



## Long-term impact of organic and conventional farming on soil physical properties under rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system in north-western Indo-Gangetic plains

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### ABSTRACT

Long-term (13 years) impact of organic and conventional farming on soil physical properties was evaluated under a rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) cropping system in a sandy clay loam soil at New Delhi. The treatments included unfertilized control (T<sub>1</sub>), conventionally managed (T<sub>2</sub>) and five organic treatments (T<sub>3</sub>: FYM @ 10 t/ha to rice and wheat, T<sub>4</sub>: SGM for rice and LGLM for wheat, T<sub>5</sub>: SGM + BGA for rice and LGLM + *Azotobacter* for wheat, T<sub>6</sub>: SGM + FYM for rice and LGLM + FYM for wheat, and T<sub>7</sub>: SGM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat). The application of organic amendments had positive influence on soil physical properties such as saturated hydraulic conductivity (K<sub>s</sub>), field capacity (FC) and permanent wilting point (PWP), plant-available water capacity (PAWC), water holding capacity (WHC), distribution of aggregate size fractions, bulk density (D<sub>b</sub>), and porosity in the 0-15 and 15-30 cm soil layer. A favourable effect of organic amendments was also found on soil strength (at depth 0-70 cm). Even, values related to these properties were significantly affected by the kinds of organic amendments. But, T<sub>1</sub> and T<sub>2</sub> had no improvement in soil physical properties over the organic ones. Value of K<sub>s</sub> decreased with increase in soil depths. T<sub>7</sub> and T<sub>3</sub> were superior in K<sub>s</sub> to other treatments for 0-15 and 15-30 cm soil depths. Volumetric moisture content at FC ( $\theta_{FC}$ ) and PWP ( $\theta_{WP}$ ) increased with addition of organic amendments and got varying response due to the kinds of organic amendments or their combinations.  $\theta_{FC}$  and  $\theta_{WP}$  were decreased substantially under T<sub>1</sub> and T<sub>2</sub>, because of no addition of organic inputs. As a result of  $\theta_{FC}$  and  $\theta_{WP}$ , PAWC had also signified an improvement under the influence of different organic amendments over T<sub>1</sub> and T<sub>2</sub>. Generally (for both depths), PAWC of T<sub>3</sub>, T<sub>6</sub> and T<sub>7</sub> were 17-26% more than T<sub>1</sub>, T<sub>2</sub>, T<sub>4</sub> and T<sub>5</sub>. WHC of upper soil layer (0-15 cm) was greater for organic amended plots than plots devoid of organic inputs and lower values were recorded for 15-30 cm soil layer. WHC of T<sub>3</sub>, T<sub>7</sub> and T<sub>6</sub> was highest in comparison to plots amended only with (without FYM) green manure, BGA or *Azotobacter* as well as T<sub>1</sub> and T<sub>2</sub> for both depths (0-15 and 15-30 cm). A better soil aggregation was observed under organic amended plots for large and small macro-aggregates (LM - >2 and SM-0.25-2 mm) in both soil depths. Lowest value of D<sub>b</sub> with highest percentage of pore space was noted under T<sub>7</sub> than other treatments in both soil layers. Soil strength was significantly lower in organic amended plots than T<sub>1</sub> and T<sub>2</sub>. This study clearly indicated that application of organic inputs especially FYM, improved the soil physical properties, which resulted in better soil aggregation, porosity and soil moisture retention.

**Key words:** Organic and conventional farming, Rice-wheat cropping system, Soil physical properties

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) is the most prominent cropping system of South-Asia occupying around 13.5 Mha area of the Indo-Gangetic

plains of India and parts of Pakistan and Bangladesh (Ghosh *et al.* 2016a, Arshad *et al.* 2017). This cropping system provides food to nearly 15% population, i.e. more than 1 billion people of the world (Sah *et al.* 2014). Generally, the productivity of irrigated rice-wheat system is high on account of availability of irrigation water and application of more amounts of fertilizers to it. However, the stability (consistency in production) of the system is at stake due to the reliability of irrigation system. In the same way, sustainability (maintaining a production level over a long term) of irrigated rice-wheat cropping system currently is at risk because of salinization, the incidence of pests or diseases, deterioration of soil physical properties, soil erosion etc. In the recent years, productivity losses occur in the

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rice-wheat system is due to the effect of climate variability such as high temperature, floods, droughts and unexpected extreme events of weather (Lobell *et al.* 2012). In addition to this, a disparity in fertilization, discontinuation of the use of organic manures, monocropping, etc. are responsible for losses in productivity of this cropping system. Along with crop productivity, the nutritional quality of the food grains is also affected.

The dependency of this system has been shifted from organic to inorganic fertilizer inputs mostly after green revolution. This led to upset the self-sufficiency (autonomy) of rice-wheat system. In order to enhance production, the farmers have stressed only on macro-nutrients without paying attention to add micro-nutrients and organic manure, causing imbalanced fertilization (Sihl *et al.* 2017). The consequence of reckless use of mineral fertilizers adversely affected soil physicochemical properties, which ultimately hampered the productivity of the rice-wheat cropping system (Kakraliya *et al.* 2017). A large amount of pesticides has been used in rice-wheat system that becomes a non-point source of pollution contaminating soil and water bodies (surface as well as ground water). Of late, these agrochemicals (fertilizers, pesticides, growth hormones etc.) have become contaminants. This is an emerging concern (Glassmeyer *et al.* 2017) that poses a health risk to either human or other organisms (Stuart *et al.* 2012). In this way, such conventionally managed rice-wheat agroecosystem is responsible for increasing environmental problems.

