The Journal of Animal & Plant Sciences, 28(5): 2018, Page: 1432-1440
ISSN: 1018-7081

IMPACT OF CONSERVATION AGRICULTURE ON SOIL PHYSICAL PROPERTIES IN RICE-WHEAT SYSTEM OF EASTERN INDO-GANGETIC PLAINS

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ABSTRACT

Soils of Indo-Gangetic plains (IGP) of India are prone to physical degradation due to their low organic matter content, and presence of carbonates, gypsum or other soluble salts. To address these challenges, conservation agriculture (CA) based crop management practices are being developed. Our objective was to study how CA practices affected soil physical indicators under rice-wheat cropping system. The experiment was carried out in long term ongoing experiment during 2013 (Rice) and 2013-2014 (Wheat) at crop research centre of Dr. Rajendra Prasad Central Agricultural University, India with the aim to compare the impact of conservation agriculture practices on some selected soil physical properties including the soil moisture, soil temperature and root growth of rice and wheat. The experiment was laid out in Randomized Block Design, with seven treatments and three replications. The treatments involved seven combinations of tillage, crop establishment and residue management practices in a rice-wheat rotation - puddled transplanted rice-conventional tillage wheat (T_1: PTR-CTW); zero tillage rice-zero tillage wheat on beds having 50% rice residue retained in wheat cycle and 25% wheat residues retained in rice cycle (T_2: PBZTR-ZTW +RB); zero tillage rice-conventional tillage wheat without residues (T_3: ZTR-CTW -R); zero tillage rice-zero tillage wheat without residues (T_4: ZTR-ZTW -R); zero tillage rice-zero tillage wheat having 50% rice residue retained in wheat cycle and 25% wheat residues retained in rice cycle (T_5: ZTR-ZTW +RB); unpuddled transplanted rice-zero tillage wheat with 25% rice residues retained in wheat cycle (T_6: PuTR-ZTW +RR); zero tillage rice with *Sesbania aculeata* brown manure-zero tillage wheat without residues (T_7: ZTRBM-ZTW -R). The observations were made in one cycle of rice-wheat cropping after 7-years at three stages *i.e.*, before rice sowing/transplanting, after rice harvest and after wheat harvest. Results revealed that CA practices, zero tillage (ZT) with or without residues retention significantly improved the soil moisture content (SMC) and modified the soil temperature (ST) before and after irrigation in both the cropping ($P \leq 0.05$). ZT with or without residues retention significantly reduced the soil bulk density (BD), and improved the air filled porosity (AFP), aggregation (MWD), water holding capacity (WHC), hydraulic conductivity (K_{fs}) and matric flux potential (ϕ_m) ($P \leq 0.05$). Better soil conditions significantly improved root growth of both the crops under CA practices ($P \leq 0.05$). The most favourable impact on soil physical properties was observed due to ZT with brown manuring. A positive Polynomial relationship was obtained between soil BD and MWD, WHC and MWD, and K_{fs} and ϕ_m at all the three stages. Thus, the evaluation of long term CA practices is potentially recommended to different agro-ecologies for their large scale adoption in the north eastern IGP.

Keywords: Zero tillage; residues retention; physical properties; root growth; rice; wheat.

INTRODUCTION

The physical properties of a soil play an important role in determining its suitability for crop production. The characteristics like supporting power and bearing capacity, tillage practices, moisture storage capacity, and its availability to plants, drainage, ease of penetration by roots, aeration, retention of plant nutrients and its availability to plants are all intimately connected with soil physical properties.

Rice-wheat is a major cropping system of Eastern Indo-Gangetic plains (IGP) of India and the soil is characterized by low organic carbon (OC) content and poor water retention ability and suffers from the problems of mechanical impedance, scarcity of water and high summer and low winter temperature. Over fertilizations and improper management of these soils have further aggravated the deterioration of soil physical properties that threatened the soil productivity potential in this region.

Soil water plays a significant role in controlling the energy balance of the soil and of its overlying micro environment by modifying its radiation exchanges and thermal properties (Kar *et. al*., 2009). The rate of organic matter decomposition and mineralization of the organic form of nitrogen increases with temperature. The biological decomposition as well as uptake and movement of water practically cease under very low temperature (Tripathi and Tomar, 2009). Soil bulk density (BD) is an index of the soil mechanical resistance to root growth used in soil quality studies (Reynolds *et al*., 2007). Another soil physical stress is soil air filled porosity (AFP), an important for physicochemical properties that affect plant growth and biological process (Tripathi and Tomar, 2009).

