Effect of cropping system and tillage practices on soil physical properties and maize growth

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Abstract
Conservation practices (CA) are one of the most suitable options to improve productivity and ensure food security. Conservation agriculture (CA) practices such as zero tillage (ZT) and permanent raised beds (PB) accelerate deposition of soil organic matter, reduce compaction and bulk density. Therefore, we analysed the effect of three medium-term tillage practices and three intensive crop rotations on selected physical properties of soil. The tillage practices consist of ZT, PB and conventional tillage (CT) in main plots and three crop rotations (MM, maize–maize; MW, maize–wheat; MC, maize–chickpea) in subplots. The experimental design was split-plot with three replications. After 7 years, we observed a significant positive effect of CA practices on soil organic carbon (SOC) content, soil compaction, bulk density, root length density (RLD) of maize. Thus, our medium-term (≥5-years) study showed that the combination of CA (PB and ZT) practices and appropriate choice of rotations (MC) appears to be the most appropriate option for restoration and improvement of the soil health of medium to coarse textured Inceptisols through the accumulation of soil organic matter (SOM) and improvement in soil physical properties.

Keywords: Conservation agriculture, penetration resistance, root length density, organic matter

Introduction
Intensive agriculture has accelerated degenerative soil processes such as soil erosion, nutrient depletion, compaction and salinization, triggering deterioration of soil structure and depletion of organic carbon. Tillage operations often degrade long-term soil health through several mechanisms. For example, the breakdown of aggregates and burial of surface residue can lead to soil crust formation. When residues left on the surface, these can absorb much of the impact force of rainfall, thus protecting aggregates from further breakdown, particle separation, and the eventual sealing of surface pores (Jury and Horton, 2004) [29]. An increased risk of erosion by wind or water due to the breakdown of soil structure (Franzluebbers, 2002) [18], and the increased decay of soil organic matter (SOM) by aeration and microbial activity (Vance, 2000) [46]. Due to the conversion of natural to agricultural ecosystems leads to losses of soil organic carbon (SOC) of up to 60% have been observed in temperate regions and up to 75% in tropical soils, (Lal, 2004) [32]. Hardpan formation below the tillage depth is also a common result in clay soils, as the weight of the equipment compacts and smears the soil at the base of contact (Van Es and Hill, 1995) [45]. Minimum tillage (MT) and no-till (NT) practices are meant to preserve soil health, primarily through erosion reduction and SOM conservation (American Society of Agricultural Engineers, 1985) [1]. On the other hand No-till systems are also resistant to plow pan formation; however, they can still be affected by deep compaction (sometimes up to 61 cm deep) caused by wheeled traffic (Hamza and Anderson, 2005) [22]. Soil compaction has various adverse impacts on soil quality, crop growth and the environment (Huber et al., 2008; Keller et al., 2013; Unger and Kaspar, 1994) [26, 30, 44]. As a consequence, compaction restricts plant root growth either by increasing mechanical resistance (Hettiaratchi, 1990; Unger and Kaspar, 1994) [28, 43] or by decreasing supply of oxygen (Czyz’, 2004) [13], and thereby impedes plant development (Cook et al., 1996) [11] and reduces crop yield (Letey, 1985; Ishaq et al., 2001; Saqib et al., 2004; Vrindts et al., 2005) [33, 27, 41, 47]. Chen and Weil (2011) [9] found that on no-till fields cover crops positively affect maize root penetration into deeper compacted layers and that (cover) crops with tap roots like forage radish and rapeseed are more capable to penetrate compacted soil than fibrous-rooted crops like rye.
(Chen and Weil, 2010)\(^6\). Overall, roots with greater diameter and/or sharper root tip opening angle may penetrate compacted soils better and faster than roots with smaller diameters or blunt opening angle (Colombi et al., 2017b; Materechera et al., 1991)\(^{10, 36}\). However, the benefits of cover crops vary depending on crop species and compaction level (Arvidsson and Håkansson, 2014; Chen and Weil, 2011; Goutal et al., 2012)\(^{2, 9, 21}\).

Improved knowledge of the effects of tillage practices on soil compaction, organic matter and crop yields may assist in the development of agricultural management practices to mitigate the effects of compaction on agricultural production and environmental resources. Keeping in view the above facts in mind the present study has been planned under on-going experiment of conservation agriculture titled “Resource conservation technologies for stabilizing yield under different cropping system” laid out at the SAC, Farm, Sabour with the objective: To determine the level of soil compaction, and the responses of root distribution and crop yield to different tillage and cropping system in maize based cropping system.