In making difference with conventionally grown cropping system (e.g. rice-wheat), organically managed system is environmentally very sound and facilitates production of crop produce in a safe way (Sihl *et al.* 2012). Organic food contains more amounts of anti-oxidants and very less or negligible quantity of pesticides (Barański *et al.* 2014). This is the reason behind a great value to organic food compared to the food produced from conventionally grown crops. Organic system is eco-friendly because this system keeps balance with nature by promoting below as well as above ground biodiversity, and does not show any negative impact on environment. The application of naturally occurring organic material to the field enriches all essential nutrients that also assists in optimizing deficient nutrient level in soils. Organic amendment also helps to build up soil organic matter, thus increases organic carbon which improves soil aggregation and its stability, reduce soil compaction, increase porosity and water holding capacity.

In rice-wheat system, puddling operation is one of the major constrains for ideal soil structures and is responsible for breakdown of soil aggregates, causes soil compaction with less numbers of pore spaces. Due to soil compaction, a root growth and density of the succeeding crop like wheat is hampered. It is impossible to avoid puddling operation, therefore, it is hypothesized that naturally occurring organic inputs possibly minimize such constrains up to some extent by retaining structural quality of soil. Therefore, an experiment was performed to study the long-term impact of organic and conventional nutrient management on physical

properties of soils under rice-wheat system.

## MATERIALS AND METHODS

A field experiment was carried out during 2014-15 and 2015-16 in an ongoing long-term organic and conventional experiment conducted since 2003 at the Experimental Farm of the ICAR-Indian Agricultural Research Institute, New Delhi (situated at 28° 38'23"N latitude, 77° 09'27"E longitude and at an altitude of about 228.6 m above mean sea level). The plots under conventional (applied only recommended dose of NPK) treatment were selected from neighbouring field with rice-wheat cropping system. The climate of the New Delhi is characterized as sub-tropical, semi-arid condition with hot summer and short period of severe winter. The soil type of the organic and conventional experimental field was sandy clay loam (*Typic Ustochrept*). A composite soil sample of the whole experimental plot had pH 8.16, oxidizable organic carbon (OC) 0.71% and mineralizable N, available P and available K were 271.9, 19.73 and 381.45 kg/ha, respectively. Whereas, conventionally managed plots had pH 8.25, OC 0.63%, and, mineralizable N, available P and available K were 193.5, 14.7 and 369.3 kg/ha, respectively. The soil (mean value of organic and conventional field) is having 51.51% sand, 23.63% silt and 24.86% clay in 0-15 cm soil depth, whereas 51.43% sand, 24.52% silt and 24.05% clay in 15-30 cm depth of soil. Details of different treatment combinations are given in Table 1.

In the beginning, this organic farming experiment was started with rice-wheat cropping system and is continuing till now. Varieties of rice and wheat used for sowing were Pusa Basmati-1 and HD-2967, respectively. A well-decomposed FYM was distributed evenly at 10 t/ha in the concerned treatment plots after preparation of final layout, but before transplanting of rice and sowing of wheat crop. *Sesbania aculeata* was grown in plots with *Sesbania* green manure (SGM) treatment and incorporated at 20 t/ha. *Sesbania* was buried into the soil at about 40% flowering with the help of a tractor drawn disc plough, but prior to

Table 1 Treatment details of long-term field experiment

Treatment code	Details of fertilization
T <sub>1</sub>	Unfertilized (control)
T <sub>2</sub>	Recommended dose of N, P and K through mineral fertilizer (Conventionally managed)
T <sub>3</sub>	FYM @ 10 t/ha to rice and wheat
T <sub>4</sub>	SGM for rice and LGLM for wheat
T <sub>5</sub>	SGM + BGA for rice and LGLM + <i>Azotobacter</i> for wheat
T <sub>6</sub>	SGM + FYM for rice and LGLM + FYM for wheat
T <sub>7</sub>	SGM + FYM + BGA for rice and LGLM + FYM + <i>Azotobacter</i> for wheat

FYM - Farmyard manure, SGM - *Sesbania* green manuring, LGLM - *Leucaena* green leaf manuring and BGA - Blue green algae

rice transplanting. Tender twigs of *Leucaena leucocephala* (*Subabul*) were manually collected from the area near the experimental field and incorporated at 5 t/ha in the field for wheat crop. *Leucaena leucocephala* green leaf manure (LGLM) was incorporated 20 days before wheat sowing. Four type of blue-green algae (BGA) strains like *Aulosira fertilissima*, *Tolypothrix tenuis*, *Anabaena variabilis* and *Nostoc muscorum* were taken from the National Centre for Conservation and Utilization of Blue Green Algae, IARI, New Delhi. BGA strains were mixed with multani mitti (Fuller's earth) to form a culture. This culture was applied uniformly at 2.5 kg/ha to BGA treatment plots for rice crop 10 days after transplanting (DAT). *Azotobacter chroococcum* strain were obtained from the Division of Microbiology, IARI, New Delhi. Seeds of wheat were treated with *Azotobacter chroococcum* before sowing in the associated treatment plots. Control plots remained unfertilized without any kind of organic amendments since 2003 (starting of experiment). Conventionally grown plots with rice-wheat cropping system were kept away from organic field and also managed in the same way as an organic system. These plots were fertilized with 120(N):60(P):50(K) and 120(N):60(P):40(K) kg/ha for rice and wheat respectively, using same varieties as in case of organic system. Rice was transplanted after 15 July and wheat was sown after 15 November every year. Ploughing was done with the help of tractor drawn disc plough, nearly upto 15 cm depth for both crops before their sowing. Individual plot size was 25 m<sup>2</sup> (5 × 5 m) for both organic and conventional system. Soil samples were collected for analysis after wheat harvest during both years (2014-15 and 2015-16).

