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Conservation Agriculture in Cotton-Wheat System: Effect on Physico-Chemical Properties of Sandy Loam Soil in North-Western IGP

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Abstract: For sustainable of the system, it is vital to know how soil properties change when agricultural management systems change. Conservation agriculture based cotton (*Gossypium hirsutum* L.)-wheat (*Triticum aestivum* L.) crop rotations with intensification of mungbean are advocated as alternate to conventional cotton-wheat (CW) system in South Asia due to better strategies for tackling the issues of soil health deterioration, plant nutrients status and over exploitation of underground water resources, particularly in conventional tillage based intensive crop rotations. Two-years field experiment was conducted at Borlaug Institute for South Asia (BISA), Ladhowal in Punjab, India to evaluate the impacts of promising RCTs such as permanent broad beds (PBB), relay planting of wheat in cotton and integrating mungbean in cotton under PBBc+MB was 28 and 17.8 % higher SOC compared to CT in CW system under 0–15 cm and 15–30 cm layer, respectively. BD was significantly higher 9.4–10.6 and 4.3–7.4 at 0–15 and 15–30 cm layer compared to CT. Similarly, hydraulic conductivity was higher by 1.19 and 1.10 times and 1.17 and 1.31 times higher under PBB & ZT at 0–10 cm and 10–20 cm layer over CT, respectively. Steady state infiltration rate was significantly higher under conservation tillage and crop establishment techniques than CT and was about 1.41 times higher under beds compared furrow. Soil aggregates was 44.8, 74.2 and 25.1% higher under PPBc+MB with WSA, macro-aggregates and micro-aggregates in 0-15 cm layer compared CT, respectively. Electrical conductivity and pH of soil were improved due to RCTs practices compared CT. PBBc+MB was significantly higher under N, P & K available status in 0–15 and 15–30 cm layer compared CT, respectively.

Keywords: Chemical and physical properties, Conservation agriculture, Permanent beds, Zero tillage

Cotton (*Gossypium hirsutum* L.) - wheat (*Triticum aestivum* L.) system is a well-established crop production system in South Asia (SA) occupying 4.5 Mha with approximately 2.6 Mha in India (Das et al 2014). The crop residues are not incorporated in the field. The sticks of cotton are pulled out, removed from the field and used as fuel. In wheat crop following cotton, the same tillage operations as in cotton are repeated, but the straw of wheat is either removed from the fields or is burnt due to shortage of time between harvesting of wheat crop (mid-April) and sowing of cotton crop (end of April to mid of May) that causes loss of carbon and other nutrients (Jalota et al 2008). Deterioration of land quality due to different forms of soil degradation and excess residue burning are other pervasive problems in the region (Das et al 2013). Tillage is an important management practice involving physical manipulation of soil for crop establishment. Optimization of tillage practices lead to improvement in soil health. Soil health is a dynamic and complex system, and its functions are mainly mediated by agricultural management practices (Congreves et al 2015). Intensive agricultural practices often leads to changes in soil health governing properties like, soil structure, aggregation, porosity, strength, hydraulic conductivity, infiltration, bulk density, soil moisture content, soil carbon content, microbial biomass and their activities (Parihar et al 2016). Sandy loam (Typic Haplustept) soil is the most dominant soil texture of Indo Gangetic Plains. Cotton-wheat system integrating with mungbean (MB) on permanent broad beds (PBB) enhanced system productivity by 37% and sustained the productivity of current CWS in NW India (Choudhary et al 2016).

Crop management practices (tillage systems or cropping sequences) can affect soil health (FAO 2011). Conservation agriculture based management practices have potential to promote conjunctive use of organics (avoids residue burning), improve soil health and promote timely planting of crops to address issues of terminal heat stress to wheat in the region and increased water infiltration leading to groundwater recharge, improved soil quality, reduced methane emissions and short-term carbon sequestration in soil due to retention of crop residues instead of burning (Jat et al 2011). Hydraulic conductivity and infiltration can be improved and evaporation can be decreased by no-tillage and crop residue cover (Li et al 2011). Therefore, long term study (>5 years) on effect of tillage practices for maintaining or enhancing soil physical, chemical and biological characteristics of sandy loam (Typic Haplustept) soil are needed (Singh et al 2016). Bed planting generally saves irrigation water (Gathala et al 2011).

Mungbean (*Vigna radiata* L.) being a leguminous crop has the capacity to fix atmospheric nitrogen through symbiotic nitrogen fixation, and as short duration crop, it also fits well in various multiple and intercropping systems. Similarly, diversification in crop rotations can also affects soil health by affecting carbon contents, due to the difference in chemical composition of different crop residues that are added to soil (Srinivasarao et al 2013). However, precise information on the long term effects of different tillage practices and intensified mungbean based crop rotations on soil health in the IGP region of South Asia is lacking. In this backdrop, the objectives of present study were to determine the effects of different tillage practices and conservation tillage based sustainable intensification of cotton-wheat sequence on soil physico-chemical properties, carbon sustainability index of a sandy loam soil and plant nutrients use efficiency in north-western Indo-Gangetic Plains.