**Method and Materials**

The present investigation was carried out during 2018 in kharif season at the area specified for Conservation Agriculture near maize section at Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India. The geographical location of Bhagalpur comes under the Middle Gangetic plain region of Agro-climatic Zone IIIA. It is situated between 25°50″ N latitude and 87°19″ E longitude and at an altitude of 52.73 meters above mean sea-level. The area is characterized by a sub-tropical climate with hot desiccating summer, cold winter and moderate rainfall. May is the hottest month with an average maximum temperature of 35 to 39°C. January is the coldest month of the year with mean minimum temperature varying from 5 to 10°C. The average annual rainfall is 1231.4 mm, precipitating mostly between mid June to mid October (during south west monsoon). The experimental crop was preceded by maize-wheat-chickpea in rabi season. Since this experiment was started in Kharif, 2011, the same cropping history was being adopted for last seven years. The experiment comprised three tillage practices, namely Zero tillage (ZT), Permanent raised bed (PB) and Conventional tillage (CT) in main plots as well as six cropping systems in sub-plot, out of which only three cropping systems, i.e. maize-maize(MM), maize-wheat(MW), and maize-chickpea(MC) were chosen for the present study. The field was prepared by ploughing and followed by 2-3 harrowing or 3-4 inter crossing ploughing with the local plough in conventional plots. Planking was done after each ploughing. Then layout out of the field was done as per plan of the experiment for allocation of treatments. Channels and bunds were also made concurrently. Finally, a seedbed was prepared for sowing of maize seeds. In ZT and PB, sowing of maize was done without ploughing. The initial soil properties are presented in Table 1.

The soil was slightly acidic and mostly medium to coarse textured (Typic Ustifluvents). The maize seed was sown on 3rd July, 2018. One seed was planted at every 60 cm in rows 20 cm apart in conventional and ZT plots. 10-20% more seeds than the desired plant population were planted to compensate for various field losses. The harvesting of maize was performed in the month of October. The in-situ and laboratory determinations were made for various soil physico-chemical characteristics at the end of the experiment i.e. after maize harvesting.

### Table 1: Initial physico-chemical properties of soil

| Particulars | Values | Method |
|-------------|--------|--------|
| A. Physical properties | | |
| Sand (%) | 47.4 | Hydrometer method (Bouyocous, 1962)\(^{16}\) |
| Silt (%) | 32.6 | Textural triangle (Black, 1965)\(^{14}\) |
| Clay (%) | 19.6 | Black, (1965)\(^{14}\) |
| Texture class | Sandy loam | |
| Bulk density (g cm\(^{-3}\)) | 1.49 | |
| B. Chemical properties | | |
| pH | 7.5 | 1:2.5 soil water suspension by using glass electrode pH meter (Jackson, 1973)\(^{28}\) |
| EC (dSm\(^{-1}\)at 25 °C) | 5.3 | Rapid titration method (Walkley and Black, 1934)\(^{40}\) |
| Available N (kg ha\(^{-1}\)) | 0.15 | Electrical conductivity bridge (1:2.5 soil water suspension) |
| Available P (kg ha\(^{-1}\)) | 147.84 | Alkaline permanganate method (Subbiah and Asija, 1956)\(^{63}\) |
| Available K (kg ha\(^{-1}\)) | 27.19 | Olsen's method (Olsen et al., 1954)\(^{37}\) |
| | 213.06 | Flame photometer method (Jackson, 1973)\(^{28}\) |

The sieved soil samples were analyzed for pH (1:2.5 soil:water suspension) with a glass electrode Jackson (1973)\(^{28}\), electrical conductivity (EC. 1:2.5 soil:water supernatant) using a conductivity meter Jackson (1973)\(^{28}\), and SOC was analyzed by Rapid Titration Method as proposed by Walkley and Black (1934)\(^{40}\). The in-situ determination of soil bulk density (ρ\(_b\)) was made with the help of a cylindrical core having 6.0 cm height and 6.0 cm diameter at 0-15 and 15-30 cm depths with three replications. The cores were dried in an oven at 105°C until the weight of the soil became constant. The ratio of dry soil mass (M\(_d\)) and internal volume (V\(_i\)) of the cylindrical ring is expressed as bulk density (ρ\(_b\)) of soil (Mg m\(^{-3}\)) (Blake and Hartge, 1986)\(^3\):

\[ \rho_b = \frac{M_d}{V_i} \]
carefully separated from the soil by washing the nets under water. The washed roots were further cleaned to remove any leftover weed roots, seed, and other organic debris. These roots were then dried in an oven at 60°C and were weighed on precision balance to calculate the RMD.

