monsoon kharif season. The detailed weather data of crop period is given in the Figure 1.

Common cultural practices adopted for rice cultivation

After the harvest of rabi season crops in 2016-17, the field was left fallow during summers and treated with a spray of glyphosate @ 1 kg a.i. ha⁻¹ + 2,4-D @ 1 kg a.i. ha⁻¹ for clearing the standing weeds in the experimental field. The seeds of rice variety Sahbhagi Dhan were drilled in rows 30 cm apart @ 30 kg ha⁻¹ along with calculated amounts of muriate of potash and single super phosphate based on the general recommended dose of 40 kg P₂O₅ ha⁻¹ and 20 kg K₂O ha⁻¹ for rainfed rice and N application mentioned below in another section. All visible weed plants were manually uprooted as and when observed in the experimental field. The harvesting of the crop was done from the base of the stem, keeping the net plot harvest separated from the border areas, sun dried for 4–5 days, weighed and threshed to estimate the grain and straw yield.

Treatments and experimental details

The experiment on fertigation in zero till direct-seeded rice based cropping systems was laid out in a split design with three fertigation treatments in rice as the main plots: W₁-N @ 20 kg ha⁻¹ in rice through fertigation followed by 200 mm irrigation in post rice crops, W₂-N @ 40 kg ha⁻¹ in rice through fertigation followed by 300 mm irrigation in post rice crops W₃-N @ 60 kg ha⁻¹ in rice
through fertigation followed by 400 mm irrigation in post rice crops. The six zero till direct-seeded crops of durum wheat, barley, chickpea, lentil and lathyrus constituted the sub-plots. All the treatments were replicated three times. Nitrogen was applied as urea @ 75%, 50% and 25% of the rainfed recommended dose of fertilizer (RDF) of 80 kg ha$^{-1}$ in the respective treatments (i.e. 60, 40 and 20 kg ha$^{-1}$ N, respectively). Nitrogen was applied in three split doses. One third of the respective dose of nitrogen was drilled along with the P and K fertilizers before sowing of seeds in the rows. The other two split doses of nitrogen were applied through fertigation at the time of panicle initiation and active tillering respectively. The size of each sub-plot was 4.0 m$^2$ and was separated from the surrounding plots by a bund measuring 0.5 m in width. All crop rows were spaced 30 cm apart and drip laterals of an inline fertigation system were laid out 60 cm apart so that each lateral catered to fertigate one crop row on each side.

Soil sampling and analysis

Soil sampling

Soil samples were collected randomly in triplicate from all plots from the depths 0–15 cm, 15–30 cm and 30–45 cm using a post hole auger after the harvest of rice crop. A composite sample representative of each plot depth wise was prepared by mixing the samples of respective depth. Immediately after collection, part of the composite soil sample of each plot was air dried and ground to pass through a 2 mm sieve for the determination of SOC. The remainder of the sample was stored in a refrigerator at 4 °C for the analysis of soil aggregation, aggregate associated carbon and soil carbon pools. Two undisturbed soil cores for three depths (0–15 cm, 15–30 cm and 30–45 cm) were also collected using a core samples from each plot for measuring bulk density.

Soil analysis

i. Oxidizable organic carbon (OXC) was determined by wet digestion method [24]

ii. Soil organic carbon (SOC) in soil was estimated using a CHNS analyzer (Model- Euro Vector) applying the principle of dry combustion.

iii. OXC content was apportioned into different active carbon pools by the modified Walkley-Black method as explained by [25] oxidizing with graded strength of sulphuric acid of 12.0, 18.0 and 24.0 (in normality). Four different carbon pools were:

iv. Very labile pool (Pool I)-OXC oxidized by 12.0 N H$_2$SO$_4$

v. Labile pool (Pool II)-Difference in OXC oxidized by 18.0 N H$_2$SO$_4$ and 12.0 N H$_2$SO$_4$

vi. Less labile pools (Pool III)-Difference in OXC oxidized by 24.0 N H$_2$SO$_4$ and 18.0 N H$_2$SO$_4$

vii. Non-labile pool (Pool IV)-Difference in SOC and OXC oxidized by 24.0 N H$_2$SO$_4$.

viii. Bulk density was estimated by using the core sampling method [26]
Aggregates size distribution and aggregate associated carbon

Aggregates size distribution of soil was carried out by wet sieving method [27]. A 50 g air-dried soil clod (aggregate size less than 8000 µm) was put into a nest of sieves having diameter 2000 µm, 250 µm, 53 µm and wet sieved for 10 min. Each size aggregates wet dried at 40 °C and weighted.