MATERIAL AND METHODS

Experimental site, soil and climate characteristics: Field experiment on CW system was conducted for two consecutive years (2013-14 and 2014-15) at CIMMYT's Borlaug Institute for South Asia (BISA), Ladhowal (30.99°N latitude, 75.44°E longitude, Punjab located in Trans-Gangetic alluvial plains of India. The soil of the experimental site was sandy (Typic Haplustept) loam in texture with alkaline in reaction, poor in organic carbon content, Olsen P and 1M NH_4OAc-extractable K. The initial soil characteristics of the experimental field are presented in Table 1. Experimental site represented the sub-tropical climate with hot and dry (May-June) to wet summers (July-November) during the mungbean/cotton growing season and cool dry winters (December-April) during wheat growing season with average annual pan evaporation was about 850 mm. May and June were the hottest month (40-44.8°C), while January was the coldest month (as low as 1.6°C). Total rainfall received during the growing periods of wheat, cotton and mungbean was 220.4, 1033.7 and 376.4 mm during 2013-14 and 202.2, 490.9 and 114.8 mm during 2014-15, respectively (Fig. 1).

Treatments and experimental design: Seven combinations of CA-based tillage and crop establishment (planting method and crop geometry) were described in Table 2. In bed planting, crops were grown on the raised beds alternated by furrows. The experiment was laid out in a completely randomized block design with three replications.

Figure 2 shows the configuration of cotton, wheat and mungbean crops under different treatments. The plot size for each treatment was 450 m^2. The field experiment was laid out in the previous wheat season of 2012-13 after conventional tillage and the fresh beds were prepared using bed maker. The beds were maintained by reshaping once a year after wheat harvest. The reshaping included use of relay seeder attached to high clearance tractor after adjusting the tynes for reshaping of beds using shapers.

Crop establishment and management: Cotton after harvest of uniform crop of wheat in mid-April of 2013, Bt cotton hybrid (MRC 7017) was planted in the end of May

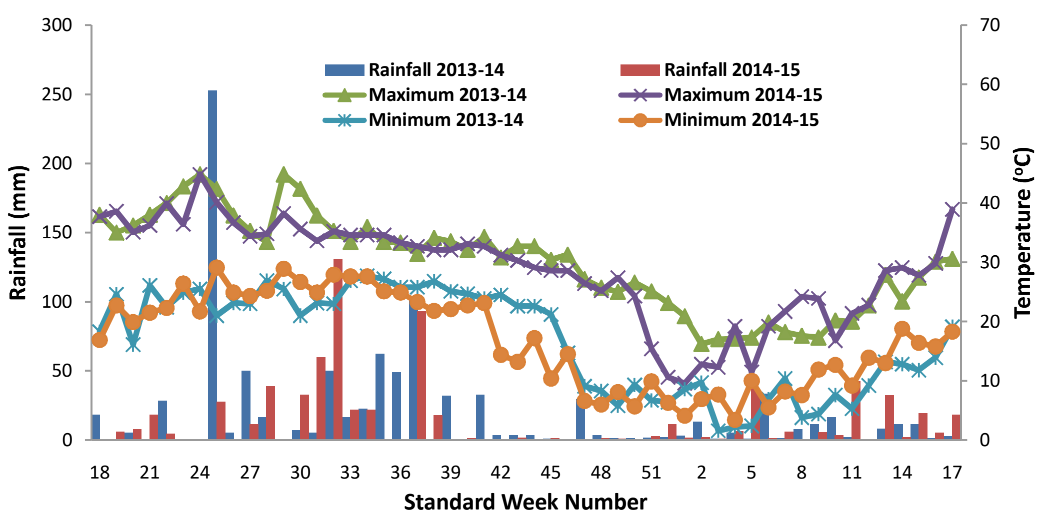

Fig. 1. Monthly rainfall, temperature (Maximum and minimum) during the crop season in 2013-14 and 2014-15