Conservation agriculture (CA) is a concept designed for optimizing crop yields, and reaping economic and environmental benefits. Appropriate CA technology encompasses innovative crop production system that combines three basic principles: minimum mechanical disturbances of soil, rational retention of adequate crop residues on the soil surface for long time, and use of sensible crop rotation. CA technologies can influence soil physical properties by altering soil conditions and consequently have a direct bearing on crop growth and subsequent sustainable production. CA technologies like, zero tillage dry seeded rice followed by zero tillage wheat planting (double zero till planting) combined with residue retention have been coined as sustainable cultivation systems (Hobbs *et al*., 2008) due to a combined potential to increase profits (Bhushan *et al*., 2007; Jat *et al*., 2009), increase the water balance in the system due to residue retention and bed planting (Kukal *et al*., 2010), improved soil quality and, water and nutrient use efficiency (Humphreys *et al*., 2010). More such studies are needed to evaluate CA practices over conventional practices under different soil and climatic condition in terms of soil physical health for long term sustainability of rice-wheat rotation on sandy loam soil in Eastern IGP of India. Therefore, current study aimed at evaluating the effect of different combinations of tillage, crop establishment and residues management on some selected soil physical properties that may provide valuable information for the propose of soil management for optimal production in Eastern IGP of India.

MATERIALS AND METHODS

Experimental site and treatments: The experiment was carried out during rice-wheat cropping season from June-October, 2013 and November-March, 2013-14 in ongoing long term experiment which is being conducted in association with CIMMYT in India since monsoon 2006 in sub-tropical humid climate at the crop research center of Dr. Rajendra Prasad Central Agricultural University, Samastipur, Bihar, India (25° 30' N, 85° 40' E). The site has hot and humid summers and too cold winters with average rainfall of 1344 mm of which 70% is received during the monsoon period (mid June - mid September). The mean minimum and maximum temperatures during the rice season (June 2013-October 2013) were 24.99 °C and 32.58°C, respectively. Likewise, during the wheat season (November 2013-March 2014) the mean minimum and maximum temperatures were 24.32 °C and 11.61°C, respectively. The soil of the experimental site belongs to order Entisol, sandy loam in texture with alkaline pH (8.6), medium in OC (0.48%) and available N, P and K (111.96, 14.02 and 60.49 mg kg^{-1}, respectively).

The experiment was laid out in Randomized Block Design, replicated thrice within a block and involved seven combinations of tillage, crop establishment and residue management practices in a rice-wheat rotation - puddled transplanted rice-conventional tillage wheat (T_1: PTR-CTW); zero tillage rice-zero tillage wheat on beds having 50% rice residue retained in wheat cycle and 25% wheat residues retained in rice cycle (T_2: PBZTR-ZTW +RB); zero tillage rice-conventional tillage wheat without residues (T_3: ZTR-CTW -R); zero tillage rice-zero tillage wheat without residues (T_4: ZTR-ZTW -R); zero tillage rice-zero tillage wheat having 50% rice residue retained in wheat cycle and 25% wheat residues retained in rice cycle (T_5: ZTR-ZTW +RB); unpuddled transplanted rice-zero tillage wheat with 25% rice residues retained in wheat cycle (T_6: PuTR-ZTW +RR); zero tillage rice with *Sesbania aculeata* brown manure-zero tillage wheat without residues (T_7: ZTRBM-ZTW -R).

Field measurement of soil properties: Volumetric soil moisture content (SMC) was determinedin each plot by using a moisture probe meter (MP406) in 0-15 cm soil depth before and after each irrigation during the period of experimentation. Soil temperature (ST) readings were recorded at 15 cm depths during the moisture estimation using soil temperature meter. Soil bulk density (BD) in 0-15 cm was determined by core method (Blake and Hartage, 1986). In the laboratory, samples were carefully trimmed and dried at 105 °C to a constant weight. The air filled porosity (AFP) of the 0-15 cm soil layer was determined after crop harvest from data on BD using the relationship:

$$AFP = 1 - \frac{BD}{PD} \times 100 \quad (1)$$

Where: PD - particle density assumed to be 2.65 g cm^{-3} (Mcbride and Joose, 1996).