Mean weight diameter (MWD) of the aggregates was estimated by the equation [28,29]:

\[
MWD = \sqrt[n]{\frac{\sum_{i=1}^{n} X_i Wi}{\sum_{i=1}^{n} Wi}}
\]

Where, \(X_i\) is the mean diameter of any particular size range of aggregates separated by sieving, and \(Wi\) is the weight of the aggregates in that size range as a fraction of the total dry weight of the sample analyzed.

The geometric mean diameter (GMD) of the aggregates was calculated by the equation [29]:

\[
GMD = \exp\left[\left(\frac{1}{n}\sum_{i=1}^{n} Wi \log X_i\right) - \left(\frac{1}{n}\sum_{i=1}^{n} Wi\right)\right]
\]

Each size aggregates were ground and passed through 0.25 mm sieve and aggregate associated carbon was determined by trapping the evaluated carbon dioxide after wet oxidation method [30].

i. Soil organic carbon stock

The SOC was calculated using the formula proposed by [31].

\[
\text{SOC stock} \ (\text{Mg ha}^{-1}) = \frac{\text{SOC} \ (\text{g kg}^{-1}) \times \text{Bulk density} (\text{Mg m}^{-3}) \times \text{soil depth (m)} \times 10}{\text{GMD}^{\frac{1}{2}}}
\]

Statistical analysis

The data generated from the study was analyzed for ANOVA for split plot design. The mean and standard error was calculated and the treatments were compared using least significant difference at 5% probability [32]. Correlation and regression analysis among treatments was carried using MS EXCEL.

Results

Bulk density (BD) and soil organic carbon (SOC)

Data shown in the Table 1 shows that fertigation and cropping systems did not significantly \((p \leq 0.05)\) influence the BD. The highest values of BD were recorded in the surface soil (0–15 cm) and in the fertigation treatment W1 followed by W2 and the lowest in W3. Similar trend was observed in two subsurface soil layers (15–30 cm and 30–45 cm). Bulk density was the highest in C1 (rice-durum wheat) in all the soil depths and the lowest in C6 (rice-lathyrus) treatments at the soil depth 0–15 cm, C2 (rice-barley), C3 (rice-linseed) and C4 (rice-chickpea) in the soil depth 15–30 cm and C3 (rice-linseed) in the soil depth 30–45 cm. Combined effect of fertigation levels and cropping systems was found non-significant for BD (Table 1).

The data listed in Table 1 shows that in surface soil (0–15 cm) the highest SOC was found in the treatment W1 which was at par with the treatment W2. The SOC value was significantly lower in the treatment W1 in the surface soil. Similar trend was observed in two subsurface soil layers. Among the cropping systems, C4 (rice-chickpea) accumulated the highest SOC, which was at par with C5 (rice-linseed) and C6 (rice-lathyrus) and significantly higher than C1, C2 and C5 (rice-lentil). Treatment C2 (rice-barley) recorded significantly lower SOC content than treatments C3, C4, C5 and C6 in the surface soil (0–15 cm). Non-significant differences among the subplots treatments were observed at 15–30 cm, however in the soil depth 30–45 cm C4 accumulated the highest SOC, which was recorded significantly higher than all other treatments. Combined effect of fertigation levels and cropping systems was found significant for SOC in the soil depths 0–15 cm and 15–30 cm and non-significant in the soil depth 30–45 cm (Table 1).

| Depth (cm) | BD (Mg m\(^{-3}\)) | SOC (g kg\(^{-1}\)) |
|-----------|--------------------|-------------------|
| 0-15      | 1.52, 1.48         | 5.95, 6.73        |
| 15-30     | 1.51, 1.48         | 6.47, 7.33        |
| 30-45     | 1.51, 1.48         | 7.33, 8.13        |
| LSD(p ≤ 0.05) | NS, NS          | NS, NS           |