under two geometries (67.5 cm row by 75 cm plant spacing and 102 cm row by 50 cm plant spacing). Seed drill having inclined plate seed-metering system was used for planting cotton with a seed rate of 3 kg ha^{-1}. Recommended doses of 150 kg N, 30 kg P and 25 kg K ha^{-1} were applied as urea, di-ammonium phosphate (DAP) and muriate of potash (MOP), respectively, in both the years. While whole of the P and K was applied at the time of seeding, balance of fertilizer N (total minus added through DAP) was applied in two equal splits (50% at thinning or 35 days after seeding (DAS) and 50% at flowering stage or 80 DAS) coincided with irrigation events. Mungbean (var. SML 668) was sown in last week of April in both years using high clearance tractor with a seed rate of 20 kg ha^{-1}. Three rows of mungbean were planted in PBBc + MB treatment on alternate side of beds. Mungbean seeds were treated with cultures of *Rhizobium* and phosphate solubilizing bacteria before seeding. The basal dose of 100 kg ha^{-1} of DAP (18% N and 46 % P_2O_5) was applied at the time of sowing. Wheat var. HD 2967 was sown with a seed rate of 100 kg ha^{-1} in second week of November. Seed was treated with chlorpyrifos (20 EC, 400 ml 100 kg $seed^{-1}$ mixed in 5 liters of water) to control termite attack. High clearance 4-wheel tractor-mounted two types of relay seeders with 12 and 15 rows were used for relay seeding of wheat into 67.5 and 102 cm wide rows of cotton. A uniform fertilizer dose of 120 kg N, as urea 26 kg P as DAP and 33 kg K as MOP kg ha^{-1} was applied to wheat on all plots. One-third of N and whole of P and K fertilizers were drilled below the seed at the time of sowing, and the remaining N was applied in two equal splits at first irrigation (25-30 days after sowing) and at 2^{nd} irrigation (50-55 days after sowing). Tank mix solution of total (sulfosulfuron + metsulfuron) at 16 g ha^{-1} was applied to control *Phalaris minor* weed at 25-30 days after sowing. For managing weeds, herbicide glyphosate was sprayed @ 1.0 kg ha^{-1} in the ZT and PB plots about two days before sowing of each crop.

Residue management: The entire cotton sticks were removed from the field, which are used as fuel in the region. About 75% of the wheat straw after combine harvesting is generally collected from the fields for use as animal fodder and the remaining portion is burnt in-situ. In study, wheat from experimental plots was manually harvested at ~25-30 cm height from the ground to simulate combine harvesting. After removing grains, the straw was removed and the anchored stubbles were retained in all plots. Cotton residue left after removing sticks included the leaves and tender twigs. In case of mungbean all the residues after removing pulse grains were retained under PBBc+MB plots. The amounts of wheat, cotton and mungbean residues retained in the plots averaged (for the two years) were about 2 .0, 0.6, and 3.0 Mg ha^{-1}, respectively.

Soil sampling and processing: The soil was sampled in

Table 1. Initial status (Prior to wet season, 2013) of soil properties at the experimental site

A. Soil Physical properties

Soil properties	Depth (cm) 0-15	15-30	30-60
BD (Mg m^{-3})	1.48	1.48	1.59
HC (mm hr^{-1})	13.04	11.39	
Infiltration (mm ha^{-1})	On Top	Furrow	
	22.20	16.65	

B. Soil aggregation

Depth (cm)	Total WSA%	% Of micro aggregate (<0.25 mm)	% Of micro aggregate (>0.25 mm)	MWD (mm)	GMD (mm)	Particle size distribution Sand (%)	Silt (%)	Clay (%)	Soil texture
1-15	58.81	33.89	24.91	0.79	0.56	62.0	30.9	7.1	SL
15-30	51.35	30.10	21.25	0.68	0.53	65.5	25.2	9.2	SL
30-60	47.73	28.64	19.09	0.60	0.52	66.1	25.5	8.4	SL

C. Soil chemical properties

Depth (cm)	pH	EC (dS/m)	SOC (g kg^{-1} of soil)	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)
0-15	8.2	0.27	4.6	127.4	10.56	149.4
15-30	8.3	0.22	3.1	72.61	7.10	110.1
30-60	8.3	0.18	1.5	43.13	5.1	90.0

HC= Hydraulic conductivity; BD= Bulk density; SL= Sandy loam; Water stable aggregates; SOC= Soil organic content; MWD= Mean weight diameter; GMD= Geometric mean diameter; WSA= Water stable aggregates

2013-14 (prior to establishing the experiment) and 2014-15 (after harvest of *Rabi* season crop) from fixed plots. Soil physical and chemical parameters were recorded at end of the research experiments. The soil samples for bulk density, pH, EC, available nutrient NP&K and total organic carbon of soil profile (0-15, 15-30 and 30-60 cm) were collected in triplicate from each experimental unit by a core sampler with core of 5 cm height and 5 cm diameter. Soil samples from 0-15, 15-30 and 30-60 cm layers were collected using hand shovel for aggregate analysis. After drying in shade, they were broken by giving gentle stroke in a wooden hammer and only aggregates of 4-8 mm size were used for aggregate analysis.