*Methodologies employed for analysis of soil physical properties:* Representative soil samples were collected separately from each treatment in triplicate. Soil samples were collected from 0-15 and 15-30 cm depth of soil with the help of core sampler to collect undisturbed soil sample for bulk density ( $D_b$ ), saturated hydraulic conductivity ( $K_s$ ), whereas 2 mm sieved soil samples were used for water holding capacity (WHC).  $D_b$  was calculated on the basis of oven dried (at 105 °C for 48 hours) weight of soil divided by its volume.  $K_s$  was analysed using constant head method (Reynolds and Elrick 2002), whereas WHC was determined by Keen Rackzowski box method (Viji and Rajesh 2012). Even, undisturbed soil samples using a core sampler were also collected for determining soil water content (SWC) at -33 kPa ( $\theta_{FC}$  - Soil water content at FC) and -1500 kPa ( $\theta_{WP}$  - Soil water content at PWP) using a pressure plate apparatus. Plant available water capacity (PAWC) of soil was obtained from the difference of FC and PWP moisture content. Soil aggregates were separated using a wet sieving method and these aggregates were divided into four sizes [Large macro-aggregates ( $LM$ ) - >2 mm, small macro-aggregates ( $SM$ ) - 0.25–2 mm, micro-aggregates ( $mi$ ) - 0.053–0.25 mm and 'silt + clay' sized aggregates ( $sc$ ) - <0.053 mm] using particular size sieves (Elliott 1986, Ghosh *et al.* 2016b). Soil porosity was calculated by using equation -  $100*[1-(\text{bulk density}/\text{partical density})]$ . Soil

strenght was measured using a penetrometer after wheat harvest. Observations of a penetrometer were taken when moisture content reached at field capacity.

*Statistical analysis of computed data:* Data of the soil parameters were statistically analysed with the aid of online software WASP 1.0 and Microsoft Excel (Windows 2008) using Randomized Block Design.

## RESULTS AND DISCUSSION

### *Impact on $K_s$ , $\theta_{FC}$ , $\theta_{WP}$ , PAWC and WHC*

Saturated hydraulic conductivity ( $K_s$ ), soil moisture content ( $\theta_{FC}$ ,  $\theta_{WP}$  and PAWC) and water holding capacity (WHC) of soil at 0-15 and 15-30 cm soil depth as affected by different treatments are presented in Table 2 and Table 3, respectively. It was observed that at 0-15 cm soil depth,  $K_s$  was highest under treatment  $T_7$  (SGM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat) in the year 2014-15 and 2015-16. These values were statistically similar with  $T_3$  and  $T_6$ . On the other hand, lower  $K_s$  values were registered for treatment  $T_1$ ,  $T_2$ ,  $T_4$  and  $T_5$  for both years (2014-15 and 2015-16). The overall (pooled) data showed that  $K_s$  values in treatment  $T_7$ ,  $T_3$  and  $T_6$  were more than that of  $T_1$ ,  $T_2$ ,  $T_4$  and  $T_5$  treatments. The value of  $K_s$  for  $T_7$  was 17.7 and 16.1% higher than  $T_1$  and  $T_2$  on the basis of pooled mean, respectively (Table 2). Similarly, plots treated with FYM markedly improved the  $K_s$  due to more organic matter content, increased biological activity, better soil aggregation, and optimum pore volume and the effective connectivity of the pores (Chakraborty *et al.* 2010, Rasoulzadeh and Yaghoubi 2014). In the same way,  $K_s$  values at 15-30 cm soil depth under  $T_7$ ,  $T_6$  and  $T_3$  were also more than other treatments. But, the overall values of  $K_s$  in the 15-30 cm layer were less in all treatments than that of 0-15 cm soil layer, owing to changes in soil separates especially clay and lower organic matter content and higher bulk density at lower layer.

Soil volumetric water content at field capacity ( $\theta_{FC}$ ) (-33 kPa) and permanent wilting point ( $\theta_{WP}$ ) (-1500 kPa) showed that addition of organic matter made a difference in all treatments. Additionally, type of organic matter also affected the soil water contents among organic treatments. The treatments like  $T_7$ ,  $T_6$  and  $T_3$  had better water contents at field capacity and permanent wilting point than  $T_1$ ,  $T_2$ ,  $T_4$  and  $T_5$  for both years in the 0-15 and 15-30 cm soil layer. Plots with FYM had higher soil water content than plots only with green manure plus blue green algae (BGA) or *Azotobacter* and without any organic matter in the both soil layers. Likewise, plant available water content (PAWC) was also more for those treatments which had FYM. Treatments containing green manure (SGM or LGLM) or green manure (SGM or LGLM) + BGA or *Azotobacter* had similar PAWC as that of control and conventionally grown plots. This could be due to more amounts of organic carbon in FYM containing plots and this supports more number of micro-pores, which is responsible for more amount of water retention. But, treatments with green manure without

Table 2 Long-term impact of organic and conventional rice-wheat cropping system on saturated hydraulic conductivity ( $K_s$ ), soil moisture or water content ( $\theta_{FC}$ ,  $\theta_{WP}$  and PAWC) and water holding capacity (WHC) in the 0-15 cm soil layer