W1 = N @ 20 kg/ha in rice through fertigation followed by 200 mm irrigation in post-rice crops, W2 = N @ 40 kg/ha in rice through fertigation followed by 300 mm irrigation in post-rice crops, W3 = N @ 60 kg/ha in rice through fertigation followed by 400 mm irrigation in post-rice crops, C1 = Rice-Durum Wheat, C2 = Rice-Barley, C3 = Rice-Linseed, C4 = Rice-Chickpea, C5 = Rice-Lentil, C6 = Rice-Lathyrus.
There was a significant variation in the very labile and labile carbon in different soil depths whereas less labile and non-labile fractions of carbon were not influenced significantly either by fertigation or cropping systems (Table 2). The highest very labile carbon content was found in the treatment having fertigation with W3 followed by W2 and the lowest in treatment W1 in the soil depths 0–15 cm and 15–30 cm while in the soil depth 30–45 cm very labile carbon was highest in the treatment having fertigation with W1 followed by W3 and the lowest in treatment W2.

In the soil layer 0–15 cm, the highest very labile carbon fraction was found in the cropping system C3 which was at par with C4 and C5. The lowest value was observed in the C1. In case of labile carbon fraction, the highest value was in C6 which was significantly higher than C4, C1, and C5. However the lowest value was recorded in C3. There was non-significant effect of cropping systems on less labile and non-labile carbon fractions (Table 2).

In the 15–30 cm soil layer, the highest very labile fraction was recorded in C6 which was at par with C1 and C2. The lowest value was obtained in C5. In labile carbon fraction the highest value was in C2 which was significantly higher than C1 and at par with C3, C4, C5 and C6. There was non-significant effect of cropping systems on less labile and non-labile carbon fractions (Table 2). In the 30–45 cm soil layer, the highest very labile fraction was recorded in C6 which was at par with C1 and C2. The lowest value was obtained in C4. There was non-significant effect of cropping systems on less labile and non-labile carbon fractions (Table 2). Fertigation levels and cropping systems together did not cause any significant variation in soil carbon pools.

Soil aggregation

Soil aggregation was significantly (p ≤ 0.05) influenced by the fertigation level and rice based cropping systems. The contribution of microaggregate (<53μm and 53–250 μm) was higher than the macroaggregate (>250 μm) irrespective of soil depths (Table 3). The contribution of macro and micro aggregate was varied from 12–20% and 80–88%, respectively from 0–45 cm soil depth. The resulting fractions of microaggregate were 1.13–3.98 times higher than the macroaggregate among the fertigation management practices whereas cropping systems resulted the fraction of microaggregate by 1.13–3.59 times higher than the macroaggregate in 0–45 cm soil depth. At 0–15 cm soil depth, the highest mean weight diameter was found in the treatment W3 and the lowest was in the treatment W1. Similar pattern was found in the 15–30 and 30–45 cm soil layers (Table 3).

Among the cropping systems, C4 recorded the highest MWD and GMD in the 0–15 cm soil depth and the lowest in C1 (Table 3). However, there was non-significant effect of cropping systems on soil aggregation in soil depths. Fertigation levels and cropping systems together caused a significant variation in soil aggregations (Table 3).

Aggregate associated carbon

The data shown in the Table 4 depicted significant variations in aggregate associated carbon content as influenced by the fertigation levels and cropping systems. Soil carbon content was increased with aggregate size. Maximum carbon content was found in the 2000–5000 μm fraction and it was 3.22–4.22 (in 0–15 cm soil layer), 1.84–4.20 (in 15–30 cm soil layer) and 3.43–6.62 (in 30–45 cm