Soil physical properties: Physical properties of soil such as bulk density, hydraulic conductivity, infiltration rate, soil aggregation and soil moisture were calculated by adopting the following methodologies. The procedure for determining bulk density was followed as described by Chopra and Kanwar (1991). The soil collected for bulk density with the core sampler (0-10 and 10-20 cm depth) was used for determining the hydraulic conductivity using constant head method (Mishra and Ahamed 1987). Direct moisture infiltration was measured by double ring infiltrometer (Bouwer 1986). Infiltration rate measured on top (Without tractor wheel passed with included plant row line) and furrow (Tractor wheel passed with excluded plant row line). Two infiltrometer rings were set across uniform and well levelled plots to a depth of 15 cm after dry field preparation at the beginning and termination of experiment. The infiltration rate was expressed as mm hr^{-1}. Soil water stable aggregates (WSA) >0.053 were determined by wet sieving procedure (Cambardella and Elliot 1993). The aggregate size distribution of soil was determined by wet sieving method using Yodders apparatus (Yodder 1936). Mean weight diameter (MWD) of aggregates was estimated (Kemper and Rosenau, 1986) using the formula of Eq.

$$\mathrm{MWD(mm)} = \sum_{i=1}^{i=n}(\mathrm{XiWi}) \sum_{i=1}^{i=n}(\mathrm{Wi})$$

Where, Wi, is the proportion of aggregates retained on each sieves in relation to the whole, Xi is the mean diameter of the sieve (mm). The geometric mean diameter (GMD) was determined by using the following formula of Eq.

$$\mathrm{GMD\ (mm)} = \exp\left(\left(\sum_{i=1}^{i=n} \mathrm{Wi} \log \mathrm{Xi} \Big/ \sum_{i=1}^{i=n} \mathrm{Wi}\right)\right)$$

Soil chemical properties: The samples were air-dried and organic carbon content in soil samples were determined by Walkley and Black (1934) method. Soil pH of surface and profile soil samples were measured (1:2 soil: water suspension) using pH meter fitted with calomel glass electrode. Electrical conductivity of 1:2 soil: water

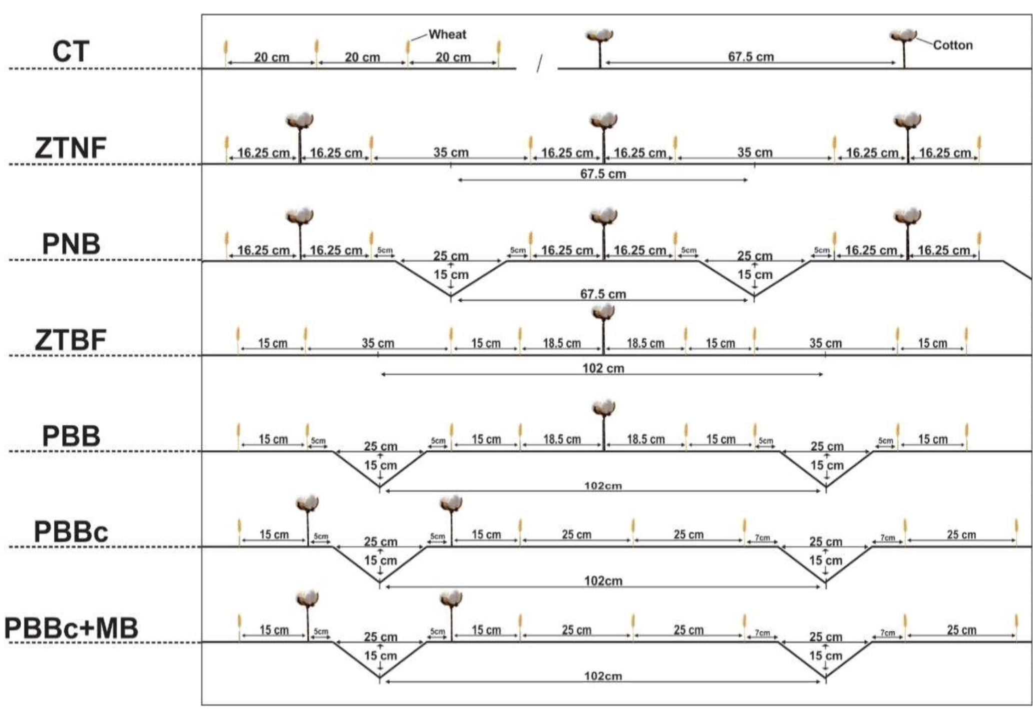

Fig. 2. Configuration of cotton, wheat and mungbean crops under different treatments in cotton-wheat system. For treatment descriptions refer to Table 1

supernatant (kept overnight) was estimated using solubridge (Richards et al 1954). The available N was estimated by alkaline $KMnO_4$ method suggested by Subbiah and Asija (1956) and expressed in kg ha^{-1}. The available P content in soil was estimated by Olsen's method (Olsen et al 1954). Available K was determined using neutral normal ammonium acetate extraction (flame photometer) method as described by Jackson (1973) and expressed in kg ha^{-1}.

Statistical analysis: The data recorded for different parameters were analyzed with the help SAS 9.1 software (SAS Institute, Cary, NC). Tukey procedure was used to study treatments.

