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Effect of Tillage and Crop Residue Management on Soil Physical Properties

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Abstract

Tillage and crop residue management play an important role on soil physical and chemical properties and eventually affects the crop productivity. Crop residue is the material which usually not taken away but rather left in the field after the crop harvesting which include leaves, straw, stubble and roots stalks. Management of soil physical properties such as bulk density, infiltration, porosity, soil organic carbon, saturated hydraulic conductivity and soil temperature, plays an important role in crop productivity. A compatible combination of tillage and crop residue management found an impactful strategy to improve the properties of soil for provision of favourable environment to crop plants. Conservational tillage practices such as zero tillage, minimum tillage and reduced tillage along with retaining crop residues on soil surface have a great advantage over conventional tillage. Incorporating crop residue with tillage practices have advantage through adding organic matter and carbon to the soil that are preconditions for the better physical, biological as well as for chemical properties. Allowance of crop residue to the soil surface reduces its bulk density and compaction. Infiltration and hydraulic conductivity also reported to be greater under no tillage than in tilled soils because of the larger number of macrospores and increased microbial activity. Crop residue incorporation into the soil also increases infiltration rate, saturated hydraulic conductivity and regulation of soil temperature. Soil organic carbon content and aggregate stability also found increased because of crop residue incorporation.

Key words: Crop residue, Soil physical properties, Tillage, Microbial activity

Introduction

Soil physical properties are related to the size and arrangement of soil particles and movement of liquid and gases in soil which affect the appearance and structure of soil. Major physical properties of soil are texture, structure, density, porosity, soil water, soil temperature and soil colour. Various cultivation practices assign to agricultural production greatly affect soil physical properties (except soil texture). Tillage and crop residue management play important role in maintaining soil physical properties as well as on chemical properties and ultimately affect the crop productivity. Tillage simply is the physical and mechanical manipulation of soil to prepare ideal land for agriculture production. Thus, tillage is the most effective way to modify the soil properties because of its effect on density, pore space, residue cover and surface roughness. There lie many tillage practices used in agricultural field, some of them are conventional and few are modern or improved tillage practices. Different tillage practices leave a different impact on soil properties.

Crop residue is the material which is left in the field after the crop harvesting which includes leaves, roots stalks, stubble, pods etc. and this material is always organic in nature. Extent of crop residue produced on-farm and off-farm each year in India is roughly 500 million tones. Nearly 30% of gross residue produced is available as surplus after utilizing as cattle feed, animal bedding, cooking fuel and organic manure etc. That suggests its future perspectives to be used for improving soil properties. Crop residues have multipurpose uses such as animal feeding, mulching, manuring, thatching for rural homes and fuel for domestic and industrial use. Despite the known of crop residue benefits, farmers burn a significant portion on-farm.

Effect of Tillage and Crop Residues on Soil Physical Properties

Soil physical properties such as bulk density, porosity, water sorptivity and aggregation determine the water infiltration characteristics of the soil. Management practices that do not disturb the soil and produce more residue biomass on the soil surface, have the potential to decrease soil bulk density, increase porosity, sorptivity and aggregation in the soil hence increased infiltration. The decreased bulk density and increased porosity and macro-aggregation also decreases the potential for runoff, erosion and evaporation by increasing the potential for faster water capture and make more water availability for plant use. Residue cover increases infiltration and reduces evaporation but under extended dry conditions there are no differences from bare soil (Godwin, 1990). Crop residues retained on the soil surface supply additional soil organic matter (SOM) to the soil, improving soil structure, root development and plant growth (Bassem Dimassi, 2013). The residue management strategy affects soil structure, organic matter content, nutrient availability, hydraulic properties and crop productivity (Bronick and Lal, 2005). The impact of different tillage practices on soil physical properties, specifically infiltration has been well investigated using tension infiltro-meter (Logsdon and Kaspar, 1995). Saturated hydraulic conductivity was found greater for tilled than untilled soils at the beginning of the growing season because of increased porosity caused by tillage (Suwardji and Eberbach, 1998), whereas it can be lower at the end of the season.