### Table 2. Effect of fertigation and cropping systems on soil carbon pools in rice based cropping systems.

| Depth (cm) | Very Labile | Labile | Less Labile | Non Labile | Very Labile | Labile | Less Labile | Non Labile | Very Labile | Labile | Less Labile | Non Labile |
|------------|-------------|--------|-------------|------------|-------------|--------|-------------|------------|-------------|--------|-------------|------------|
| 0-15       |             |        |             |            | 1.67        | 1.48   | 1.32        | 2.42       | 2.63        | 1.92   | 1.49        | 1.53       |
|            | W1          | 1.44   | 1.86        | 1.66       | 2.03        |        |             |            |             |        |             |            |
|            | W2          | 2.63   | 1.38        | 1.43       | 2.29        |        |             |            |             |        |             |            |
|            | W3          | 2.94   | 1.21        | 0.76       | 2.51        |        |             |            |             |        |             |            |
|            | LSD (p < 0.05) | 0.99   | 0.29        | 0.72       | NS          |        |             |            |             |        |             |            |
| 15-30      |             |        |             |            | 1.65        | 1.08   | 1.46        | 1.51       | 1.33        | 0.44   | 0.76        | 0.99       |
|            | W1          | 1.44   | 1.86        | 1.66       | 2.03        |        |             |            |             |        |             |            |
|            | W2          | 2.63   | 1.38        | 1.43       | 2.29        |        |             |            |             |        |             |            |
|            | W3          | 2.94   | 1.21        | 0.76       | 2.51        |        |             |            |             |        |             |            |
|            | LSD (p < 0.05) | 0.99   | 0.29        | 0.72       | NS          |        |             |            |             |        |             |            |
| 30-45      |             |        |             |            | 1.65        | 1.08   | 1.46        | 1.51       | 1.33        | 0.44   | 0.76        | 0.99       |
|            | W1          | 1.44   | 1.86        | 1.66       | 2.03        |        |             |            |             |        |             |            |
|            | W2          | 2.63   | 1.38        | 1.43       | 2.29        |        |             |            |             |        |             |            |
|            | W3          | 2.94   | 1.21        | 0.76       | 2.51        |        |             |            |             |        |             |            |
|            | LSD (p < 0.05) | 0.99   | 0.29        | 0.72       | NS          |        |             |            |             |        |             |            |

**W1** = N @ 20 kg/ha in rice through fertigation followed by 200 mm irrigation in post-rice crops, **W2** = N @ 40 kg/ha in rice through fertigation followed by 300 mm irrigation in post rice crops, **W3** = N @ 60 kg/ha in rice through fertigation followed by 400 mm irrigation in post-rice crops; **C1** = Rice-Durum Wheat, **C2** = Rice-Barley, **C3** = Rice-Linseed, **C4** = Rice-Chickpea, **C5** = Rice-Lentil, **C6** = Rice-Lathyrus.
Table 3. Effect of fertigation and cropping systems on soil aggregation in rice based cropping systems.

| Aggregate size fraction (µm) | Treatment | 0-15 | 15-30 | 30-45 |
|-----------------------------|-----------|------|------|------|
| W1                          | 0-15      | 1.83 | 0.60 | 0.60 |
| W2                          | 15-30     | 1.86 | 2.00 | 2.14 |
| W3                          | 30-45     | 3.58 | 2.74 | 8.10 |
| LSD (p ≤ 0.05)              |           | 0.14 | 0.44 | 0.49 |

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Correlation coefficients between yield aggregate size and soil carbon pools

| Correlation coefficients between yield aggregate size and soil carbon pools | Soil carbon stock |
|--------------------------------------------------------------------------|------------------|
| Grain yield and straw yield                                              | SOC stock (µg)    |
| Grain yield and straw yield                                              | SOC stock (µg)    |
| Grain yield and straw yield                                              | SOC stock (µg)    |
| Grain yield and straw yield                                              | SOC stock (µg)    |
| Grain yield and straw yield                                              | SOC stock (µg)    |
| Grain yield and straw yield                                              | SOC stock (µg)    |

The data presented in Figure 3 revealed that grain and straw yields were significantly correlated with SOC stock (µg) in C1, C2, C3, C4, C5, and C6. The trend was observed in different soil depths. Soil carbon stock (µg) was highest in C1 (rice-Durum Wheat), C2 (rice-barley), C3 (rice-linseed), C4 (rice-chickpea), C5 (rice-lentil), and C6 (rice-lathyrus).
aggregate size and associated carbon (Table 6 and Figures 4 and 5) revealed that weight of aggregate size between >2000 μm, 2000–250 μm and <53 μm were significantly correlated with associated carbon (0.419*, 0.451** and 0.455*, respectively) and weight of aggregate size obtained in between 250–53 μm were significantly and negatively correlated with associated carbon (r = -0.77**).