RESULTS AND DISCUSSION

South Asia faces the issues of soil health deterioration and over exploitation of underground water resources; particularly in conventional tillage based intensive crop rotations. The Conservation agriculture (CA) based tillage and crop establishment practices such as zero tillage (ZT) and permanent raised beds (PB) with residue hold potential to improves soil physico-chemical properties, carbon sustainability index and plant nutrients use efficiency of cotton-wheat system compared to conventional tillage systems with a wide variety of soils and agro-ecological conditions.

Effect on soil physical properties: CA-based management practices showed significant effect on soil physical properties in cotton-wheat sequence after two years studies.

Bulk density: The bulk density under conservation based management practices (PB-N, ZT-N, PBB-A, ZT-B, PBB and PBBc+MB) was significantly lowered by 9.4-10.6% in 0-15cm and 4.3-7.4% in 15-30cm soil profile than CT practices (Table 3). The decrease in BD under CA could be due to higher SOC content, better aggregation and increased root growth. Elsewhere, the similar findings reported by Salem et al (2015). PBBc+MB was significantly minimum BD due to intensification of mungbean crop. The similar findings of lower BD due to pulses inclusion were also reported by Verhulst et al (2011). Permanent bed planting techniques (PBBc+MB, PBBc, PBB and PNB) of crop establishment resulted significantly lower values of the BD over flat planting (ZTNF and ZTBF) in upper layers of the soil profile under respective tillage practices. The maximum BD was under CT (1.60 Mg m^{-3}) at 0-15 cm. While, lowest BD was recorded with PBBc+MB (1.43 g cm^{-3}) in 0-15 cm soil depth (Table 3). The BD was recorded higher in lower layers of the soil profile due to absence of residue and low organic matter content than upper layers under all the treatments. The similar results were also reported by Obalum and Obi (2010).

Table 2. Description of the treatments

Treatment abbreviation	Cotton	Wheat
CT	Residues of previous wheat removed. Conventional tillage (CT) for cotton included two ploughings with disc harrow and one with cultivator followed by planking. Cotton planted at 67.5 cm row spacing with seed cum-fertiliser drill.	Stalks of previous cotton removed. Conventional tillage for wheat included two ploughings with disc harrow and one with cultivator followed by planking. Wheat planted with seed cum fertiliser drill
ZTNF	ZT narrow (67.5 cm) flat. Cotton planted in the middle of each bed. Same as above	Same as in PNB treatment.
PNB	Permanent narrow raised bed (PNB). The PNB system consisted of permanent raised beds of 67.5 cm (42.5 wide from top and separated by furrow of about 25 cm wide, and 15 cm deep). Permanent beds involved no ploughing, but minor reshaped and cotton planted in a single operation using a high clearance tractor operated relay seeder. One row of cotton planted in the middle of 67.5 cm wide raised beds.	Permanent beds involved no ploughing, but minor reshaped and relay seeded in single operation (2 rows/ bed on either side of cotton row) with 4-wheel high clearance tractor using double ZT disc opener relay seeder.
ZTBF	ZT broad (102 cm) beds flat. Cotton planted at 102 cm row spacing in the centre of flat beds.	Relay sowing (4 rows/bed; two paired wheat rows on either side of cotton row)
PBB	Permanent broad (102 cm) raised bed (PBB) prepared by making adjustments in normal bed planter using narrow wheel tractor. The PBB system consisted of broad beds of 102 cm wide, with 77cm from top of beds separated by furrow of about 25cm wide and 15 cm deep. Cotton planted in the centre of 102 cm wide beds.	Same as above.
PBBc	Permanent broad (102 cm) raised bed. Cotton planted at alternate side of the bed.	Relay sowing (3 rows/bed) on the opposite side of the cotton row on the bed).
PBBc+MB	Permanent broad (102 cm) raised bed. Cotton planted at alternate side of the bed. Mungbean (3 rows/bed) planted after wheat harvest in the same rows.	Relay sowing (3 rows/bed) of wheat on the opposite side of cotton row on each bed.

Hydraulic conductivity: The average saturated hydraulic conductivity (HC) of soil was influenced significantly due to conservation practices and crop establishment techniques in the surface (0-10 cm soil depth) as well as sub surface (10-20 cm soil depth) soil layers (Table 4). Moreover, hydraulic conductivity was higher 11.9 % at 0-10 cm soil depth compare to 10-20 cm soil depth. The increase in HC under conservation agriculture practices (PB and ZT) was mainly attributed to decrease in bulk density and increase in effective pore volume because of better soil aggregation in these practices. Similar findings have also been reported Li et al (2011). The maximum values of hydraulic conductivity was measured under PBBc+MB (15.67 and 14.66 mm hr^{-1}) in 0-10 and 10-20 cm soil depth, respectively; in the former depth (0-10 cm) it was significantly greater than rest of the treatments, but at par with PBBc. Saturated hydraulic conductivity of PBBC+MB was 25% and 41% higher than for CT in both the layers, respectively (Table 4). While in the later depth (10–20 cm) it was significantly higher as same trend in depth of 0-10cm. Permanent broad bed planting resulted significantly 8.9% and 12.4% higher rate of the HC compared flat planting in both the soil layers in respective tillage practices. Bed system was also probably due to better root growth and continuous channels formed by decaying roots serve as routes linking the soil surface to deeper layers. ZTNF, PNB and PBB were significantly higher than CT and ZTBF and it was significantly greater than CT in both the layers. Residue application also significantly improved the hydraulic conductivity due to addition of the organic matter in the soil which improves the soil macro-aggregates that might facilitate easy movement of water in the soil over no-residue application under CT in both the layers in respective planting systems. The similar results were also reported by Blanco-Canqui and Lal (2007).

