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Effect of conservation agriculture and precision nutrient management on soil properties and carbon sustainability index under maize-wheat cropping sequence

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Abstract

Conventional practices has for many years resulted in the deterioration of soil quality through depletion of soil organic matter and nutrients. Maize based system is being recommended as an alternate to rice-based systems to address the issues of resource degradation. Therefore, a two year field experiment was conducted in farmer's participatory strategic research mode at Taraori, Karnal, India to evaluate the effect of conservation agriculture (CA) and green gram integration with precise nutrient management on soil quality and carbon sustainability index (CSI). Four treatment namely conventional tillage (CT), conventional tillage with green gram (CT+GG), permanent bed (PB) and permanent bed with green gram (PB+GG)] layered with three nutrient management strategies [farmer's fertilizer practice (FFP), recommended dose of fertilizer (RDF) and site specific nutrient management (SSNM)]. The PB+GG recorded 29.4% higher water stable aggregates and lower BD. In PB+GG soil penetration resistance was reduced and infiltration was increased compared to CT. Soil organic carbon was significantly higher under PB+GG. Available N and P was 4 and 14 percent higher at 0-15 cm soil depth as compared to CT. SSNM recorded 1.72 and 3.50 % higher SOC as compared RDF and FFP, respectively at 0-15 cm soil depth. PB+GG recorded 18% higher CSI as compared to CT. SSNM increased CSI by 20 and 25% as compared to FFP during 2012-13 and 2013-14, respectively.

Keywords: Carbon sustainability index, conservation agriculture, maize-wheat system, precision nutrient management, soil physical and chemical properties

Introduction

Rice-wheat cropping system is crucial for the country's food security, but not to ensure sustainability of natural resources and crop productivity for long-period. Several scientist documented multiple challenges of sustainability in rice-wheat (RW) rotation especially the rapidly falling water tables and the deteriorating soil health (Bhatt *et al*., 2016; Sharma *et al*., 2012) [5, 30]. Therefore, it is important to diversified crops and cropping systems, which are not only environmental friendly, but also efficient in conserving available natural resource (Aulakh and Grant, 2008; Jat *et al*., 2008, 2013) [2, 41]. Maize-wheat cropping system (MW) has emerged as a pre-dominant option for diversification of existing rice-based cropping systems in Indo-Gangetic Plain (IGP) of India (Parihar *et al*., 2017) [45]. Maize-wheat rotation is the third dominant cropping system of Indian IGP occupying 1.86 million ha (Mha) with 2.3% contribution in food basket in Indian IGP (Jat *et al*., 2013; Sepat and Rana 2013) [41, 50]. The conventional farmer`s practices of growing these crops are expensive, inefficient in use of water and nutrients leading to low productivity and input efficiency (Govaerts *et al*., 2006; Singh *et al*., 2016) [22, 31]. In this sense, alternative best crop management options like conservation agricultural practices which include zero tillage and permanent beds have demonstrated potential benefits on crop yield and profits while saving water, energy and restoring soil degradation across diverse ecologies (Jat *et al*., 2013; Das *et al*., 2014) [41, 15]. In this perspective, conservation agriculture (CA), legumes inclusion and precise nutrient management strategies has drawn considerable attention of researchers as it has potential to improve crop productivity, profitability, nutrient use efficiency and soil health, besides many environmental benefits (Limon-Ortega *et al*., 2000; Ghathala *et al*., 2011b; Busari *et al*., 2016; Parihar *et al*., 2016) [37, 5, 44].

Conservation agriculture based crop management, *viz*. zero-tillage (ZT), permanent raised beds (PRB) with residue retention can offset high production costs and problems related with land preparation (Malik *et al*., 2004; Ladha *et al*., 2009; Saharawat *et al*., 2012) [39, 26, 51]. ZT leads to positive changes in the physical (Gathala *et al*., 2011b; Jat *et al*., 2013) [41, 26], chemical (Parihar *et al*., 2016; Singh *et al*., 2016; Busari *et al*., 2016) [5, 45] and biological properties of a soil (Bescansa *et al*., 2006) [4] and simultaneously conserves water, reduces farm energy needs (Kumar *et al*., 2013) and increases crop production. Permanent bed (PB) planting with only superficial reshaping in the furrows between the raised beds as needed before planting of each succeeding crop can reduce machine traffic, limiting compaction to furrow bottoms, allows the use of lower seeding rates than with conventional tilled flat (CTF) planting systems and reduces crop lodging (Sayre and Moreno-Ramos, 1997).

The use of blanket nutrient management recommendations in IGP region has led to low nutrient use efficiencies, increasing soil pollution, lowered economic return and promoted air pollutions(Pampolino*et al*.,2012)[42].Nutrient recommendations in IGP regions are based upon crop response data averaged over large geographic areas and do not take into account the variability of spatial as well as temporal in indigenous nutrient supplying capacity of soils (Majumdar *et al*., 2013) [38]. Surveys in the IGP region revealed that farmers often apply higher than recommended rates of fertilizer N and P, but ignore the sufficient application of potassium and other secondary and micro-nutrients (Yadvinder-Singh *et al*., 2005) [68]. Site specific nutrient management (SSNM) enhances the soil health, crop yield, and nutrient use efficiency of maize-wheat system. SSNM captures the spatial and temporal variability in soil fertility in smallholder production system and provides an approach to “feeding” crops with all the required nutrients based on crop’s needs and thus improves the crop yields and quality of soil, crop and environment (Das *et al*., 2009; Tiwari *et al*., 2006; Sapkota *et al*., 2014) [14] with greater nutrient use efficiency (IPNI, 2013). Crop residues are the source of organic C input in the maize-based cropping systems and are often attributed to the increase in soil physico-chemical properties and carbon sustainability index (CSI) (Yadvinder-Singh *et al*., 2005; Jat *et al*., 2013) [41, 68].