Discussion

Effect of fertigation and rice based cropping systems on SOC

The cereals crops have a deeper root system than legume crops and in the present study, the roots remained undisturbed due to absence/reduced tillage. Zero tillage facilitates slowing of SOC decomposition resulting in its short term accumulation in deeper root zones i.e. in 15–30 cm soil layer. This effect was not so prominent in the still deeper soil layer (30–45 cm) due to absence of sufficient root biomass in that zone and soil factors might have come into play. At the depth of 30–45 cm, significantly higher SOC was found in the rice-lentil cropping. This could be due to more biological fixation of nitrogen and low water use in lentil, which allowed more decomposition of organic matter and its movement down the profile with water applied through fertigation. [33] reported that after third year of direct seeded rice with brown manuring followed by zero tilled wheat, there was a significantly higher gain in SOC in the 0–30 cm soil layer than other treatments. The application of balanced mineral fertilizers (NPK) significantly increased SOC content by increasing the accumulation of root biomass in soil over time [34].
increase in SOC content during the study is, therefore attributed to improved soil aggregation especially higher proportion of macroaggregates under zero till.

Although significant effects of difference rice based cropping systems were observed during the analysis of soil samples drawn before establishment of rice crop, these have not translated into any significant differences in bulk density across various cropping systems. Profuse plant root development in soils tends to produce soils with a higher bulk density [35]. However, in the present study, the differences in root profuseness expected under various cropping systems are not reflected in the bulk density measurements that have been taken only after the harvest of the rice crop. It is likely that the differences might be prominent after the harvest of the rabi (winter) season crops. [36] reported from a short-term (3 years) study that some changes in soil properties may not actually stay over a long-period, but could be indicator of the direction of changes. The lack of significant effects on such soil properties may also be due to high field variability and short duration under these cropping systems and fertigation regimes. [37] also reported that the lack of significant effects of cover crops on some soil properties could be due to high field variability and short duration under cover cropping.

**Effect of fertigation and rice based system on soil carbon pools and yield**

Rotating different crops after rice on a long-term basis affects SOC dynamics [13]. Several studies

**Figure 3. Effect of fertigation(a) and cropping systems (b) on Grain and Straw yield in rice based cropping systems**

\[
\begin{align*}
\text{LSD (p<0.05) Grain yield = 270, Straw yield = 301} \\
\end{align*}
\]

| Aggregate size | Aggregate associated carbon |
|----------------|-----------------------------|
| >2000          | 0.419*                      |
| 2000-250       | 0.451*                      |
| 250-53         | -0.773**                    |
| <53            | 0.455*                      |

*Significant at 0.05 and 0.01 probability levels, respectively.

**Table 6. Correlation between Soil aggregate size and associated carbon in rice based cropping systems.**

| Aggregate size | Aggregate associated carbon |
|----------------|-----------------------------|
| >2000          | 0.419*                      |
| 2000-250       | 0.451*                      |
| 250-53         | -0.773**                    |
| <53            | 0.455*                      |

*Significant at 0.05 and 0.01 probability levels, respectively.

**Figure 4. Effect of soil carbon concentration on soil aggregation influenced by fertigation and cropping system.**

**Table 5. Correlation between Yield, Aggregate size and soil carbon pools in rice based cropping systems.**

| Grain  | Very Labile | Labile | Less Labile | Non Labile | MWD  | GMD  | TOC  |
|--------|-------------|--------|-------------|------------|------|------|------|
| Grain  | 1.00        |        |             |            |      |      |      |
| Very Labile | 0.12        | 0.89** | 0.53**      | 0.45*      |      |      |      |
| Labile | -0.63**     | 0.91** | 0.48*       | 0.36       | 0.36 | 0.91**| 1.00 |
| Less Labile | -0.36       | 0.20   | 0.19        | 0.33       | 0.18 | 0.18 | 1.00 |
| Non Labile | 0.09        | 0.36   | 0.40*       | 0.20       | 0.32 |      |      |
| MWD    | 0.17        | 0.91** | 0.78**      | 0.57**     |      |      |      |
| GMD    | 0.12        | 0.31   | 0.48*       | 0.19       | 0.33 | 0.91**| 1.00 |
| TOC    | 0.20        | 0.91*  | 0.82**      | 0.91       | 0.18 | 0.18 | 1.00 |