Infiltration rate: The mean initial infiltration rate (initial infiltration rate after 5 min) was significantly higher under CT

Table 3. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on soil organic carbon content and bulk density in different soil layers

Treatments†	Organic carbon content (g kg^{-1})			Bulk density (Mg m^{-3})		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
CT	3.72c‡	2.70b	1.42a	1.60a	1.63a	1.65a
ZTNF	4.85a	3.15a	1.40a	1.44b	1.52b	1.56a
PNB	4.70ab	3.10a	1.80a	1.44b	1.53b	1.56a
ZTBF	4.82a	3.12a	1.30a	1.45b	1.56b	1.62a
PBB	4.72ab	3.40a	1.42a	1.43c	1.53b	1.59a
PBBc	4.60b	2.90ab	1.80a	1.44b	1.51b	1.58a
PBBc +MB	4.90a	3.42a	1.70a	1.43c	1.52b	1.59a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05

Table 4. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on hydraulic conductivity and infiltration rate

Treatments†	Hydraulic conductivity (mm hr^{-1})		Infiltration rate (mm hr^{-1})		
	0-10 cm	10-20 cm	Initial$	Steady state	
				On top #	Furrow ¥
CT	12.54d‡	10.40d	135.8a	20.72c	14.62c
ZTNF	14.45b	12.78b	98.7c	30.57b	21.62b
PNB	14.37b	12.64b	103.3b	34.50ab	22.51ab
ZTBF	13.15c	11.62c	95.3c	31.67b	21.71b
PBB	14.51b	12.94b	105.3b	34.67ab	23.39a
PBBc	15.59a	14.63a	103.7b	34.89ab	22.16ab
PBBc +MB	15.67a	14.66a	110.0b	36.72a	23.77a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05; $Indicate initial infiltration rate after 5 min, #steady state infiltration rate on top (Without tractor wheel passed with included plant row line) and ¥furrow (Tractor wheel passed with excluded plant row line), respectively

plots than all rest of treatment plots, but in case of steady state infiltration rate under conservation practices (PB&ZT) were influenced significantly due to conservation tillage and crop establishment techniques compared CT. The mean initial infiltration rate (initial infiltration rate after 5 min) was significantly 23.45–42.6 % higher under CT plots than all rest of treatment plots (Table 4), but in case of steady state infiltration rate under conservation practices (PB&ZT) were influenced significantly due to conservation tillage and crop establishment techniques compared CT. The increase of hydraulic conductivity and infiltration rate by tillage and bed system was also probably due to better root growth and continuous channels formed by decaying roots serve as routes linking the soil surface to deeper layers. The Steady state infiltration rate on top was about 1.49 times compared on furrow (Table 4). Steady state infiltration rate on top was significantly higher under conservation tillage and crop establishment techniques than CT with 47.5-52.8 and 66.5-77.2% under ZT and PB, respectively (Table 4). Similarly, steady state infiltration on furrow (Tractor wheel passed with excluded plant row line) rate was significantly higher 62.58 % in PB compared to CT. Tillage and residue management also influenced steady-state infiltration (Verhulst, et al 2011).

Soil aggregation: Effect of tillage and crop establishment techniques were significantly higher WSA %, macro-aggregates, micro-aggregates, MWD and GMD in different soil layers but except 30-60cm layer (Table 5 & 6). The WSA% was significantly (71.4%) highest under PBBc+MB compared all remain treatments and followed by PNB, PBB & PBBc were significantly higher than CT, ZTNF and ZTBF at 0–15 cm soil layer. CT was significantly inferior compared all the rest of treatments. At 0-15cm layer of soil was recorded 44.8, 74.2 and 25.1% higher under PPBc+MB with water stable aggregates (WSA), macro-aggregates and micro-aggregates, respectively compared CT after harvest the last rabi crop (wheat). The highest WSA, macro-aggregates and micro-aggregates under ZTNF with 35.5, 58.7 and 18.6 % higher compared CT at 15-30 cm layer, respectively (Table 5). In minimum tillage systems, new aggregates were formed due to incorporation of crop residues in the soil and storage of excess organic matter in biochemically degraded fraction especially in the surface soil (Chaudhary et al 2015).