Studies on changes in soil physico-chemical properties and carbon sustainability index under precision conservation agriculture in MW cropping system are very limited in Indian IGP. Therefore, an attempt was made to study on soil physico-chemical properties and carbon sustainability index under precision conservation agriculture for addressing the second-generation problems of RWS.

Materials and methods

Experimental site and climate

The study was conductedfor two consecutive years during 2012-2014 at participatory strategic research and learning platform for climate smart agriculture, Taraori, Karnal, (29°48’51 N latitude, 76°55’26 E longitude and 256 meters above mean sea level), Haryana, India. The study area represents irrigated and input intensive region of the Upper Gangetic Plain (UGP) zone of the Indo-Gangetic plain of India. The climate of the region is semi-arid and subtropical with extreme hot and dry (June) to wet summers (July-September) during the maize growing period and cold dry winters (November-April) for wheat, with an average annual rainfall of 670 mm (75-80% of which is received during southwest monsoon), minimum temperature of 0-4 °C in January, maximum temperature of 40-46 °C in June, and relative humidity of 60-95% throughout the year. Basic soil properties of the experimental site were determined at the start of the experimentation using standard protocols and are given in Table 1.

Table 1: Initial soil characteristics (0-15 cm soil depth) of experimental site

Soil properties	Values
Clay (%)	30.5
Silt (%)	37.4
Sand (%)	32.1
Soil texture	Clay loam
Bulk density (Mg m^{-3}) (Blake and Hartge, 1986) [7]	1.52
pH (1:2.5 soil: water) (Piper, 1950) [46]	8.02
EC (dS m^{-1}) (1:2.5 soil:water) (Piper, 1950) [46]	0.39
Organic C (g kg^{-1}) (Walkley and Black, 1934) [62]	5.70
Available N (kg ha^{-1}) (Subbiah and Asija, 1956) [58]	157.05
Available P (kg ha^{-1}) (Olsen *et al*., 1954) [41]	17.68
Available K (kg ha^{-1}) (Jackson, 1973) [24]	235.22

Table 2: Residue (t ha^{-1}) retained/ incorporated on the surface under different treatment during two years of study

Treatments	CT	CT+GG	PB	PB+GG	Mean
FFP	Remove[a]	21.36	16.12	22.65	15.03
RDF	Remove	22.58	17.56	24.27	16.10
SSNM	Remove	24.20	18.78	25.77	17.19
Mean	Remove	22.71	17.49	24.23	

[a] crop was harvested at ground level and all the above ground residue was removed after straw retrieval

Experimental design and treatments

The experiment was laid out in a split-plot design with tillage/crop establishment practices [Conventional tillage (CT), Conventional tillage with green gram, (CT+GG), Permanent bed (PB) and Permanent bed with green gram (PB+GG)] as main-plot and nutrient management [Farmers’ Fertilizer Practice (FFP), Recommended dose of fertilizers (RDF) and Nutrient Expert® decision support tool based fertilizer application (Pampolino *et al*., 2012) [42] (SSNM)] as sub-plot treatments. The 12 treatment combinations with a harvested subplot size of 30.15 m^2 (7.5 m length x 4.02 m width) were replicated thrice every year (for all the three years) of study. The details of treatment are summarized in Table 3. All treatments were completely randomized and replicated thrice within a block, each of 112 m^2 sizes (20 m×5.6 m). The border row of upper and bottom sides in the experimental field was kept as four meters allowing the space for turning the tractor. Crop residue was managed as per allocated treatments (Table 2).

Table 3: Description of tillage, crop establishment and residue management under different treatments

S. No.	Treatment abbreviation	Tillage			Crop establishment			Residue management		
		Maize	Wheat	Green gram	Maize	Wheat	Green gram	Maize	Wheat	Green gram
1	CT	2 pass of cultivator, 1 pass of rotavator, 1 pass of bed planter for making bed	3 pass of rotavator (2 pass before and 1 pass after broadcasting of seed)	-	Ridge seeding Line sowing	Broadcasting, random geometry	-	All removed	All removed	-
2	CT+GG	2 pass of cultivator, 1 pass of rotavator, 1 pass of bed planter for making bed	3 pass of rotavator (2 pass before and 1 pass after broadcasting of seed)	2 pass of rotavator (1 pass before and 1 pass after broadcasting of seed)	Ridge seedingLine sowing	Broadcasting, random geometry	Broadcasting, random geometry	50% maize residue incorporate in wheat cycle	Partial wheat residue (anchored) incorporate in green gram cycle	All green gram residue incorporate in maize cycle
3	PB	Zero till	Zero till and reshaping of beds	-	Direct drilling on permanent beds Line sowing	Direct drilling on permanent beds Line sowing	-	50% maize residue retained in wheat cycle	Partial wheat residue (anchored) retained in maize cycle	-
4	PB+GG	Zero till	Zero till and reshaping of beds	Zero till	Direct drilling on permanent beds Line sowing	Direct drilling on permanent beds Line sowing	Direct drilling on permanent beds Line sowing	50% maize residue retained in wheat cycle	Partial wheat residue (anchored) retained in green gram cycle	All green gram residue retained in maize cycle

*In the first crop cycle tilled, fresh beds were prepared with 67.5-cm spacing between furrows for the PB treatment using a bed planter. The beds were 15 cm height and 37 cm wide at the top; furrows were 30.5 cm wide. From this point on, this treatment was not tilled again – the beds were only reshaped as needed in the furrows for all succeeding crops.