Treatment	$K_s$ (cm/hr)				$\theta_{FC}$ ( $m^3/m^3$ )				$\theta_{WP}$ ( $m^3/m^3$ )				PAWC (cm/15 cm soil layer)				WHC (%)			
	2014-15	2015-16	Pooled		2014-15	2015-16	Pooled		2014-15	2015-16	Pooled		2014-15	2015-16	Pooled		2014-15	2015-16	Pooled	
T <sub>1</sub>	1.02 <sup>d</sup>	1.02 <sup>b</sup>	1.02 <sup>b</sup>	0.273 <sup>b</sup>	0.276 <sup>b</sup>	0.275 <sup>b</sup>	0.120 <sup>c</sup>	0.121 <sup>b</sup>	0.121 <sup>c</sup>	0.121 <sup>b</sup>	0.121 <sup>c</sup>	2.300 <sup>b</sup>	2.315 <sup>b</sup>	2.298 <sup>b</sup>	39.4 <sup>c</sup>	39.2 <sup>c</sup>	39.3 <sup>c</sup>			
T <sub>2</sub>	1.04 <sup>cd</sup>	1.03 <sup>b</sup>	1.04 <sup>b</sup>	0.287 <sup>b</sup>	0.274 <sup>b</sup>	0.281 <sup>b</sup>	0.121 <sup>c</sup>	0.122 <sup>b</sup>	0.122 <sup>c</sup>	0.122 <sup>b</sup>	0.122 <sup>c</sup>	2.500 <sup>b</sup>	2.285 <sup>b</sup>	2.385 <sup>b</sup>	40.4 <sup>bc</sup>	40.1 <sup>bc</sup>	40.3 <sup>bc</sup>			
T <sub>3</sub>	1.22 <sup>ab</sup>	1.24 <sup>a</sup>	1.23 <sup>a</sup>	0.324 <sup>a</sup>	0.326 <sup>a</sup>	0.325 <sup>a</sup>	0.129 <sup>a</sup>	0.128 <sup>a</sup>	0.129 <sup>a</sup>	0.128 <sup>a</sup>	0.129 <sup>a</sup>	2.927 <sup>a</sup>	2.960 <sup>a</sup>	2.943 <sup>a</sup>	45.2 <sup>a</sup>	45.6 <sup>a</sup>	45.4 <sup>a</sup>			
T <sub>4</sub>	1.09 <sup>c</sup>	1.06 <sup>b</sup>	1.08 <sup>b</sup>	0.283 <sup>b</sup>	0.287 <sup>b</sup>	0.285 <sup>b</sup>	0.122 <sup>c</sup>	0.123 <sup>b</sup>	0.123 <sup>c</sup>	0.123 <sup>b</sup>	0.123 <sup>c</sup>	2.415 <sup>b</sup>	2.455 <sup>b</sup>	2.430 <sup>b</sup>	41.8 <sup>b</sup>	42.1 <sup>b</sup>	42.0 <sup>b</sup>			
T <sub>5</sub>	1.08 <sup>cd</sup>	1.08 <sup>b</sup>	1.08 <sup>b</sup>	0.279 <sup>b</sup>	0.276 <sup>b</sup>	0.277 <sup>b</sup>	0.122 <sup>c</sup>	0.122 <sup>b</sup>	0.122 <sup>c</sup>	0.122 <sup>b</sup>	0.122 <sup>c</sup>	2.355 <sup>b</sup>	2.310 <sup>b</sup>	2.330 <sup>b</sup>	40.8 <sup>bc</sup>	42.2 <sup>b</sup>	41.5 <sup>b</sup>			
T <sub>6</sub>	1.17 <sup>b</sup>	1.19 <sup>a</sup>	1.19 <sup>a</sup>	0.326 <sup>a</sup>	0.320 <sup>a</sup>	0.323 <sup>a</sup>	0.127 <sup>b</sup>	0.128 <sup>a</sup>	0.128 <sup>a</sup>	0.128 <sup>a</sup>	0.128 <sup>a</sup>	2.980 <sup>a</sup>	2.880 <sup>a</sup>	2.925 <sup>a</sup>	44.8 <sup>a</sup>	45.8 <sup>a</sup>	45.3 <sup>a</sup>			
T <sub>7</sub>	1.24 <sup>a</sup>	1.25 <sup>a</sup>	1.24 <sup>a</sup>	0.323 <sup>a</sup>	0.316 <sup>a</sup>	0.320 <sup>a</sup>	0.130 <sup>a</sup>	0.129 <sup>a</sup>	0.130 <sup>a</sup>	0.129 <sup>a</sup>	0.130 <sup>a</sup>	2.895 <sup>a</sup>	2.805 <sup>a</sup>	2.848 <sup>a</sup>	44.8 <sup>a</sup>	45.9 <sup>a</sup>	45.4 <sup>a</sup>			
SEm $\pm$	0.020	0.023	0.020	0.273	0.007	0.004	0.0010	0.0014	0.0007	0.0014	0.0007	0.1251	0.1059	0.0680	0.608	0.798	0.618			
CD (P = 0.05)	0.061	0.070	0.061	0.02	0.021	0.013	0.0029	0.0041	0.0020	0.0041	0.0020	0.3770	0.3192	0.2049	1.833	2.405	1.862			

$K_s$  - Saturated hydraulic conductivity,  $\theta_{FC}$  - Soil water content at field capacity,  $\theta_{WP}$  - Soil water content at permanent wilting point, PAWC - Plant available water content and WHC - Water holding capacity. T<sub>1</sub>: Unfertilized control, T<sub>2</sub>: Conventionally managed, T<sub>3</sub>: FYM @ 10 t/ha to rice and wheat, T<sub>4</sub>: SGM for rice and LGLM for wheat, T<sub>5</sub>: SGM + BGA for rice and LGLM + *Azotobacter* for wheat, T<sub>6</sub>: SGM + FYM for rice and LGLM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat, and T<sub>7</sub>: SGM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat.