Table 5. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on soil aggregates in different soil layers (cm)

Treatments†	WSA %			Aggregate (>0.25)			Aggregate (<0.25)		
	0-15	15-30	30-60	0-15	15-30	30-60	0-15	15-30	30-60
CT	49.3d‡	47.0c	53.4a	19.8d	20.1c	25.3a	29.5d	26.9c	28.1a
ZTNF	61.2c	63.7a	55.4a	30.2c	31.9ab	25.9a	31.0c	31.9a	29.4a
PNB	67.5b	58.1ab	52.3a	32.8b	28.5ab	24.7a	34.7b	29.7ab	27.6a
ZTBF	61.6c	62.4a	53.8a	30.4c	31.4ab	25.4a	31.2c	31.0a	28.4a
PBB	67.5b	58.5ab	52.1a	32.8b	28.6ab	24.5a	34.7b	29.9ab	27.6a
PBBc	65.2b	55.9b	53.9a	31.3b	27.3b	25.0a	33.9b	28.5b	28.9a
PBBc +MB	71.4a	59.7ab	52.3a	34.5a	29.3ab	24.97a	36.9a	30.4ab	27.4a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05.

Table 6. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on mean weight diameter (MWD) and grand mean diameter (GMD) of soil aggregates in different soil layers

Treatments†	MWD			GMD		
	0-15	15-30	30-60	0-15	15-30	30-60
CT	0.76c‡	0.66c	0.65a	0.57b	0.53b	0.56a
ZTNF	1.13b	0.91a	0.67a	0.63a	0.63a	0.56a
PNB	1.24a	0.81b	0.66a	0.63a	0.58a	0.55a
ZTBF	1.14b	0.89a	0.70a	0.62a	0.63a	0.57a
PBB	1.24a	0.81b	0.65a	0.63a	0.58a	0.55a
PBBc	1.19a	0.77b	0.65a	0.63a	0.58a	0.54a
PBBc +MB	1.28a	0.85ab	0.67a	0.63a	0.61a	0.56a

†Refer table 2 for treatment description
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05

The MWD was significantly (1.28) highest under PBBc+MB compared CT, ZTNF and ZTBF but it was statistically ($P < 0.05$) at par with PNB, PBB & PBBc in 0-15 cm layer (Table 6). PBBc+MB was 68.42 % higher at 0-15cm layer than CT. ZTNF was significantly highest (0.91) MWD than all the treatment, only except ZTBF and PBBc+MB at 15–30 cm layer. At 30-60cm layer of soil MWD was recorded non-significant. In case of GMD, all conservation tillage practices (all treatments) were significantly (8-10%) higher than CT at 0-15 and 15-30 cm layer. GMD was recorded non-significant in all treatments at 30-60 cm layer. This might be due to non-disturbance of the soil with tillage and addition of residues might have contributed for increased MWD and GMD (Meena and Behera 2008).

Effect on soil chemical properties: CA-based management practices showed significant effect on soil chemical properties (except pH) in cotton-wheat sequence after two years' studies.

Soil organic carbon: Total soil organic carbon content (SOC) under PBBc+MB was significant higher (28 % or 4.90 g kg^{-1}) SOC in 0-15 cm layer compared CT but it was statistically similar with all remain treatments only except PBBc. All conservation tillage treatments (ZT&PB) were significantly 0.9-1.18 g kg^{-1} higher compared CT at surface layer. Crop residues application significantly ($P>0.05$) increased the SOC under PBBc+MB, ZTNF, ZTBF, PBB and PNB by 31.7, 30.3, 29.6, 26.9 and 26.3 % over CT, respectively in 0-15 cm layer of soil. Permanent raised beds with full residue retention with mungbean intensification increased soil organic C 1.28 times more over the conventional tilled at 0–15 cm layer and 1.17 times more at 15–30 cm layer (Table 3) Similar findings were also reported by Sarkar and Kar (2011). In case of 15-30 cm layer of soil, SOC was significantly (0.90 g kg^{-1}) higher than CT but it was statistically at par with all remain treatments only except PBBc. SOC was non-significant in all treatments at 30-60 cm layer of soil. Total soil organic carbon content (SOC) was affected significantly due to conservation tillage, permanent beds with residue management and diversified crop rotations on total soil organic carbon in soil (Kaiser et al 2014).

Soil pH and electrical conductivity: The pH of soil was not influenced significantly due to different continuous tillage, crop establishment techniques and diversified crop rotations (Table 7). The maximum value of pH was recorded under CT (8.25) followed by ZTBF (8.22), while least was recorded under PBBc+MB (8.10) at 0-15 cm layer of soil depth. It was similar trend at 15-30 and 30-60cm layer. Electrical conductivity was influenced significantly highest (0.26 dS/m) under PNB due conservation tillage, permanent beds with residue management and diversified crop rotations compared CT but it was statistically at par with all remain treatment (conservation tillage) in 0-15 cm layer of soil (Table 7). It was recorded non-significantly under all the treatment at 15-30 and 30-60 cm layer of soil depth. The similar results were also reported by Verhulst et al (2011). Opposite to pH, EC values were slightly decreased under residue applied treatments over no-residue (CT) applied treatments. Tillage and straw management usually had little or no effect on soil pH in any soil layer (Malhi et al 2011).