In situ saturated hydraulic conductivity (K_{fs}) of soil was determined by using Guelph permeameter (2800K1) as suggested by Reynolds (1993) applying two sets of water head for measurement of K_{fs} and matric flux potential (ϕ_m). Calculations applied for measurement are: Set H_1= 5 cm (determine R_1); Set H_2 = 10 cm (determine R_2)

$$K_{fs} = (0.0041)(Y)(R_2) - (0.0054)(Y)(R_1) \quad (2)$$

$$\phi_m = (0.0572)(Y)(R_1) - (0.0237)(Y)(R_2) \quad (3)$$

Where: H_1 = first head of water established in the well hole, measured in cm. R_1 = steady state rate of fall of water in the reservoir when the first head H_1 of water is established, rate of fall expressed in cm sec^{-1}. H_2 =

second head of water established in the well hole, measured in cm. R_2 = steady state rate of fall of water in the reservoir when the second head H_2 of water is established, rate of fall expressed in cm sec^{-1}. Y= reservoir constant used when the inner reservoir only is selected, expressed in cm^2.

Root growth: Root growth parameters like length, volume and density were determined at grain filling stage of the crop using metallic cores (10 cm internal diameter and 15 cm height) for taking samples from each treatment. The sample cores were kept in water overnight and then soil was removed from the roots by washing with a fine jet of water. The roots were collected on fine sieves for final washing with a micro jet tap and preserved in formaldehyde solution, 35%. Root length, volume and density were determined with the help of a root scanner (Win-RHIZO software) as suggested by Banarjee *et al*. (2012). To determine the root biomass, three quadrants of 1×1 ft were laid down randomly in each plot. Finally, the roots were dried in oven at 65 ºC for 48 hours and weighed to determine the root biomass.

Laboratory measurement of soil properties: Representative soil samples from 0-15 cm depth were collected at three stages *i.e*., before rice transplanting/ sowing (2013), after rice harvesting (2013) and after wheat harvesting (2014). Collected soil samples were air dried in shade and ground with the help of pestle and mortar, then passed through a 2 mm sieve and stored in polyethylene bags before analysis. The water holding capacity was determined by means of Keen's Raczkowski box method as described by Piper (1950). Clumps of soils were collected from 0-15 cm soil depth with the help of shovel followed by shade drying. Small peds were made from dry soil clumps for the analysis of soil aggregation.Mean weight diameter (MWD) of water stable soil aggregates was determined by using the wet-sieving method (Yoder, 1936) and was calculated by the following formula:

$$MWD = \sum_{i=1}^{n} xi.\,wi \quad (4)$$

Where, *xi* = is the mean diameter of fractions: *wi* = is the proportion of the total sample weight occurring in the fraction

Statistical analysis: The data generated for soil moisture content, soil temperature, soil bulk density, soil air filled porosity, water stable soil aggregates, water holding capacity, hydraulic conductivity, matrix flux potential and root growth were subjected to statistical analysis using the statistical package SPSS 13.0 software (Analyse - General Linear Model – Univariate) (SPSS Inc., Chicago, USA). The same letters with table value represent statistically identical values of the examined CA practices according to Tukey's HSD test determining the least significant difference (LSD) at 5% for testing the significant difference among the treatment means (Gomez and Gomez, 1984). Regression coefficient between obtained variables was determined using Microsoft Excel.

RESULTS AND DISCUSSION

Soil moisture and soil temperature: The trends of data on SMC and ST recorded before and after irrigation were almost the same (Table 1) ($P \leq 0.05$). Therefore, for the sake of convenience, the SMC and ST data before each irrigation in a crop were averaged and statistically analysed and explained.

CA practices T_5, T_6 and T_7 recorded significantly higher increment in SMC which varied from 6.31-6.95 cm, before irrigation, as compared to T_1 (CT). Almost similar trend was observed after irrigation. In wheat cropping also, the same treatments (T_5, T_6 and T_7) registered significant increment in SMC, on an average 5.84 and 6.67 cm before and after irrigation, respectively as compared to T_1. Surface retention of stubbles provides shading to prevent evaporation of moisture from soil and reduce vapour diffusion to the atmosphere (Sharma and Kumar, 2014). Lamm *et al*. (2009) also reported higher SMC under ZT than under CT.