Table 3 Long-term impact of organic and conventional rice-wheat cropping system on saturated hydraulic conductivity ( $K_s$ ), soil moisture or water content ( $\theta_{FC}$ ,  $\theta_{WP}$  and PAWC) and water holding capacity (WHC) in the 15-30 cm soil layer

Treatment	$K_s$ (cm/hr)				$\theta_{FC}$ ( $m^3/m^3$ )				$\theta_{WP}$ ( $m^3/m^3$ )				PAWC (cm/15 cm soil layer)				WHC (%)			
	2014-15	2015-16	Pooled		2014-15	2015-16	Pooled		2014-15	2015-16	Pooled		2014-15	2015-16	Pooled		2014-15	2015-16	Pooled	
T <sub>1</sub>	0.92 <sup>b</sup>	0.90 <sup>c</sup>	0.91 <sup>d</sup>	0.237 <sup>c</sup>	0.232 <sup>c</sup>	0.235 <sup>c</sup>	0.115 <sup>cd</sup>	0.114 <sup>bc</sup>	0.115 <sup>d</sup>	0.114 <sup>bc</sup>	0.115 <sup>d</sup>	1.830 <sup>c</sup>	1.775 <sup>b</sup>	1.800 <sup>c</sup>	37.0 <sup>cd</sup>	35.6 <sup>c</sup>	36.3 <sup>c</sup>			
T <sub>2</sub>	0.94 <sup>b</sup>	0.95 <sup>bc</sup>	0.95 <sup>cd</sup>	0.242 <sup>bc</sup>	0.238 <sup>bc</sup>	0.240 <sup>c</sup>	0.114 <sup>d</sup>	0.113 <sup>c</sup>	0.114 <sup>d</sup>	0.113 <sup>c</sup>	0.114 <sup>d</sup>	1.920 <sup>c</sup>	1.865 <sup>b</sup>	1.885 <sup>bc</sup>	36.4 <sup>d</sup>	35.5 <sup>c</sup>	36.0 <sup>c</sup>			
T <sub>3</sub>	1.04 <sup>a</sup>	1.05 <sup>a</sup>	1.05 <sup>ab</sup>	0.284 <sup>a</sup>	0.289 <sup>a</sup>	0.287 <sup>a</sup>	0.123 <sup>ab</sup>	0.124 <sup>a</sup>	0.124 <sup>ab</sup>	0.124 <sup>a</sup>	0.124 <sup>ab</sup>	2.425 <sup>ab</sup>	2.475 <sup>a</sup>	2.443 <sup>a</sup>	42.8 <sup>a</sup>	42.3 <sup>a</sup>	42.6 <sup>a</sup>			
T <sub>4</sub>	0.96 <sup>b</sup>	0.99 <sup>ab</sup>	0.98 <sup>bcd</sup>	0.260 <sup>b</sup>	0.253 <sup>b</sup>	0.257 <sup>b</sup>	0.118 <sup>c</sup>	0.118 <sup>b</sup>	0.118 <sup>c</sup>	0.118 <sup>b</sup>	0.118 <sup>c</sup>	2.135 <sup>bc</sup>	2.030 <sup>b</sup>	2.080 <sup>b</sup>	39.4 <sup>b</sup>	38.5 <sup>b</sup>	39.0 <sup>b</sup>			
T <sub>5</sub>	0.92 <sup>b</sup>	0.93 <sup>a</sup>	0.92 <sup>d</sup>	0.246 <sup>bc</sup>	0.241 <sup>bc</sup>	0.244 <sup>bc</sup>	0.116 <sup>cd</sup>	0.117 <sup>bc</sup>	0.117 <sup>c</sup>	0.117 <sup>bc</sup>	0.117 <sup>c</sup>	1.945 <sup>c</sup>	1.865 <sup>b</sup>	1.903 <sup>bc</sup>	38.4 <sup>bc</sup>	38.1 <sup>b</sup>	38.3 <sup>b</sup>			
T <sub>6</sub>	0.98 <sup>ab</sup>	1.03 <sup>bc</sup>	1.00 <sup>abc</sup>	0.292 <sup>a</sup>	0.285 <sup>a</sup>	0.289 <sup>a</sup>	0.122 <sup>b</sup>	0.124 <sup>a</sup>	0.122 <sup>b</sup>	0.124 <sup>a</sup>	0.123 <sup>b</sup>	2.560 <sup>a</sup>	2.410 <sup>a</sup>	2.483 <sup>a</sup>	42.5 <sup>a</sup>	41.5 <sup>a</sup>	42.0 <sup>a</sup>			
T <sub>7</sub>	1.05 <sup>a</sup>	1.05 <sup>a</sup>	1.05 <sup>a</sup>	0.291 <sup>a</sup>	0.290 <sup>a</sup>	0.290 <sup>a</sup>	0.125 <sup>a</sup>	0.125 <sup>a</sup>	0.125 <sup>a</sup>	0.125 <sup>a</sup>	0.125 <sup>a</sup>	2.490 <sup>a</sup>	2.470 <sup>a</sup>	2.478 <sup>a</sup>	42.4 <sup>a</sup>	41.7 <sup>a</sup>	42.0 <sup>a</sup>			
SEm $\pm$	0.024	0.024	0.022	0.0069	0.0067	0.0047	0.0009	0.0013	0.0007	0.0013	0.0007	0.1064	0.1045	0.0689	0.565	0.792	0.588			
CD (P = 0.05)	0.071	0.072	0.067	0.0207	0.0203	0.0143	0.0028	0.004	0.002	0.004	0.002	0.3205	0.3148	0.2077	1.702	2.386	1.770			

$K_s$  - Saturated hydraulic conductivity,  $\theta_{FC}$  - Soil moisture content at field capacity,  $\theta_{WP}$  - Soil moisture content at permanent wilting point, PAWC - Plant available water content and WHC - Water Holding Capacity. T<sub>1</sub>: Unfertilized control, T<sub>2</sub>: Conventionally managed, T<sub>3</sub>: FYM @ 10 t/ha to rice and wheat, T<sub>4</sub>: SGM for rice and LGLM for wheat, T<sub>5</sub>: SGM + BGA for rice and LGLM + *Azotobacter* for wheat, T<sub>6</sub>: SGM + FYM for rice and LGLM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat, and T<sub>7</sub>: SGM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat.