Crop establishment

In May 2012, before the start of the experiment, the field was deep (30 cm) tilled using chisel plough to break the hard pan below the plough layer and was laser levelled. In CT fresh beds were developed using bed planter in every year. In the first year (July 2012), fresh raised beds were developed using bed planter which were maintained as permanent beds (PB) for subsequent years. The width of the beds (mid-furrow to mid-furrow) was 67.5 cm, with 37 cm wide flat tops, and 15 cm furrow depth. In every year of experimentation reshaping of permanent beds was done in one go simultaneously, while the crop was planted by using bed planter. Maize (NK-6240) was sown with seed rate of 20 kg ha^{-1} on top of the raised bed in PB by keeping plant spacing of 20 cm during third week June in rainy season and harvested in first week of October (in 2 years of the study). Wheat (cv. PBW 621-50) was broadcasted with a seed rate of 100 kg ha^{-1}in the last week of October to first week of November in every year. In PB two rows of wheat were planted on the top of the bed keeping a row spacing of 18.5 cm, with 82.5 kg ha^{-1} seed rate. Crop was harvested in second and third week of April during all the study years. Green gram cultivar SML-668 was seeded in second week of April with a seed rate of 18 and 25 kg ha^{-1}in PB+GG and CT+GG plots, respectively. Green gram was broadcasted in CT+GG, while two rows of green gram were planted on the top of the PB+GG keeping a row spacing of 18.5 cm, harvesting/pod picking was done in 3rd and 4th week of June during both the years. Prior to sowing, maize and wheat seeds were treated with imidachloprid and tabuconazole @5 ml kg^{-1} and 1 g kg^{-1} seed, respectively. The seed of green gram were inoculated with specific and efficient *Rhizobium* strain as per the standard procedure.

Under farmer's fertilizer practice, N-dose of 138 and 195 kg ha^{-1} in maize and wheat, respectively and 58 kg P_2O_5 ha^{-1} in both crops was applied as per the survey reports obtained from fifty farmers of nearby villages to the experimental site. RDF for maize and wheat was 150:60:60 kg ha^{-1} of N, P_2O_5 and K_2O based on the recommendation of CCS Haryana Agricultural University, Hisar, India. The site-specific nutrient management (SSNM) doses for maize and wheat were worked out by Nutrient Expert®, an interactive computer-based decision support tool that can provide 4R compliant fertilizer recommendations in Indo-Gangetic plains. It is a user-friendly tool developed by International Plant Nutrition Institute (IPNI) based on the SSNM principles.

The nutrient doses calculation by Nutrient Expert® were based on plant nutrient demand for a targeted crop yield, applied nutrient to previous crop, residue recycling, soil fertility status, and the economics of fertilizer input and prices of crop produce in the market. The SSNM recommendations based on the Nutrient Expert® decision support tool were 157:50:70.5 and 155:63:65 kg ha^{-1} of N: P_2O_5: K_2O (average of all tillage practices in 2 years) for maize and wheat, respectively. Calculated 1/3rd dose of N and full dose of P_2O_5 and K_2O were applied during final land preparation. Remaining 2/3rd dose of N was applied in two equal splits at the eight leaves (V8) and tasseling (VT) stages in maize, and at the 1st and 3rd irrigation in wheat. In PB plots, weeds before sowing of maize and wheat were killed using glyphosate @ 900 g a.i. ha^{-1}. To prevent weed germination in CT maize, pre-emergence spray of Atrazine (Atrataf 50 WP) @1.5 kg a.i.ha^{-1}was done on next day of sowing. In all CT plots, hoeing was also done as and when required at 30-35 days after sowing. For wheat, tank mix solution of sulfosulfuron + metsulfuron @32 g a.i. ha^{-1} or clodinafop-ethyl + metsulfuron @60+4 g a.i. ha^{-1} at 35 days after sowing was applied to control grassy as well as broad leaf weeds.

Soil sampling and analysis

Samples from 0-15 and 15-30 cm soil layers were collected with a core sampler (inner diameter of 50 mm) after 2 years of Maize-wheat-Green gram cropping cycle in June 2014 (after green gram harvest) from each plot. The soil samples were air-dried in shade, ground to pass through a 2-mm sieve, stored in plastic jar for laboratory analysis of selected soil chemical properties.

Measurement of soil parameters

Soil textural analysis was performed by following International Pipette Method (Piper, 1966). The textural class was determined by the United States Department of Agriculture (USDA) system (Soil Survey Division Staff, 1993). Soil bulk density was measured by core method using 5 cm long and 5 cm internal diameter metal cores by placing the core in the middle of each soil layer (Blake and Hartge 1986) [7]. Soil penetration resistance (SPR) was measured in 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45 and 45-50 cm soil layers at beginning of experiment and after two years of study using a manual cone penetrometer (Eijkelkamp Agri search Equipment, Germany). Double-ring infiltrometer with a 30 cm diameter of inner ring and 60 cm diameter of outer ring were used to measure the infiltration rate. One end of the rings was sharpened to facilitate the pushing into the soil. The two infiltrometers per plot were pushed into the ground to 10 cm depth. The infiltration rate was measured by recording the amount of water needed to maintain a constant level in the inner ring as a function of time (Bouwer 1986). To minimize the risk of altering the soil surface at the beginning of the infiltration process, a nylon guard cloth was placed on the soil surface. A constant water level (20 cm) was maintained in both the inner and outer rings of the infiltrometer. The measurements were recorded at 0 min, 5 min, 10 min, 15 min, 30 min, 45 min, 60 min, 120 min, 180 min, 240 min, 300 min and 360 min until a steady state infiltration rate was achieved.

Soil pH and electrical conductivity (EC) in soil: water ratio of 1:2.5 was determined by following standard methods (Jackson 1973) [24]. Soil organic carbon content in 0-15 and 15-30 cm soil layer as measured by Walkley and Black's wet oxidation method as described by Jackson 1973 [24]. The available N was estimated by alkaline $KMnO_4$ method suggested by Subbiah and Asija (1956) [58] and expressed in kg ha^{-1}. The available P_2O_5 content in soil was estimated by Olsen's method (Olsen *et al*., 1954) [41]. Available K_2O was determined using neutral normal ammonium acetate extraction (flame photometer) method as described by Jackson (1973) [24] and expressed in kg ha^{-1}.