During rice cropping the summer temperature before irrigation, was significantly ($P \leq 0.05$) reduced by 3.85 °C, 4.40 °C, and 4.05 °C over T_1, in T_2 and T_7, respectively. Similar trend was also observed after irrigation. However, ST was significantly improved by 0.95-1.50 °C after irrigation under ZT with residues retention treatments T_2, T_5, T_6 and T_7 over T_1 during wheat cropping. This moderation of ST can be attributed to the insulating effect and higher moisture retention due to residue which reduces the negative heat flux to the atmosphere (Sharma and Kumar, 2014). Our findings are consistent with those of Ram *et al*. (2012) who reported reduced maximum temperature and enhanced minimum temperature in ZT with residues as compared to without residues.

Soil bulk density and Air filled porosity: In general, ZT plots showed reduction in BD (0-15 cm) while treatments T_2, T_5, and T_7 involving residue retention/ brown manuring, significantly reduced the BD ($P \leq 0.05$) (Table 2) over T_1 at the three stages, and the maximum reduction in BD by 3.38%, 4.76% and 6.85% over T_1 was observed by T_7. This may be attributed to lesser soil disturbance and higher soil OC content (5.61-8.96 g kg^{-1}) in ZT. These findings are in accordance with those of Alam *et al.*(2014). Strong and negative correlation (r = -0.78) was found between BD and MWD (Figure 1) after completion of one cycle of rice-wheat cropping.

AFP increased with decreased value of BD ($P \leq 0.05$) (Table 2). Increase in AFP under ZT with residue retention at the three stages may be due to higher OC content, more extensive network of root channel, low BD and improved MWD. AFP reduced with tillage and puddling practices due to destruction of soil aggregates. The results are comparable with those of Singh *et al*. (2014).

Water stable aggregate and water holding capacity: CA practices significantly improved the MWD and WHC at the three stages ($P \leq 0.05$) (Table 2 & 3) as compared to CT recording the highest value of MWD and WHC in treatment T_7. Very strong correlation (r = 0.86) was found between MWD and WHC of soil after completion of one cycle of rice-wheat cropping (Figure 2). This may be partly explained by the fact that this system has readily decomposable brown manure that stabilized the soil aggregate and improved WHC. ZT either with or without residue retention also improved the MWD and WHC which might be due to non disturbance of soil matrix and higher levels of soil OC (Singh *et al*., 2014).

Hydraulic conductivity and matric flux potential: In general, K_{fs} increased with decreased BD. ZT with bed planting (T_2) showed the significant superiority to rest of the treatments ($P \leq 0.05$) (Table 3) by maintaining higher values of K_{fs} which varied from 2.06-2.57 cm hr^{-1} in one crop cycle. Other CA practices also significantly improved K_{fs} (0.74-1.63 cm hr^{-1}) as compared to CT. Corresponding increment in ϕ_m was also obtained with these treatments at the three stages. A very strong correlation (r = 0.92) was found between K_{fs} and ϕ_m (Figure 3) after completion of one cycle of rice-wheat cropping owing to lower BD and higher porosity, better soil aggregation, maximum root biomass (Bhattacharyya *et al*., 2006). These findings are in accordance with those of Sharratt *et al*. (2006).

Root growth: CA practices had significant impact on root growth parameters like length, density, volume, and biomass of rice and wheat crops ($P \leq 0.05$) (Table 4). ZT with brown manuring recorded the highest root growth of rice due to additional nitrogen through fixation by *Sesbania aculeata*. Likewise, ZT with or without residues retention also significantly enhanced the root proliferation as compared to CT. In wheat cropping, ZT on bed planting with residues retention (T_2) maintained the highest value of all the root growth parameters ($P \leq 0.05$) (Table 4) which was closely followed by T_5. The most likely reason for higher value of root growth attributes in ZT with residues retention compared to CT, is better soil-air-water relation and moderation of hydrothermal regimes which helped in better proliferation and elongation of roots (Sharma and Kumar, 2014; Moreno *et al*., 1997).

Table 1. Effect of conservation agriculture on soil moisture content (SMC) and soil temperature (ST) in 0-15 cm soil depth before and after each irrigation under rice-wheat cropping.