Soil organic carbon

Soil organic matter (SOM) is the material produced by living organisms returned to the soil and undergoes decomposition (Bot and Benites, 2005). It improves the physical, chemical and biological properties of the soil. SOM acts as a source of plant nutrients and water absorbent (Lal, 2004). Govaerts *et al.* (2009b) reported that crop residue retention is a key to maintain SOC level. Its effect depends on soil type, climate and management factors. An increase in quality and quantity of soil organic carbon (SOC) can improve the soil productivity (Lal, 2004). Yadvinder-Singh *et al*. (2004) observed that organic carbon content in soil increased from 0.41 to 0.59 g kg^{-1} soil after 7 years of rice residue incorporation before sowing wheat. The percent increase in organic carbon content is greater on sandy loams than on silt loams with lower initial organic carbon content (Yadvinder-Singh *et al.,* 2009). The use of reduced and no-tillage practices generally increases the SOC concentration in surface few centimeters compared to conventionally tilled soils (Yang and Wander, 1999).

Aggregation and soil structure

Aggregation is an important soil physical property because it affects bulk density, porosity, and subsequently, water infiltration, water use efficiency, wind and water erosion and crop yield. Aggregation is affected by many factors, especially organic matter and soil texture. The mechanism involved in the binding of soil particles into stable aggregates varies with factors related to soil parent material, climate, vegetation, and management practices (Kay, 1990). All of these factors are important for crop production and sustainability. Blanco-Canqui and Lal (2009) reported a large decrease in aggregate stability with increasing rate of crop residue removal due to decrease in organic matter. Aggregation is also a dynamic factor that is affected or reduced by tillage. The use of tillage in crop production decreases the aggregate stability and the decomposition of different crop residues have also been shown to degrade soil structure. Systematic removal of stover from no tilled (NT) soils by 0, 33, 66, and 100% for 5 consecutive years did not reduce aggregate stability in a sandy loam (Rold´an *et al.,* 2003). More stable aggregates in the upper surface of soil have been associated with no-till soils than tilled soils and resulting high total porosity under NT plots. It has been also found that NT not only increase aggregate stability but also improves SOM inside the aggregates. Crop residues increase soil aggregation and structural stability (Cannell and Hawes, 1994; Singh *et al.,* 1994). Soil structure is the shape, size and arrangement of primary and secondary particles into a certain definite structural pattern. Crop residue helps to improve soil structure through effects on soil strength, porosity, hydraulic properties, air diffusion capacity, soil aggregates etc. Soil aggregates in turn are proposed to be the basic units of soil structure and, organic residues applied to soil with different management systems have been shown to improve structure (Lynch and Bragg, 1985). Soil structure improvement is not solely dependent on the total amount of organic C present, but is a function of a number of factors including the chemical composition of the organic matter and employed management system (Martin, 1971; Dormarr, 1983).

Saturated hydraulic conductivity (K_s)

Hydraulic conductivity simply is the flow or movement of water within the soil. The water movement within the soil is greatly increased with increase in porosity. Puddling reduces saturated hydraulic conductivity (K_s) because of breakdown of aggregates and reduction in macro pores (Tripathi *et al.,* 2003); but these needs to be optimized for rice-wheat system for minimum deterioration in soil quality (Tripathi *et al.,* 2005). Increased amount of crop residues on soil surface can increase the saturated hydraulic conductivity and removal of residues can decrease hydraulic conductivity. Tripathi *et al.* (2007) reported that crop residue removal decreases saturated hydraulic conductivity (K_s) in all the tillage systems. Chan and Mead (1989) reported that untilled soils had greater hydraulic conductivity than tilled soils. The hydraulic conductivity of untilled soils can be significantly affected by macro pores formed by earthworms, soil insects or roots, but these macrospores are destroyed in tilled soils. Suwardji and Eberbach (1998) also observed saturated hydraulic conductivity greater for tilled than untilled soils at the beginning of the growing season because of increased porosity caused by tillage whereas it can be lower at the end of the season.