Available N, P & K: Available nitrogen (N) status in soil under PBBc+MB was influenced significantly (144.50 kg ha^{-1}) highest than all the remains treatments, but it was statistically at par PBB. PBBc was significantly higher N compared CT but, it was similar ZTBF and PNB. However, Available P and K status in soil were found similar trend as well as N status in 0-15cm layer of soil (Table 8). PBBc+MB was reported 38.22, 48.23 and 23.8 % higher under N, P & K available status in 0-15cm layer compared CT, respectively. In case of 15-30cm

Table 7. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on electrical conductivity and pH in different soil layers

Treatments[†]	pH			EC (dS/m)		
	After study			After study		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
CT	8.25a	8.34a	8.42a	0.22b‡	0.19a	0.15a
ZTNF	8.18a	8.25a	8.28a	0.24a	0.24a	0.18a
PNB	8.11a	8.21a	8.25a	0.26a	0.23a	0.20a
ZTBF	8.22a	8.30a	8.30a	0.24a	0.18a	0.16a
PBB	8.12a	8.22a	8.30a	0.24a	0.18a	0.16a
PBBc	8.15a	8.27a	8.28a	0.24a	0.22a	0.18a
PBBc +MB	8.10a	8.20a	8.30a	0.25a	0.20a	0.16a

[†]Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05.

Table 8. Effect of conservation tillage, permanent beds with residue management and diversified crop rotations on available nitrogen, phosphorus and potassium (kg ha^{-1}) content of soil in different soil layers

Treatments†	0-15 cm			15-30 cm			30-60 cm		
	N	P	K	N	P	K	N	P	K
CT	104.54c	8.77c‡	128.20c	70.27b	6.67a	109.31b	42.73a	4.92a	89.90a
ZTNF	140.27a	12.20a	156.61a	73.55a	7.83a	113.75a	43.44a	5.37a	92.89a
PNB	131.71b	10.73b	154.52b	72.74a	7.53a	112.58a	43.20a	5.13a	92.36a
ZTBF	131.07b	10.50b	153.17b	73.59a	7.33a	114.84a	43.86a	4.33a	92.29a
PBB	140.69a	12.83a	158.55a	71.97a	7.33a	111.66a	43.86a	5.42a	94.38a
PBBc	134.28b	12.00b	155.94b	71.46a	6.33a	114.65a	42.19a	4.86a	95.87a
PBBc +MB	144.50a	13.00a	158.77a	74.69a	7.34a	115.21a	42.61a	5.42a	89.90a

†Refer table 2 for treatment description.
‡Means in the same column followed by different lowercase letters differ significantly from each other based at p=0.05.

layer, available N and K status in soil were influenced significantly due to different continuous tillage, crop establishment techniques and with residue management compared CT, but available P was non-significant in 15-0cm layer (Table 8). PBBc+MB was recorded 6, 5.4 and 5.4 % higher with available N, P and K status in 15-30cm layer compared CT, respectably. However, Available N, P and K status were non-significantly in 30-60 cm layer of soil. The higher amount of SOC in surface soil layer in CA is due to higher accumulation of crop residue which also increases nutrient availability (Marahatta et al 2014).

CONCLUSIONS

The major aim of this study was to evaluate the impacts of promising RCTs on soil physico-chemical properties in cotton–wheat system in the western IGP. Our study showed that RCTs such as permanent broad beds (PBB), relay planting of wheat in cotton and integrating mungbean in cotton under PBBc+MB was recorded 28 and 17.8 % higher SOC compared to CT in CW system under 0-15 cm and 15-30 cm layer, respectively. BD was significantly higher (9.4-10.6 and 4.3-7.4) in 0-15 and 15-30cm layer compared CT. Similarly, hydraulic conductivity was increased 1.19 & 1.10 time more under PBB (PBBc+MB) and ZT practices at 0-10 cm layer compared CT. The Steady state infiltration rate was about 1.41 times higher under PB practices (PBBc+MB) compared on furrow. Soil aggregates was recorded 44.8, 74.24 and 25.1% higher under PPBc+MB with WSA, macro-aggregates and micro-aggregates in 0-15cm layer compared CT, respectively. The pH and Electrical conductivity of soil was improved due to RCTs practices compared CT. PBBc+MB was significantly 38.22, 48.23 and 23.8 % higher under N, P & K available status in 0-15cm layer compared CT, respectively. Thus, these results are of tremendous importance in terms of identification of a suitable sustainable management practice under a non-rice based cotton-wheat system, and are very novel in the South Asia. Thus, the said PBBc + MB package of practice has a wide scope for adoption in the cotton-wheat system of this region and other countries with similar agro-ecologies, where intensive tillage is practiced.

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