Treatments	SMC (cm)				ST (°C)			
	Rice		Wheat		Rice		Wheat	
	Before irrigation	After irrigation	Before irrigation	After irrigation	Before irrigation	After irrigation	Before irrigation	After irrigation
T_1: PTR-CTW	4.80^{a}	6.15^{a}	4.09^{a}	4.34^{a}	32.60^{e}	26.20^{e}	15.20^{a}	15.90^{a}
T_2: PBZTR-ZTW +RB	5.86^{ab}	8.31b^{cd}	4.80^{abc}	5.73^{bc}	28.75^{a}	21.75^{a}	15.85^{a}	17.00^{bcde}
T_3: ZTR-CTW -R	5.56^{ab}	7.33^{ab}	4.45^{a}	5.15^{ab}	32.20^{de}	25.85^{de}	14.90^{a}	16.05^{a}
T_4: ZTR-ZTW -R	5.59^{ab}	8.08^{bc}	4.55^{ab}	5.18^{ab}	31.95^{bcde}	25.80^{cde}	15.20^{a}	16.25^{abc}
T_5: ZTR-ZTW +RB	6.95^{b}	10.56^{d}	6.18^{d}	7.29^{d}	28.20^{a}	21.20^{a}	15.85^{a}	17.40^{c}
T_6: PuTR-ZTW +RR	6.31^{b}	9.41^{cd}	5.65^{bcd}	6.25^{bcd}	31.95^{cde}	25.10^{bce}	15.55^{a}	16.90^{cde}
T_7: ZTRBM-ZTW -R	6.93^{b}	10.25^{d}	5.70^{cd}	6.49^{cd}	28.55^{a}	21.50^{a}	15.45^{a}	16.85^{de}

Different letters in a column indicate significant difference (at 0.05 level) between the means according to Tukey’s HSD test.

Table 2. Effect of conservation agriculture on soil bulk density (BD), soil air filled porosity (AFP), and water stable soil aggregates (MWD) in 0-15 cm depth under rice-wheat cropping.

Treatments	BD (Mg m^{-3})			AFP (%)			MWD (mm)		
	Before rice	After rice	After wheat	Before rice	After rice	After wheat	Before rice	After rice	After wheat
T_1: PTR-CTW	1.53^{cd}	1.54^{d}	1.56^{d}	42.27^{a}	42.08^{a}	41.32^{a}	1.72^{a}	1.45^{a}	1.21^{a}
T_2: PBZTR-ZTW +RB	1.49^{ab}	1.48^{ab}	1.46^{ab}	43.96^{bcd}	44.34^{bc}	45.09^{d}	3.75^{b}	3.89^{b}	5.44^{b}
T_3: ZTR-CTW –R	1.53^{d}	1.52^{bc}	1.53^{cd}	42.46^{ab}	42.83^{ab}	42.45^{ab}	2.46^{c}	3.58^{c}	3.08^{c}
T_4: ZTR-ZTW –R	1.50^{abcd}	1.50^{abc}	1.49^{abc}	43.40^{abcd}	43.40^{abc}	43.78^{bcd}	3.84^{b}	5.57^{d}	5.78^{d}
T_5: ZTR-ZTW +RB	1.48^{a}	1.48^{ab}	1.46^{ab}	44.16^{d}	44.34^{bc}	45.09^{d}	4.66^{d}	5.93^{e}	6.13^{e}
T_6: PuTR-ZTW +RR	1.52^{bcd}	1.52^{bc}	1.51^{bcd}	42.83^{abcd}	42.83^{ab}	43.21^{b}	3.24^{e}	4.93^{f}	5.71^{d}
T_7: ZTRBM-ZTW -R	1.48^{a}	1.47^{a}	1.46^{ab}	44.15^{cd}	44.53^{c}	44.91^{cd}	4.88^{d}	5.96^{e}	6.43^{f}

Different letters in a column indicate significant difference (at 0.05 level) between the means according to Tukey’s HSD test.

Table 3. Effect of conservation agriculture on water holding capacity (WHC), hydraulic conductivity (K_{fs}) and matric flux potential (ϕ_m) of soil in 0-15 cm depth under rice-wheat cropping.