Total carbon input

The carbon equivalence as suggested by Lal and Kimble (1997) for various inputs viz; chemical fertilizer (NPK), diesel, tillage, lubricants, machinery and agro-chemical etc. were used for estimation of total carbon inputs and expressed in MJ ha^{-1}.

Total carbon output

Three components of C output included for conversion in carbon equivalent:

1. Grain /seed yield
2. Straw/stover yield
3. Root biomass

Carbon sustainability index

Sustainability Indices for both the years were calculated by dividing the difference between the total C output and C input by C input (Lal, 2005).

Cs = (Co – Ci) / Ci

Cs – Sustainability Index, Co – Carbon Output, Ci – Carbon Input

Aggregate stability and mean weight diameter (MWD)

Soil samples collected from 0-15 and 15-30 cm layer with the help of a spade were air-dried, and gently crushed to pass 5 mm sieves. Air-dried soil clods were used for estimating aggregate size distribution by wet sieving method (Kemper and Rosenau (1986) using a nest of sieves of 4.00, 2.00, 1.00, 0.50, 0.25, 0.11 and 0.053 mm for the separation of four aggregate size classes namely coarse macro aggregate (>2.0 mm), mesoaggregate (2.0-0.25 mm), micro aggregate (0.25-0.05 mm) and 'silt + clay' sized fractions (<0.05 mm). One sample was kept for determination of water stable aggregates, whereas, other was used for estimating primary particles after dispersion with 0.5% (w/v) sodium hexametaphosphate in 1:3 (soil: solution) ratio by mechanically stirring the suspension for 15 min before the vertical oscillation of the apparatus for 30 min at a frequency of 50 cycles per min^{-2} with taking care that the samples on the top sieve remain immersed throughout the full stroke. Before starting the oscillation, soil was left for slaking in water for 2 min. Sieves were then taken out and kept 5 min to drain out the water. The water stable aggregates (without dispersion) and the primary particles (with dispersion) of different sizes were collected from the respective sieves separately and weighed after oven drying at 50^0C for 24 h. Water-stable aggregate was expressed as percentage aggregation (>.25 mm size). The mean weight diameter (MWD) and geometric mean diameter (GMD) of aggregates were calculated as:

$$\text{MWD (mm)} = \frac{\sum_{i=0}^{n} X_i W_i}{\sum_{i=0}^{n} W_i}$$

Where n is the number of fractions (0.1-0.25, 0.25-0.5, 0.5-1.0, 1.0-2.0, 2.0-4.0, >4.0 mm), X*i* is the mean diameter (mm) of the sieve size class (0.175, 0.375, 0.75, 1.5 and 2.0 mm) and W*i* is the weight of soil (g) retained on each sieve.

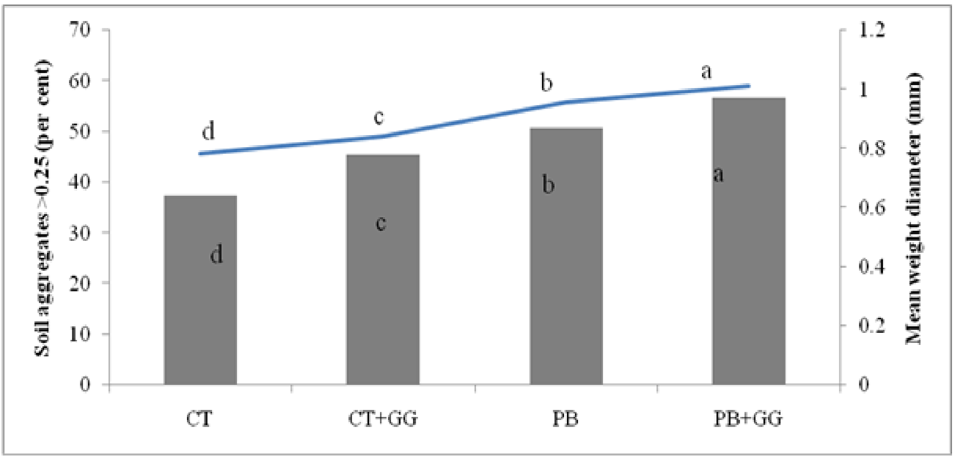
Statistical analysis and computations

All data were analyzed by two-way analyses of variance (ANOVA) in a 3×4 split-plot design (Sukhatme and Amble, 1985) using SAS 9.1 software (SAS Institute, Cary, NC).. The treatment means were compared using least significant differences for the main effects as well as their interactions at P = 0.05 level.

Results and discussion

Water stable soil aggregates

The distribution of soil mass among the size classes of water stable aggregates was significantly influenced by tillage, residue management and legumes but nutrient management practices did not influenced. In upper soil layer, PB+GG treatment had the highest water stable aggregates as compared to the other treatments (Fig. 1). Compared to conventional tillage, conservation agriculture (PB) coupled with green gram increased 29.4% water stable aggregates in surface soil. This treatment also showed the highest MWD in surface soil. In conventional tillage practices, residue incorporation resulted in 22.3 percent higher water stable macro aggregates as compared to the non-residue treatments. Similar trend was observed in MWD and it was 22.0, 35.9 and 51.5 times higher in CT+GG, PB and PB+GG treatments, respectively as compared to CT (Fig. 1). Residue incorporation or retention is the key to soil structural development and stability since organic matter is an important factor in soil aggregation (Verhulst *et al*., 2011). Application of organics in the form of residue combined with either conventional or conservation tillage improved the formation of water stable aggregates. Release of polysaccharides and organic acids during the decomposition of organic material plays a major role in stabilization of macro aggregates (Cheshire, 1979). Our results are in agreement with those of other researchers (Jat *et al*., 2013; Gathala *et al*., 2011a, 2011b) [41, 26] who reported that intensive tillage operations decreased soil aggregates stability. Physical disturbance of soil structure through tillage results in a breakdown of soil aggregates, increases turnover of aggregates (Six *et al*., 2000), and exposes fragments of roots and fungal hyphae, which are major binding agents for macro-aggregates (Bronick and Lal, 2005). In general, we found that the treatments with higher soil organic carbon (SOC) content had significantly higher MWD. The lesser soil disturbance under CA practices (PB+GG and PB) reduces oxidation of organic matter and hence improves storage of SOC. Inclusion of legumes (green gram) in PB+GG compared to without legumes rotations might result in higher SOC due to faster and easier decomposition of lower C:N ratio residues and root nodules (Srinivasan *et al*., 2004).