FYM generally had low in organic matter content. This might be due to rapid mineralization because of low C:N ratio of the applied green manure than FYM. No organic input was applied in unfertilized and conventionally grown plots, which resulted in less soil water contents. The same phenomenon also happened for all treatments with respect to soil water contents ( $\theta_{FC}$ ,  $\theta_{WP}$  and PAWC) in the 15-30 cm soil layer. But, comparatively lower proportion of clay with lesser organic matter content was responsible for less amount of water retention. Hence, water retention in all treatments of 15-30 cm layer was lower than that of 0-15 cm soil layer.

Application of organic inputs notably influenced water holding capacity (WHC) under different treatments (Table 2 and 3). For both depths (0-15 and 15-30 cm), plots with organic inputs retained more amount of water (more WHC) compared with those treatments (unfertilized and conventionally grown plots) that had no organic inputs. Treatment with FYM ( $T_7$ ,  $T_6$  and  $T_3$ ) registered better WHC than treatments without FYM ( $T_4$  and  $T_5$ ) in both depths, and in both years (2014-15 and 2015-16). This could be caused by presence of large quantity of organic matter that holds more water. Masto *et al.* (2008) also concluded from long-term fertilizer/manure experiment that the application of NPK + FYM had highest WHC over the other mineral fertilizer amended plots.

*Impact on soil aggregate fractions*

Higher proportion of large macro-aggregates (*LM*) were recorded in  $T_7$ ,  $T_6$  and  $T_3$  in the 0-15 cm soil layer (Table 4), while higher proportion of *LM* was noted in  $T_7$ ,  $T_6$  and  $T_4$  in the 15-30 cm (Table 5). Small macro-aggregates (*SM*) were also high in  $T_3$ ,  $T_4$  and  $T_7$ . At 0-15 cm depth, generally treatments like  $T_7$ ,  $T_6$  and  $T_3$  had proportionally less amounts of micro-aggregates (*mi*) and ‘silt + clay’ sized

aggregates (*sc*) (Table 4). In the 15-30 cm soil layer (Table 5),  $T_7$  and  $T_6$  recorded very less percentage of *mi* and *sc*. In contrast,  $T_1$  and  $T_2$  prominently were higher in *mi* and *sc* proportions compared to other organic treatment plots. Likewise, Das *et al.* (2014) observed that incorporation of rice and wheat straw, greengram residue, and FYM resulted greater proportion of *LM* and *SM* for 0-7.5, 7.5-15 and 15-30 cm depth of soil.

*Impact on bulk density, porosity and penetration resistance*

It is clearly depicted (Fig 1 and 2) that impact of various combinations of organic inputs in contrast to treatment plots lacking it (organic inputs) on bulk density ( $D_b$ ). Treatments fertilized with organic inputs had shown less  $D_b$  and among organic treatment plots,  $T_7$  recorded lowest  $D_b$ . The  $D_b$  of the unfertilized and conventionally grown plots was high at 0-15 and 15-30 cm soil layer. Soil porosity was highest in  $T_7$  (data) and lowest in  $T_1$  (data) followed by  $T_2$  for 0-15 and 15-30 cm soil layer. For the both depths, porosity

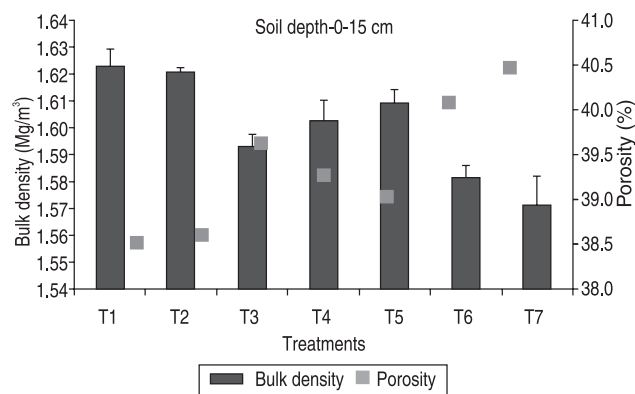


Fig 1 Relation between bulk density and porosity in the 0-15 cm soil layer as influenced by long-term organic and conventional rice-wheat cropping system. (I = Standard error bar)

Table 4 Long-term impact of organic and conventional rice-wheat cropping system on different sizes of soil aggregates of 0-15 cm soil layer