Treatments	WHC (%)			K_{fs} (cm hr^{-1})			ϕ_m (cm^2 hr^{-1})		
	Before rice	After rice	After wheat	Before rice	After rice	After wheat	Before rice	After rice	After wheat
T_1: PTR-CTW	39.92^{a}	39.89^{a}	39.45^{a}	0.39^{a}	0.38^{a}	0.36^{a}	2.01^{a}	2.04^{a}	2.08^{a}
T_2: PBZTR-ZTW +RB	42.47^{bcde}	46.52^{bcd}	52.41^{bcd}	2.06^{g}	2.07^{d}	2.57^{f}	10.97^{f}	12.61^{g}	15.87^{e}
T_3: ZTR-CTW –R	40.82^{abcd}	44.16^{abcd}	47.31^{b}	0.56^{b}	1.16^{abc}	1.00^{b}	2.61^{b}	6.76^{d}	7.55^{b}
T_4: ZTR-ZTW –R	42.75^{cde}	47.16^{cd}	53.50^{cde}	0.92^{d}	0.96^{abc}	1.33^{d}	4.65^{c}	5.70^{c}	13.31^{c}
T_5: ZTR-ZTW +RB	42.86^{de}	49.71^{de}	55.25^{de}	1.63^{f}	1.79^{bc}	1.92^{e}	8.37^{e}	9.94^{e}	14.96^{d}
T_6: PuTR-ZTW +RR	41.49^{abcde}	44.57^{abcd}	49.85^{bc}	0.74^{c}	0.90^{ab}	1.20^{c}	4.63^{c}	4.96^{b}	7.10^{b}
T_7: ZTRBM-ZTW –R	43.61^{e}	54.11^{e}	58.34^{e}	1.09^{e}	1.89^{cd}	1.88^{e}	6.70^{d}	11.22^{f}	14.66^{d}

Different letters in a column indicate significant difference (at 0.05 level) between the means according to Tukey's HSD test.

Table 4. Effect of conservation agriculture on root growth of rice and wheat in rice-wheat cropping.

Treatments	Rice				Wheat			
	Root length (cm)	Root length density (cm cm^{-3})	Root biomass (t ha^{-1})	Root volume (cm^3)	Root length (cm)	Root length density (cm cm^{-3})	Root biomass (t ha^{-1})	Root volume (cm^3)
T_1: PTR-CTW	580.77^{a}	0.49^{a}	2.09^{a}	19.00^{a}	713.61^{a}	0.61^{a}	1.98^{a}	4.63^{a}
T_2: PBZTR-ZTW +RB	1386.27^{e}	1.18^{d}	2.36^{b}	30.00^{de}	1204.25^{d}	1.02^{d}	2.34^{c}	10.68^{d}
T_3: ZTR-CTW -R	1381.83^{e}	1.17^{d}	2.19^{a}	28.00^{cd}	1121.65^{d}	0.95^{c}	2.24^{bc}	7.66^{c}
T_4: ZTR-ZTW -R	781.78^{b}	0.66^{ab}	2.36^{b}	20.00^{a}	954.36^{c}	0.81^{bc}	2.16^{b}	5.42^{ab}
T_5: ZTR-ZTW +RB	906.44^{c}	0.77^{b}	2.47^{c}	25.00^{b}	1134.85^{d}	0.96^{c}	2.30^{c}	9.37^{d}
T_6: PuTR-ZTW +RR	1146.62^{d}	0.97^{c}	2.42^{bc}	27.00^{bc}	822.56^{b}	0.70^{ab}	2.21^{b}	6.18^{b}
T_7: ZTRBM-ZTW -R	1896.35^{f}	1.61^{e}	2.50^{c}	32.00^{e}	757.19^{ab}	0.64^{a}	2.13^{ab}	4.90^{a}

Different letters in a column indicate significant difference (at 0.05 level) between the means according to Tukey's HSD test.