Results
The data in the table 2 revealed that there was no any significant difference among the soil pH & EC of all the cropping and tillage systems and interaction effect was also found non-significant. Mean value of soil pH in the plough layer was highest under conventional tillage (7.49) whereas lowest was recorded under zero tillage (7.39). There was slight decrease in soil pH from the initial status of 7.5 which means continuous cropping led to slight increase in soil acidity over the years.

Soil depth, tillage practices and cropping system significantly affected BD of soil after seven years of continuous practice of conservation agriculture while their interaction effects were not significant (Table 2). Adoption of permanent raised bed for seven years lowered bulk density to 1.37 g cm\(^{-3}\) which was significantly lower than that recorded under conventional tillage system (1.42 g cm\(^{-3}\)). Among different cropping system maize-chickpea cropping system had lower bulk density in comparison to other cropping system. Fig.1 clearly showed that the bulk density in the sub-surface soil was comparatively higher than that recorded in the surface soil. However, the trend observed under this layer was almost similar to that registered under the surface layer soil.

Tillage- practices significantly affect the SOC. Among different tillage practices maximum SOC (g kg\(^{-1}\)) was found in permanent raised bed followed by zero tillage and least under conventional tillage (Table 2). Under different cropping systems total carbon content was found to be significantly higher under maize-chickpea system (6.32 g kg\(^{-1}\)) as compared to maize-wheat and maize-maize system. Fig. 2 depicts organic carbon content of soil was slightly lower in the sub-surface soil as compared to surface layer soil. Overall trend was similar to those under plough layer: M-C>M-W>M-M and ZT> PB>CT.

### Table 2: pH, EC, Soil bulk density and Organic Carbon under different tillage practices and cropping system.

| Treatments | pH    | EC (dSm\(^{-1}\)) | Bulk Density (Mg m\(^{-3}\)) | Organic Carbon (g kg\(^{-1}\)) |
|------------|-------|------------------|------------------------------|------------------------------|
| Tillage    |       |                  |                              |                              |
| ZT         | 7.39  | 0.35             | 1.38                         | 6.60                         |
| PB         | 7.44  | 0.36             | 1.37                         | 6.73                         |
| CT         | 7.49  | 0.37             | 1.42                         | 5.11                         |
| Cropping System |   |                  |                              |                              |
| MM         | 7.43  | 0.35             | 1.42                         | 5.89                         |
| MW         | 7.43  | 0.35             | 1.38                         | 6.23                         |
| MC         | 7.45  | 0.37             | 1.36                         | 6.32                         |
| Tillage X Cropping System |     |                  |                              |                              |
| ZT-MM      | 7.36  | 0.34             | 1.42                         | 6.43                         |
| ZT-MW      | 7.39  | 0.36             | 1.38                         | 6.65                         |
| ZT-MC      | 7.42  | 0.35             | 1.35                         | 6.7                          |
| PB-MM      | 7.45  | 0.37             | 1.41                         | 6.45                         |
| PB-MW      | 7.42  | 0.32             | 1.36                         | 6.82                         |
| PB-MC      | 7.44  | 0.37             | 1.34                         | 6.91                         |
| CT-MM      | 7.47  | 0.35             | 1.44                         | 4.77                         |
| CT-MW      | 7.49  | 0.38             | 1.41                         | 5.21                         |
| CT-MC      | 7.5   | 0.38             | 1.40                         | 5.35                         |

**Statistical analysis**

LSD(<0.05) | Tillage | NS | NS | 0.015 | 0.175 |
|           | Cropping System | NS | NS | 0.027 | 0.082 |
|           | Tillage X Cropping System | NS | NS | NS | NS |

**Fig 1:** Bulk density of soil as affected by different (a) cropping system (b) tillage practices at 0-15 cm and 15-30 cm depth.
The RMD of maize was significantly affected by all the main factors. Maximum RMD (µg cm⁻³) was found at 0-15 cm depth under ZT (1.62) followed by PB (1.59) and minimum under CT (1.42) (Table 3). Highest value of RMD was recorded in case of maize-chickpea cropping system under zero tillage (2.01) and minimum in case of maize-maize cropping system under conventional tillage. Interaction between tillage and cropping system was found to be significant.
Discussion