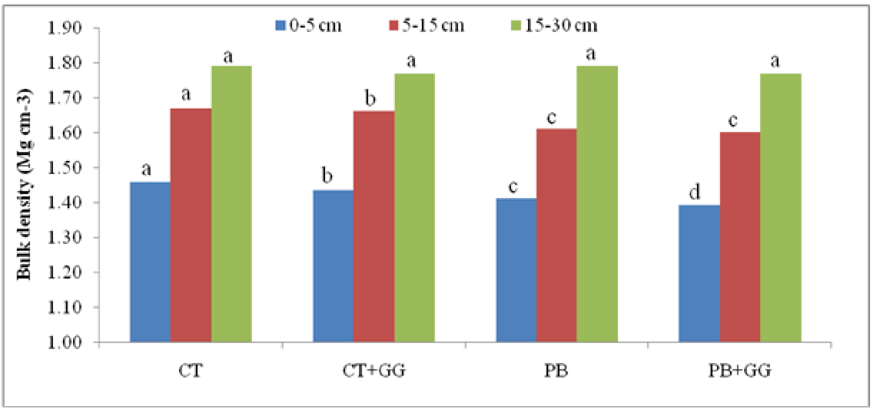


Sources	Analysis of variance (ANOVA)	
	Water stable soil aggregates (>0.25 mm)	**Mean weight diameter (mm)**
TRL	**	**
NM	NS	NS
TRL × NM	NS	NS

Fig 1: Effect of different tillage/crop establishment, residue retention and legume on water stable soil aggregates (>0.25 mm) and mean weight diameter (mm) at green gram harvest after two crop cycles of maize-wheat cropping system

Soil bulk density (BD

The bulk density (BD) of soil was influenced significantly by tillage, residue management and legumesat 0-5 cm and 5-15 cm soil depth while it remained statistically similar at15-30 cm soil depth. Generally, BD increased with an increase in depth irrespective of treatments.The BD was recorded lower by 5.0, 3.8 and 2.0% in 0-5 cm soil depth and 4.4, 3.8 and 1.0 % in 5-15 cm soil depth under PB+GG, PB and CT+GG, respectively compared to CT (Fig. 2). BD in the 0-5 and 5-15 cm layers was significantly lower in PB+GG than the rest of treatments. BD was higher by 3.5% for CT+GG than for PB+GG. The decrease in BD under CA (PB+GG and PB) could be due to higher SOC content, better aggregation, increased root growth and biomass (Unger and Jones, 1998; Jat *et al*., 2013; Busari *et al*. 2016) [41, 5]. Elsewhere, the similar findings of lower BD values under ZT were also reported by Yang and Wander (1999). In contrast, some researchers reported higher BD values in clay/silty loam soil under ZT (Kumar *et al*., 2002; Wilkens *et al*., 2002). The effect of nutrient management (NM) was not significant on BD at 0-5, 5-15 and 15-30 cm soil depths. Unger and Jones (1998) also reported that soil BD did not differ significantly due to NM. The changes in soil BD are dependent on texture, organic matter content, tillage type and intensity, and cropping system (Sharma *et al*., 2003; Kharub *et al*., 2004) [15]. The higher BD values in CT system due to lower SOC content compared to PB+GG treatment (Fig. 2). Differential chemical composition of crop residues and root biomass brings out differential addition of SOC (Congreves *et al*., 2015). Lal *et al*. (1994) concluded after 28 years that BD was lowest in no-tillage due to the retention of more crop residue on the soil surface than in conventional tillage. The bulk density did varied significantly due to planting techniques and it was significantly reduced under raised bed planting compared to flat sowing. This was attributed mainly due to more pore spaces created in the beds through modified land configuration by accumulations of the topsoil. Bed planting provides natural opportunity to reduce compaction by confining traffic to the furrow bottoms (Govaerts *et al*., 2006) [22].

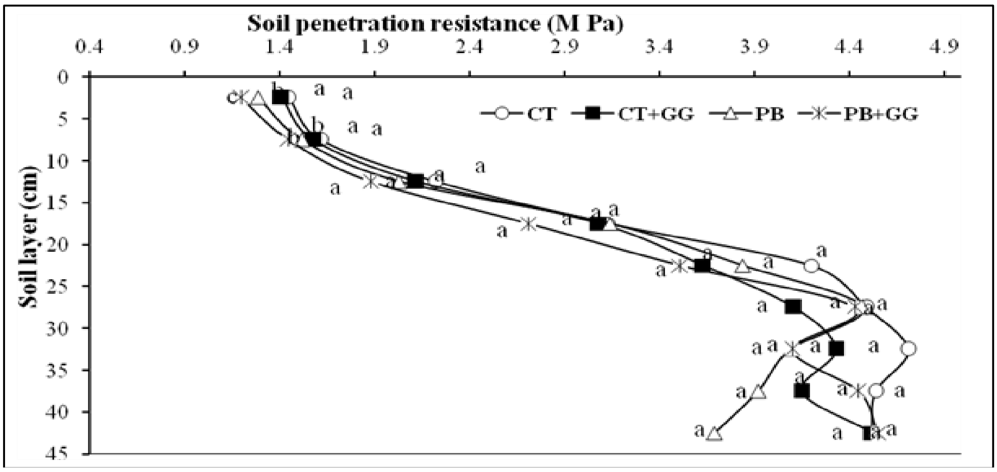


Sources	Analysis of variance (ANOVA)		
	0-5 cm	**5-15 cm**	**15-30 cm**
TRL	**	**	NS
NM	NS	NS	NS
TRL × NM	NS	NS	NS