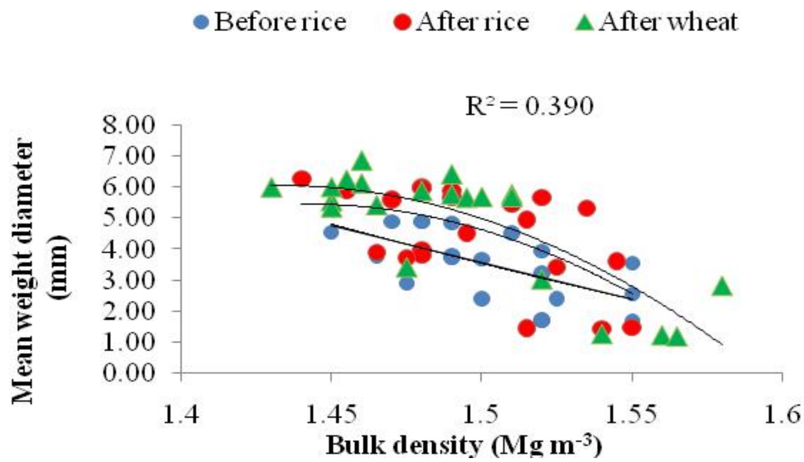

Figure 1. Polynomial relationships among soil bulk density and mean weight diameter in the 0-15 cm soil depth at all three stages of CA practices.

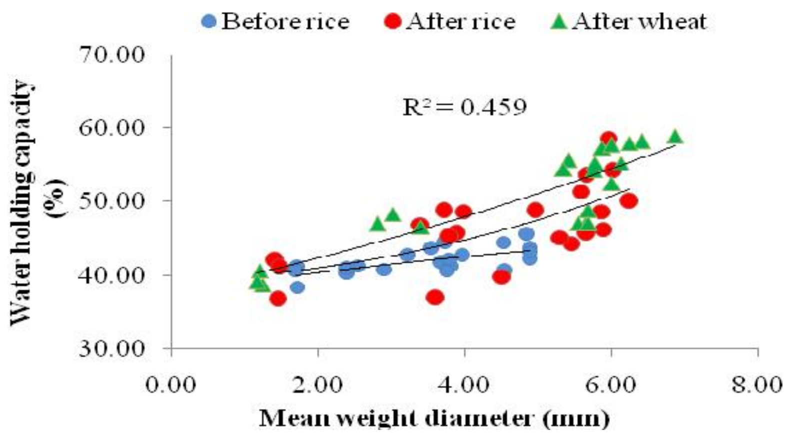

Figure 2. Polynomial relationships among water holding capacity and mean weight diameter in the 0-15 cm soil depth at all three stages of CA practices.

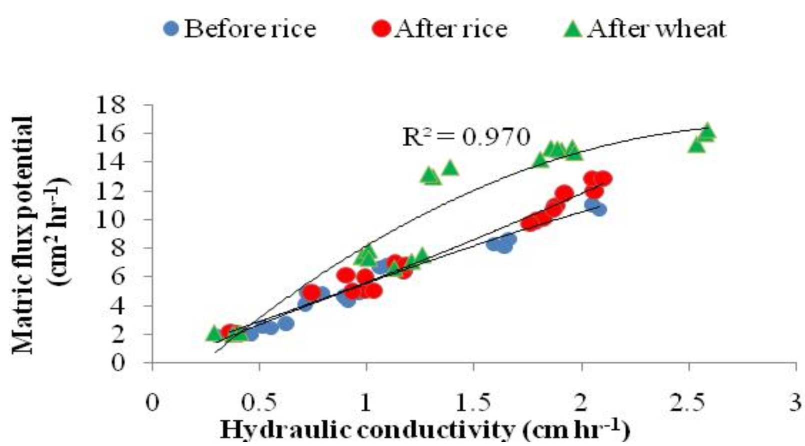

Figure 3. Polynomial relationships among hydraulic conductivity and matric flux potential in the 0-15 cm soil depth at all three stages of CA practices.

Conclusion: In conclusion, CA practices had favorable effects on soil physical properties. Proper use of crop residues with ZT has capability to improve the root growth of crops, AFP, MWD, WHC, soil moisture content, K_{fs} and ϕ_m, and to reduce the soil BD, and also to regulate soil temperature. Further the evaluation of long term CA practices is potentially recommended to different agro-ecologies for their large scale adoption in the north eastern IGP of India.

Acknowledgement: The support of Department of Soil Science, Dr. Rajendra Prasad Central Agricultural University and Borlaug Institute for South Asia (BISA), Pusa, Samastipur, Bihar for providing land, laboratory for analysis and other basic infrastructure for this trail is duly acknowledged.The financial support given by the Department of Science and Technology, New Delhi (DST-INSPIRE fellowship) is highly acknowledged.

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