*Significant at 0.05 and 0.01 probability levels, respectively.
suggest that cropping system and soil depth affect lability of carbon and it has been reported that the very labile forms, which are most easily oxidizable are changed rapidly with soil depth and the cropping system followed [38,39]. The results obtained from the study were found to be agreement with these studies. Very labile and labile carbon fractions were affected with management practices, soil depth and cropping systems. A small variability in other fractions like less and non-labile carbon was observed and it represents less sensitivity of these fractions to changes with soil depth, cropping system and management practices. Similar results were recorded by [25] who reported that in case of pastures the difference was observed mostly in very labile fractions as compared to other fractions. [40] reported similar findings in soya bean-wheat, soya bean-pigeon pea maize-chickpea and maize-pigeon pea cropping systems.

Use of legume crops in the cropping system along with fertilizer management improves the build-up of SOC in the soil. Legumes fix the atmospheric nitrogen in the soil and further improve the subsequent crop yield as well carbon status in the soil [41–43]. Soil organic carbon and yield were increased by two times on long-term basis following cropping system with legumes [44,45]. Under submerged conditions SOC is build up contributes toward labile fraction of carbon [46].

Effect of fertigation and rice based cropping system on soil aggregation and associated carbon

The contribution of microaggregate (53–250 μm) was higher than the macroaggregate (>250 μm) irrespective of soil depth. SOC content increased with aggregate size; maximum SOC content was found in the >2000 μm fractions while the highest aggregate associated carbon was found in rice-chickpea cropping system which was at par with the rice-lentil and rice-lathyrus cropping system. SOC is known as the main factor influencing soil aggregation and its stability [20–22,47]. Studies suggest either minimum/reduced or zero tillage has positive influence on soil aggregates and reduction in oxidation of soil organic matter (SOM) owing to minimal soil disturbance [48–52]. The macroaggregates (>0.25 mm) provide a healthier physical safeguard to SOM and are known as the best predictor of possible carbon responses to tillage and residue management practices [51,53,54]. Researchers have found that carbon gets incorporated in the macroaggregate in the soil first and then form the new microaggregate [22,27,50–53,55,56]. This physical safeguard of carbon in macroaggregate confines the oxidation [57] by generating a less supporting environment for microbial activities [58] and this can slow down the decomposition rate [57,59]. In the present study similar results were found regarding
improvement of the soil aggregation and aggregate stability.

Soils under minimum or zero tillage system had higher SOC stock than conventional tillage system [60]. As the aggregate class size decreases, non-labile fraction increases. The significant higher quantities of macroaggregate-associated carbon advocate slower turnover rates of macroaggregates resulting from reduced soil disturbance [39]. In this study, a significant higher quantity of SOC mostly associated with small macroaggregates indicates slower turnover under zero tillage practice, resulting in the formation and stabilization of fine intra-aggregate carbon particles. The augmented SOC can be seen as a potential indicator of improved carbon build-up [51,61] that significantly influences system productivity.

Conclusion

The effect of fertigation and rice based cropping systems on BD was found to be non-significant but SOC was significantly improved on the followed management practice. There was increase in the percentage of soil macroaggregates and associated carbon and SOC stock due to following fertigation and legume based cropping system. On an overall basis it was found that nitrogen @ 60 kg ha$^{-1}$ in rice through fertigation followed by 400 mm irrigation in post-rice crop and rice-lathyrus cropping system recorded better response in zero till direct seeded rice based cropping systems.

Disclosure statement

No potential conflict of interest was reported by the authors.

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