Fig 2: Effect of different tillage/crop establishment, residue retention and legume on soil bulk density at green gram harvest after two cycles of maize-wheat cropping system

Soil penetration resistance

Tillage and residue management significantly (P = 0.05) influenced soil penetration resistance (SPR), which showed an increasing trend with depth 0 to 30 cm and then decreased at the lower depths under all the scenarios (Fig. 3). At 0-5 cm soil depth, highest value of SPR was recorded in CT (1.45 MPa), and the lowest in PB+GG (1.20 MPa). No significant effect of different treatments was observed on SPR in 10 to45 cm soil depths. In general, SPR was higher under CT compared to CA-based practices. Our results corroborated the findings of Jat *et al*. (2017) [43] who also reported lower SPR under ZT- based management practices. Parihar *et al*. (2016) [44] observed that higher penetration resistance in repeated tilled soil as compared to no-till soil. Unger and Jones (1998) also reported that the SPR differed due to crop rotations, being lower for continuous wheat (1.79 MPa) than for wheat fallow (2.32 MPa) or wheat-sorghum-fallow (2.42 MPa).



Sources	Analysis of variance (ANOVA)								
	0-5 cm	**5-10 cm**	**10-15 cm**	**15-20 cm**	**20-25 cm**	**25-30 cm**	**30-35 cm**	**35-40 cm**	**40-45 cm**
TRL	**	*	NS	NS	NS	NS	NS	NS	NS
NM	NS	NS	NS	NS	NS	NS	NS	NS	NS
TRL × NM	NS	NS	NS	NS	NS	NS	NS	NS	NS

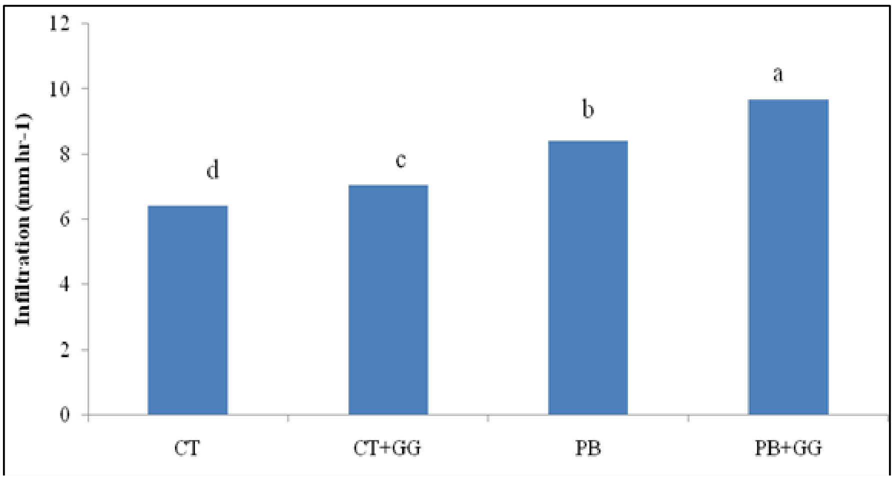
Fig 3: Effect of different tillage/crop establishment, residue retention and legume on soil penetration resistance at green gram harvest after two cycles of maize-wheat cropping system

Infiltration rate (IR)

CA-based agricultural practices and inclusion of legumes in system significantly influenced infiltration rate (Fig. 4). PB+GG (9.66 mm hr^{-1}) and PB (8.42 mm hr^{-1}) recorded highest infiltration rate whereas lowest was observed under CT (6.41 mm hr^{-1}). Lower infiltration rate in CT based system may be due to progressive destruction in soil structure and an increase in subsoil compaction or hardpan. Increased in IR after two years of CA practices (PB+GG and PB) indicating improvement in soil structure. Arshad *et al*. (2004) found average infiltration was 30% lower under CT compared to no-tillage. After three years of an experimentation Jat *et al*. (2013) [41] recorded three times higher IR under no-till flat compared to conventional flat. More infiltration in no till flat and no till bad plots might be due to the minimal disturbance that maintained the continuity of water conducting pores and the improvement in soil aggregation. A soil continuously under zero till with residue retention on the soil surface may show higher IR values due to root channels formed in soil and enhanced earthworm activity as was observed by Barnes and Ellis, 1979. The increase in IR in CA based system was may be due to improvement in aggregate stability (Gathala *et al*., 2011a) [25]. Many other research workers (Bhattacharyya *et al*., 2008; Jat *et al*., 2013; Li *et al*., 2007) [41, 6] have reported higher IR under ZT and residue retention compared to CT and removal of residues. Infiltration characteristics of the soil depend on the aggregation, and size distribution, geometry, continuity, and stability of the pores (Shaver *et al*., 2002).

Soil pH and electrical conductivity

The EC values in both the soil depths were quite lower than the critical level of 4 dS m^{-1} in all the treatments suggesting less chances of salt toxicity in plants on this soil (Table 4). Soil pH under different treatments varied from 7.91 to 7.98. Under CA practices it was 0.06 units lower as compared to CT. In general, soil pH increased with depth in all the treatments.