Bulk density is an important parameter of soil to support plant growth and thereby, the crop productivity; no matter what type of crop is being grown. This parameter signifies the quantity of pore spaces as well as soil solids. Thus soils that are loose or porous will have low weight per unit volume (low bulk density) and which are compact will have higher bulk density. Bulk density as influenced by different cropping systems and tillage practices was found to be significantly higher under CT as compared to ZT & PB due to higher organic matter addition in case of conservation tillage that is associated with increased aggregation and permanent pore development as a result of soil biological activity. MC cropping system resulted in significant lowering of bulk density as compared to MW and MM cropping system. Previous studies have also demonstrated that reduced bulk density in ZT could be attributed to higher organic matter content and better aggregation (Yang et al., 2013). Doan et al. (2005) reported similar results and concluded that legume-based cropping system improved the soil physical health by decreasing soil compaction or soil cone index. On the other hand, addition of wheat and maize had strong deep tap/fibrous root system, increases soil compaction which affect the bulk density of soil. Thus, it is concluded that MC based cropping system supposed to be good as compared to other two systems.

It was also found that continuous cropping for seven years along with adoption of conservation agriculture practices led to significant build up in soil organic carbon as compared to the initial status. Owing to the fact that reduced tillage results in the deposition of crop residues on upper soil layer, which reduce moisture and energy exchange from soil to atmosphere, these fluctuations increase the moisture content and maintain soil temperature and aeration, thus allowing plant organic residues to stay intact for longer period of time, and hence facilitating more carbon accumulation under conservation tillage system (ZT & PB) and Surface layer (0-15 cm) recorded higher SOC concentration compared to lower soil depths. Similar findings were reported in their work by Havlin et al., 1990; Franzluebbers et al., 1995; Dao, 1998 and Fuentes et al., 2009; Parihar et al., 2016b; Kumar et al., 2017.

The penetration resistance was found to be significantly higher under conventional tillage system as compared to zero tillage and permanent raised bed system. This might be due to hard pan formation by the use of heavy machinery in CT. On the other hand the increase in pb with depth in case of CT increased the cohesion of the soil particles, decreased macroporosity, reduced soil aeration, and increased the risk of soil compaction, which led to increased PR. PR increases with increase in compaction or bulk density (BD) and decreases with increase in soil water content (SWC) and increase in sand percentage (Ayers and Perumral, 1982; Vepraskas, 1984; Henderson et al., 1988; Lowery and Schuler, 1994; Puppala et al., 1995) [3, 24, 34, 39].

Maximum RMD (µg cm⁻²) was found at 0-15 cm depth under MC cropping system under ZT and minimum in case of maize-maize cropping system under CT. CT affects soil temperature (Dwyer et al., 1996) [16], soil mechanical impedance (Cox et al., 1990) [12], the continuity of macropores (Roseberg and McCoy, 1992; Shipitalo et al., 2000) [40, 42], soil water availability (Cox et al., 1990; Fuentes et al., 2003) [12, 19], and the depth and distribution of roots (Dwyer et al., 1996) [16]. Martinez et al. (2008) [35] reported higher RMD under NT in comparison with CT due to improved soil structure, more water availability and increased SOC due to continuous addition of crop residues. Both cropping system and tillage practices significantly affect maize grain yield (Table 3). This could be due to better soil physical properties and root proliferation under reduced tillage environment.

Conclusions

This study showed that reduced tillage (ZT & PB) and legume based cropping system were associated with a more favorable soil environment for crop root growth than conventional tillage, which provides an opportunity for higher crop yields. Yield increase under ZT & PB were attributed mainly to reduced soil compaction, increased water storage capacity and improved rooting systems at the 0–60-cm soil depth. The presence of higher organic matter in conservation system due to less oxidation help in reducing penetration resistance and promoting crop root growth and thus increased crop grain yield. Overall, there were no significant interaction effects between tillage and cropping system on soil properties. This
study only explored the short term effects of repeated tillage and cropping system on soil properties and crop yield in a sandy loam soil. Further studies are required to determine the longer term effects of different tillage rotation patterns on soil properties and crop yield in different soil types.

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