Treatment	Aggregates (g/100 g of soil)											
	<i>LM</i> (>2 mm)			<i>SM</i> (0.25–2 mm)			<i>mi</i> (0.053–0.25 mm)			<i>sc</i> (<0.053 mm)		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
$T_1$	12.03 <sup>c</sup>	11.99 <sup>c</sup>	12.01 <sup>e</sup>	30.07 <sup>e</sup>	29.53 <sup>e</sup>	29.80 <sup>d</sup>	35.45 <sup>a</sup>	35.27 <sup>a</sup>	35.36	22.45 <sup>a</sup>	23.21 <sup>a</sup>	22.83 <sup>a</sup>
$T_2$	12.83 <sup>c</sup>	12.52 <sup>c</sup>	12.68 <sup>e</sup>	31.16 <sup>e</sup>	30.28 <sup>e</sup>	30.72 <sup>d</sup>	37.11 <sup>a</sup>	36.99 <sup>a</sup>	37.05	18.09 <sup>b</sup>	20.21 <sup>b</sup>	19.15 <sup>b</sup>
$T_3$	36.41 <sup>a</sup>	37.31 <sup>a</sup>	36.86 <sup>b</sup>	50.75 <sup>a</sup>	49.52 <sup>a</sup>	50.14 <sup>a</sup>	10.63 <sup>d</sup>	10.67 <sup>d</sup>	10.65	2.21 <sup>d</sup>	2.50 <sup>e</sup>	2.35 <sup>e</sup>
$T_4$	32.25 <sup>b</sup>	33.20 <sup>b</sup>	32.73 <sup>d</sup>	48.53 <sup>b</sup>	47.80 <sup>a</sup>	48.16 <sup>a</sup>	15.97 <sup>c</sup>	14.23 <sup>c</sup>	15.10	3.25 <sup>ed</sup>	4.77 <sup>d</sup>	4.01 <sup>d</sup>
$T_5$	33.00 <sup>b</sup>	30.87 <sup>b</sup>	31.93 <sup>c</sup>	41.24 <sup>d</sup>	43.87 <sup>b</sup>	42.55 <sup>e</sup>	21.21 <sup>b</sup>	19.00 <sup>b</sup>	20.10	4.55 <sup>e</sup>	6.26 <sup>c</sup>	5.40 <sup>c</sup>
$T_6$	37.25 <sup>a</sup>	36.92 <sup>a</sup>	37.09 <sup>b</sup>	44.99 <sup>c</sup>	47.13 <sup>a</sup>	46.06 <sup>b</sup>	14.46 <sup>c</sup>	13.53 <sup>ed</sup>	13.99	3.30 <sup>cd</sup>	2.41 <sup>e</sup>	2.85 <sup>de</sup>
$T_7$	37.96 <sup>a</sup>	39.40 <sup>a</sup>	38.68 <sup>a</sup>	49.31 <sup>ab</sup>	47.51 <sup>a</sup>	48.41 <sup>a</sup>	9.45 <sup>d</sup>	10.87 <sup>d</sup>	10.16	2.72 <sup>d</sup>	2.20 <sup>e</sup>	2.46 <sup>e</sup>
SEm ±	0.87	0.90	0.31	0.55	1.04	0.68	1.03	1.12	0.92	0.45	0.39	0.40
CD (P = 0.05)	2.615	2.687	0.940	1.658	3.124	2.047	3.102	3.361	2.769	1.357	1.176	1.212

*LM* – Large macro-aggregates, *SM* – Small macro-aggregates, *mi* – micro-aggregates and *sc* - ‘silt + clay’ sized aggregates.  $T_1$ : Unfertilized control,  $T_2$ : Conventionally managed,  $T_3$ : FYM @ 10 t/ha to rice and wheat,  $T_4$ : SGM for rice and LGLM for wheat,  $T_5$ : SGM + BGA for rice and LGLM + *Azotobacter* for wheat,  $T_6$ : SGM + FYM for rice and LGLM + FYM for wheat, and  $T_7$ : SGM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat.

Table 5 Long-term impact of organic and conventional rice-wheat cropping system on different sizes of soil aggregates 15-30 cm soil layer

Treatment	Aggregates (g/100 g of soil)											
	LM (>2 mm)			SM (0.25–2 mm)			mi (0.053–0.25 mm)			sc (<0.053 mm)		
	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	2014-15	2015-16	Pooled
T <sub>1</sub>	4.27 <sup>c</sup>	4.46 <sup>b</sup>	4.37 <sup>c</sup>	46.39 <sup>c</sup>	46.17 <sup>d</sup>	46.28 <sup>de</sup>	39.28 <sup>a</sup>	37.22 <sup>abc</sup>	38.25 <sup>ab</sup>	10.06 <sup>a</sup>	12.15 <sup>a</sup>	11.11 <sup>a</sup>
T <sub>2</sub>	4.72 <sup>bc</sup>	4.63 <sup>b</sup>	4.68 <sup>c</sup>	47.27 <sup>c</sup>	46.90 <sup>d</sup>	47.08 <sup>d</sup>	40.02 <sup>a</sup>	38.64 <sup>ab</sup>	39.33 <sup>a</sup>	7.99 <sup>a</sup>	9.83 <sup>b</sup>	8.91 <sup>b</sup>
T <sub>3</sub>	5.87 <sup>ab</sup>	5.42 <sup>ab</sup>	5.64 <sup>b</sup>	55.51 <sup>b</sup>	53.19 <sup>c</sup>	54.35 <sup>c</sup>	33.91 <sup>bc</sup>	33.61 <sup>cd</sup>	33.76 <sup>cd</sup>	4.71 <sup>bc</sup>	7.78 <sup>b</sup>	6.25 <sup>c</sup>
T <sub>4</sub>	6.94 <sup>a</sup>	6.76 <sup>a</sup>	6.85 <sup>a</sup>	43.99 <sup>c</sup>	44.73 <sup>d</sup>	44.36 <sup>e</sup>	39.83 <sup>a</sup>	39.98 <sup>a</sup>	39.91 <sup>a</sup>	9.24 <sup>a</sup>	8.53 <sup>b</sup>	8.88 <sup>b</sup>
T <sub>5</sub>	5.24 <sup>b</sup>	5.26 <sup>ab</sup>	5.25 <sup>bc</sup>	54.41 <sup>b</sup>	54.08 <sup>bc</sup>	54.25 <sup>c</sup>	36.10 <sup>ab</sup>	35.28 <sup>bc</sup>	35.69 <sup>bc</sup>	4.25 <sup>bc</sup>	5.38 <sup>c</sup>	4.82 <sup>d</sup>
T <sub>6</sub>	6.66 <sup>a</sup>	6.58 <sup>a</sup>	6.62 <sup>a</sup>	57.45 <sup>b</sup>	57.33 <sup>b</sup>	57.39 <sup>b</sup>	30.43 <sup>cd</sup>	31.03 <sup>de</sup>	30.73 <sup>de</sup>	5.46 <sup>b</sup>	5.06 <sup>c</sup>	5.26 <sup>cd</sup>
T <sub>7</sub>	7.23 <sup>a</sup>	6.85 <sup>a</sup>	7.04 <sup>a</sup>	63.28 <sup>a</sup>	62.63 <sup>a</sup>	62.95 <sup>a</sup>	26.49 <sup>d</sup>	28.49 <sup>e</sup>	27.49 <sup>e</sup>	3.00 <sup>c</sup>	2.03 <sup>d</sup>	2.52 <sup>e</sup>
SEm ±	0.51	0.53	0.28	1.30	1.32	0.75	1.66	1.35	1.13	0.79	0.71	0.36
CD (P = 0.05)	1.55	1.61	0.83	3.92	3.97	2.25	5.01	4.08	3.40	2.37	2.14	1.09