Sources	Analysis of variance (ANOVA)
TRL	**
NM	*
TRL × NM	**

Fig 4: Effect of different tillage/crop establishment, residue retention and legume on infiltration

Soil organic carbon (SOC)

Soil organic carbon (SOC) was influenced by different tillage, residue and the effect was restricted to 0-15 cm soil depth (Table 4). Highest SOC was observed under PB+GG (6.0 g kg^{-1}) followed by PB (5.9 g kg^{-1}). Conventional farmers practice (CT) showed lowest OC (5.6 g kg^{-1}) at 0-15 cm soil depth. Addition of green gram in system increase 1.7 percent SOC carbon in CA and CT. Highest SOC (3.30 g kg^{-1}) at 15-30 cm soil depth was observed under CA compared CT.This may be due to retention of crop residues in these treatments (~15 t ha^{-1}, Table 3) and their slow decomposition due to less soil disturbance might have caused higher SOC concentrations in the surface layer under CA. Govaerts, *et al*. (2007) [21] reported that permanent raised beds (PRB) with full residue retention increased soil organic matter content 1.4 times in the 0-5 cm layer compared to conventionally tilled raised beds with straw incorporated and it increased significantly with increasing amounts of residue retained on the soil surface for PRB. The adaptation of SSNM strategies for the two consecutive years resulted significant improvement in SOC over RDF and FFP treatments at the end of the experiments. It clearly shows that balanced fertilization caused a buildup of organic carbon in soil. Our results are in conformity with Kumar *et al*. (2015).The interaction effects of TRL× NM on SOC was significant ($P<0.01$) in the 0-15 and 15-30cm soil layer. It might be due to higher residue retention and use of balance nutrient through SSNM which provide adequate nutrient to soil micro-organism for proper mineralization resulted into increase in organic carbon. Inclusion of legume (green gram in system increased SOC) (Table 4) which might have led to higher microbial activities and hence higher SOC. The surface residues in CA based system decompose more slowly than that of incorporated in CT due to reduced contact with soil microorganisms causing greater increase in SOC (Yadvinder-Singh *et al*., 2010) [68].

Nutrient availability

Available nitrogen (N) and phosphorous (P) were affected significantly influenced by TRL at 0-15 cm soil depth but it didn't at 15-30 cm soil depth (Table 4). Available N content was 4.95 and 3.06% higher in PB+GG and PB as compared to CT. The content of available nitrogen decreased as soil depth deepening.CA based system recorded 3.6% higher available N as compared to CT.Available N concentration was not influenced by nutrient management practices (Table 4). In PB+GG and PB, nutrients accumulated in the surface layer due to the recycling of the higher quantity of preceding crops residue and minimal soil disturbance compared to CT. Whereas, in case of CT+GG the residues were incorporated in deep soil layer and that leads to fast decomposition due to anaerobic conditions and might also lead to leaching of mineralized nutrient in much deeper soil layers which in turn reduces the availability of these nutrients in CT+GG. The similar findings of higher accumulation of macro nutrients due to CA practices in soil were also reported by Wang *et al*. (2008) and Jat *et al*. (2017) [44]. At 0-15 cm depth, Olsen P was 14.7%and 12.3% higher under PB+GG and PB compared to CT (Table 4). Available P concentration in soil decreased with increase in depth. The increase in available P concentration which might be attributed to higher residue retention which moderate the soil moisture and temperature congenial to crop growth at the soil surface. Our results are in agreement with those reported by Murillo *et al*. (2004) and Jat *et al*. (2017) [44]. In this study K content did not influenced significantly by tillage, residue, legumes and nutrient management practices. This may be short duration of experiment and higher uptake by crop.

Table 4: Effect of different tillage/crop establishment, residue retention, legume and nutrient management on soil electrical conductivity (EC), pH, organic carbon, nitrogen, phosphorus and potassium at green gram harvest after two cycles of maize-wheat cropping system.

Treatment	EC (dS m^{-1})		pH		Organic carbon (g kg^{-1})		Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Tillage, residue and legume												
CT	0.40^{a}	0.35^{a}	7.98^{a}	8.24^{a}	5.60^{d}	3.20^{a}	148.57^{c}	85.55^{a}	18.91^{d}	12.38^{a}	242.03^{a}	153.62^{a}
CT+GG	0.39^{a}	0.34^{a}	7.91^{a}	8.18^{a}	5.70^{c}	3.20^{a}	149.76^{c}	86.14^{a}	19.76^{c}	12.82^{a}	242.85^{a}	154.74^{a}
PB	0.40^{a}	0.35^{a}	7.92^{a}	8.16^{a}	5.90^{b}	3.30^{a}	153.13^{b}	87.57^{a}	21.24^{b}	12.64^{a}	244.55^{a}	155.32^{a}
PB+GG	0.39^{a}	0.34^{a}	7.92^{a}	8.16^{a}	6.00^{a}	3.30^{a}	155.93^{a}	87.96^{a}	21.70^{a}	12.68^{a}	245.47^{a}	155.53^{a}
Nutrient management												
FFP	0.40^{a}	0.35^{a}	7.94^{a}	8.19^{a}	5.70^{a}	3.20^{a}	150.48^{b}	86.63^{a}	20.38^{a}	12.23^{a}	243.52^{a}	154.83^{a}
RDF	0.39^{a}	0.35^{a}	7.93^{a}	8.19^{a}	5.80^{b}	3.20^{a}	151.54^{b}	86.07^{a}	20.32^{a}	12.73^{a}	243.63^{a}	154.57^{a}
SSNM	0.39^{a}	0.35^{a}	7.92^{a}	8.17^{a}	5.90^{c}	3.30^{a}	153.53^{a}	87.72^{a}	20.51^{a}	12.93^{a}	244.02^{a}	155.01^{a}
Sources	**Analysis of variance (ANOVA)**											
TRL	NS	NS	NS	NS	**	NS	**	NS	**	NS	NS	NS
NM	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
TRL × NM	NS	NS	**	NS	**	**	NS	NS	NS	NS	NS	NS

* within a column, mean followed by the same latter are not significantly different at *P*<0.05 (LSD test).