Infiltration rate (IR)

Infiltration rate is the rate at which water enter into the soil per unit time. Direct impact of rain drops clogs the pores and causes surface sealing which reduce the infiltration and induce runoff resulting in water erosion. Residue cover over the surface prevents the direct impact of rain drops and reduces the chance of erosion through increasing water infiltration. Unger and Stewart (1983) reported that crop residues protect the soil surface from physical raindrop impact, which can reduce the formation of surface seals and increase the infiltration rate. Tillage practices also affect the infiltration rate of soil. Infiltration is reported to be greater under no tillage than in tilled soils because of the large number of macropores and increased microbial activity (McGarry *et al.,* 2000). Disruption of macropore continuity by tillage is reported to reduce infiltration and hydraulic conductivity (Logsdon *et al.,* 1990). In other studies, Ferreras *et al.* (2000) also observed that infiltration and hydraulic conductivity was lower under NT than conventional tillage because of increased bulk density in NT soils and increased porosity produced by tillage. Tripathi *et al*. (2003) reported that in wheat season, infiltration rate increased than the rice season both under zero tillage (ZT) and conventional tillage (CT), because of breakdown of aggregates in the puddled layer and subsurface compaction. Shukla *et al.* (2003) also reported that because of the protection of the soil surface and effect of SOC, there is higher infiltration rates under NT than CT.

Soil water retention

Soil water content is one of the most sensitive parameter to crop residue removal. Bare soils lose moisture soon after the protective mulch cover is removed. Mulched soils are normally wetter in spring and summer than unmulched soils (Shaver *et al.*, 2002). Mulches alter soil hydrothermal characteristics in root zone, conserve soil moisture, suppress weeds growth and improves soil productivity. Different kind of crop residues vary in their ability to conserve soil moisture, regulate soil temperature, weed control, soil salinity control, nutrients availability and soil physical properties which lead to the variations in crop yield. Mulching with crop residues improves soil water storage by: 1) increasing infiltration rate and decreasing runoff losses, 2) reducing evaporation and abrupt fluctuations in soil surface temperature, and 3) increasing SOM concentration, which increases water retention capacity of the soil. Thus, soil water content and plant available water capacity decreases with increase in residue removal because of the deterioration in soil structure, depletion of residue-derived organic materials, and high losses by evaporation (Blanco-Canqui *et al.*, 2007). Mulched soils retained 20 to 50% more water than unmulched soils for 0 to -6 kPa soil water potential (Blanco-Canqui *et al.*, 2007).

Roper *et al.* (2013) showed that soil water contents in the top 12 cm soil under residue retention and no-till were higher than those under residue burned and tilled treatments. Under conservation tillage, higher water content in the top soil and more plant residues on the soil surface, resulting in declined evaporation, have been related with the lower soil temperature (Rasmussen et al., 1999). A higher evapo-transpiration (ET) in NT plots than in CT and RT plots has also been reported and was attributed to greater and deeper soil water storage (Su *et al.,* 2007) as extensive tillage usually expose soil surface to water loss and evaporation.

Bulk density and compaction

Bulk density is the ratio of soil mass to soil volume (including pore space) which is used to assess soil compactness. Bulk density has an inverse relationship with soil porosity, which in turn affects water infiltration. The increase in bulk density depends on soil texture, organic matter content, residue management and tillage intensity (Kharub *et al.,* 2004). Addition of crop residue to the soil surface reduces its bulk density because the residue accumulates in the surface soil. Shaver *et al.* (2003) reported that each ton ha^{-1} crop residue addition over a 12-year period reduced bulk density by 0.01 Mg m^{-3} and increased effective porosity by 0.3%, and each g kg^{-1} of organic C in macro aggregates increased the proportion of macro aggregates by 4.4% in 0-25 mm layer. These results suggest that increased amounts of crop residue with no-till management can increase levels of water sorptivity and infiltration. Few conventional agricultural practices that cause soil compaction leads to increase soil strength and restrict the root penetration. Crop residue management in these soils helps to reduce compaction and soil strength and make soil more permeable.