LM – Large macro-aggregates, SM – Small macro-aggregates, mi – micro-aggregates and sc - ‘silt + clay’ sized aggregates. T<sub>1</sub>: Unfertilized control, T<sub>2</sub>: Conventionally managed, T<sub>3</sub>: FYM @ 10 t/ha to rice and wheat, T<sub>4</sub>: SGM for rice and LGLM for wheat, T<sub>5</sub>: SGM + BGA for rice and LGLM + *Azotobacter* for wheat, T<sub>6</sub>: SGM + FYM for rice and LGLM + FYM for wheat, and T<sub>7</sub>: SGM + FYM + BGA for rice and LGLM + FYM + *Azotobacter* for wheat.

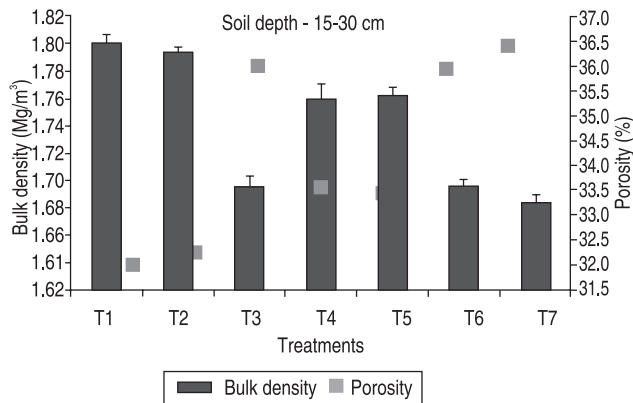


Fig 2 Relation between bulk density and porosity in the 15-30 cm soil layer influenced by long-term organic and conventional rice-wheat cropping system. (I = Standard error bar)

was negatively correlated with  $D_b$ .  $D_b$  of organic manure or inputs is low and therefore, addition of organic inputs reduced the  $D_b$  of the concerned treatments with increasing porosity. Guo *et al.* (2016) observed that treatment with the application of cattle manure compost had a positive relation with porosity, but significantly negatively correlated with  $D_b$ . The trend in penetration resistance (Fig 3) represented that resistance in soil increased with depth in all treatments. Lowest resistance (211.7 kPa) was shown in T<sub>6</sub> and highest resistance was noted in T<sub>1</sub> (613.5 kPa) at 0-10 cm soil layer. In the 10-20 cm soil layer, similar results were recorded for T<sub>1</sub> (732.7 kPa) and T<sub>6</sub> (215.2 kPa) in term of its resistance. Whereas, at 20-30 cm depth, T<sub>1</sub> (1655 kPa) was with highest in resistance, but instead of T<sub>6</sub>, T<sub>7</sub> (1104.3 kPa) recorded lowest resistance. Celik *et al.* (2010) reported that soil (Menzilat clay-loam soil) amended with compost and manure recorded lowest in penetration resistance.

Therefore it may be concluded that a long-term influence of different kinds of organic amendments or

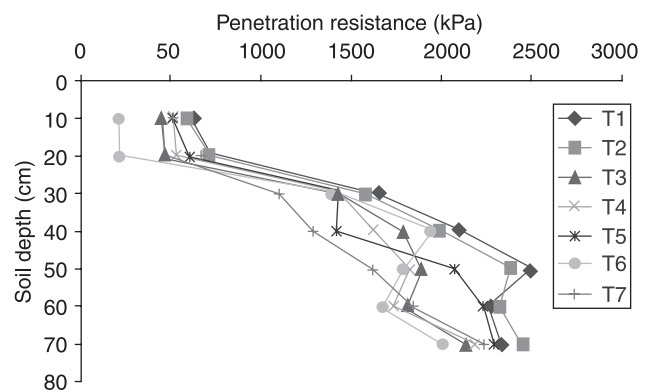


Fig 3 Long-term impact of organic and conventional rice-wheat cropping system on soil strength (soil penetration resistance) in the 0-70 cm soil layer.

their combinations resulted in varying response on soil physical properties, predominantly on soil structure, which was superior to conventionally managed system. FYM alone or FYM + green manure + BGA or *Azotobacter* combination provided positive effect on soil physical properties, viz. structural stability, soil aggregation, and porosity and, thereby improved soil moisture retention capacity.

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