Carbon budgeting and carbon sustainability index (CSI)

The total C-input, output and CSI computed for system were significantly influenced by tillage, residue, legume and different nutrient management practices (Table 5). C-inputs were associated with the inputs of production such as chemical fertilizer (NPK), diesel, tillage, labour, lubricants, machinery and agro-chemical, etc (Lal and Kimble 1997).The maximum C-input was estimated under CT+GG with 1072.19 and 983.80 MJ ha^{-1} during 2012-13 and 2013-14, respectively, while minimum under PB (Table 5). On the system basis, C-input was higher under CT+GG and PB+GG compared PB and CT was due to additional inputs required for cultivation of green gram. CT+GG treatment recorded 18% higher (mean of 2 years) C-input compared to CT due to extra inputs required for cultivation of green gram and higher inputs required for cultivation of maize and wheat under repeated tillage. Our results are in conformity with Dubey (2008) and Dubey and Lal (2009). The Maximum C-input was recorded with FFP (968.80 and 912.90 MJ ha^{-1}) during both the year of study, whereas minimum under RDF (945.60 MJ ha^{-1}) during 2012-13 but in 2013-14 under SSNM (850.44 MJ ha^{-1}) (Table 5). This may be due to unbalanced fertilizer application which increased the demand of other fertilizers. The interaction effects of TRL× NM on C-inputs were significant (*P*<0.01) in second year of the study (Table 5). CT+GG with FFP recorded higher C- input as compared to other treatment combinations.

Generally, C-output follows the trend of yields (grain and straw). The maximum C-output was recorded under PB+GG (16947 and 18329 MJ ha^{-1}), while minimum under CT (14175 and 14853 MJ ha^{-1}) in 2012-13 and 2013- 14, respectively (Table 5). This was due to higher yields of maize, wheat and green gram which converted into total C-output. CT+GG treatment produced 7.6% higher C-output compared to PB. This was due to extra yield of green gram which converted into higher C-output. However, PB produced 5.7% higher C-output from CT (Table 5). The maximum C-output was recorded under SSNM (16790.65 and 17649.70 MJ ha^{-1}), whereas minimum under FFP (14222 and 15338 MJ ha^{-1}) during 2012-13 and 2013-14, respectively. This may be due inclusion of balanced fertilizer which resulted into higher yields. These results are in conformity with those reported earlier by Chauhan *et al*. (2012), Jat *et al*. (2008) [42] and Dubey and Lal (2009). The interaction effects of TRL× NM on C-outputs were significant (*P*<0.01) in second year of the study (Table 5). PB+GG with site specific nutrient management gave higher C-input during study.

CSI was higher under PB (16.87 and 19.13) during 2012-13 and 2013-14, respectively. The minimum CSI was computed under CT+GG (13.90 and 16.40) during both the years of experimentation. PB+GG, PB recorded 18 and 17%, higher CSI, respectively as compared to CT (2 year`s mean) (Table 5). The findings are supported by Jat *et al*. (2008) [42], Parihar *et al*. (2012) [45] and Dubey and Lal (2009). The interaction effects of TRL× NM on CSI were significant (*P*<0.01) in second year of the study (Table 5). CA with SSNM recorded higher CSI as compared to other treatments. Adaptation of CA based practices with site specific nutrient management resulted in higher CSI, reflecting the ability of the crop to sequester more carbon than CT and resulting in more sustainable cropping system. Dubey and Lal (2009) also reported that conservation tillage improved CSI compared to CT system (Dubey, 2008).

Table 5: Effect of tillage, residue, legume and nutrient management on carbon sustainability index (CSI) of maize-wheat-green gram system during 2012-13 and 2013-14

Treatments	Total C-input (MJ ha^{-1})		Total C-output (MJ ha^{-1})		Carbon sustainability Index (CSI)	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
Tillage, residue and legume (TRL)						
CT	918.8^{c}	824.05^{c}	14175.71^{d}	14853.05^{d}	14.44^{c}	17.07^{c}
CT+GG	1072.19^{a}	983.8^{a}	15968.19^{b}	17093.81^{b}	13.9^{d}	16.4^{d}
PB	840.5^{d}	782.29^{d}	15014.4^{c}	15689.7^{c}	16.87^{a}	19.13^{a}
PB+GG	1005.03^{b}	947.26^{b}	16947.84^{a}	18329.35^{a}	15.87^{b}	18.41^{b}
Nutrient management (NM)						
FFP	968.8a	912.9^{a}	14222.59^{c}	15338.88^{c}	13.74^{c}	15.84^{c}
RDF	945.6c	889.7^{b}	15566.36^{b}	16485.86^{b}	15.55^{b}	17.58^{b}
SSNM	962.98b	850.44^{c}	16790.65^{a}	17649.7^{a}	16.52^{a}	19.84^{a}
Source	Analysis of variance (ANOVA)					
TRL	**	**	**	**	**	**
NM	**	**	**	**	**	**
TRL × NM	NS	**	NS	**	NS	**

*within a column, mean followed by the same latter are not significantly different at *P*<0.05 (LSD test).

Conclusions

Our results showed that CA based MW system integrated with green gram and site specific nutrient improve soil properties and availability of nutrient as compared to CT. CA based system with SSNM based nutrient management recorded higher CSI compared to CT. Crop diversification of RW system through the layering of MW system, inclusion of green gram and nutrient management following SSNM principles are possible approaches for sustainable intensification of maize-wheat system in IGP to address the issues of deterioration of soil quality through depletion of soil organic matter and nutrients.

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