Lal (1975) showed that minimum tillage was as effective as conventional tillage for upland crops in Nigeria. Minimum tillage can perform similar to conventional tillage with reduced field preparation expenses (Bajpai and Tripathi, 2000). The tillage operation performed in wheat significantly reduced soil bulk density. The minimum till system is often characterized by increased bulk density and penetration resistance, and decreased saturated hydraulic conductivity, infiltration rate and macropores (Asefa and Tanner, 1998). Fabrizzi *et al.* (2005) also reported higher bulk density and penetration resistance values under ZT compared with CT. Crop residues retention on the soil surface have improved soil quality even in a continuous no-tillage crop production system (Franzluebbers *et al.,* 2002). In semiarid regions, Bautista *et al.* (1996) observed that ZT with residue decreased bulk density considerably.

Porosity

Porosity is directly related to bulk density because as bulk density decreases, porosity increases. As crop residue increased, soil porosity increased. These results suggest that increased crop residue can lead to the improvement of soil physical properties. In Nigeria, Lal *et al.* (1980) reported that mean total porosity was 0.49 mm^3 mm^{-3} under 0 and 2 Mg ha^{-1} of rice straw, 0.55 mm^3 mm^{-3} under 4 and 6 Mg ha^{-1} of straw, and 0.59 mm^3 mm^{-3} under 12 Mg ha^{-1} of straw. Increase in straw mulch cover from 0 to 12 Mg ha^{-1} increased macropores from 0.18 to 0.38 mm^3 mm^{-3} and mesopores from 0.07 to 0.08 mm^3 mm^{-3} whereas it decreased micropores from 0.23 to 0.13 mm^3 mm^{-3}. Mulched soils often have more macropores and thus drain faster than unmulched soils. Shaver *et al.* (2002) reported that continuous cropping systems increased total porosity (0.54 mm^3 mm^{-3}) more than wheat-fallow systems (0.50 mm^3 mm^{-3}) in a 12-year NT system in the Great Plains. In contrast, Karlen *et al.* (1994) observed no differences in total porosity among soils mulched with 0, 100, and 200% of corn stover mulch.

Soil temperature

Soil temperature is an important soil physical property. Soil cover maintains and regulates thermal properties of soil and reduce the water losse through evaporation from deep layers. Surface cover provides favorable soil temperature that helps to plant thrive as best. Prihar and Arora (1980) observed that straw mulch reduces the amount of radiation reaching on the soil surface, and reduces the maximum soil temperature and increases the minimum temperature. The effect of straw mulch on soil temperature can be an advantage where soil temperature is above the optimum for germination and growth, and a disadvantage where temperature is below the optimum (Lal, 1989).

Green and Lafond (1999) reported the heat advantage of tillage and residue management and noticed that surface residues with no-till system helps in regulation of the soil temperature. They also found that the soil temperature in 5 cm depth with residue removal and conventional tillage was 0.29 ^{0}C lower during the winter than that of no-tillage and surface retained residues whereas the soil temperature during summer was 0.89 ^{0}C higher under conventional tillage than no-till surface retained residue. Gupta *et al*. (1983) claimed that temperature difference under zero tillage with and without residue cover was larger than the difference between conventional tillage and zero tillage with residue retention. Crop residues under optimal conditions has been found beneficial as it reduces maximum soil temperature and conserves water (Singh *et al*., 1994; Yadvinder-Singh *et al.,* 2010; Verhult *et al*., 2010). Zero till with residue retention keeps canopy temperature lower by 1 to 1.5 ºC during grain filling stage owing to sustained soil moisture availability to the plants for better grain filling (Gupta *et al*., 2010). Naresh *et al*. (2015) also found that zero tillage reduced the impact of solar radiation by acting as a physical barrier resulting in lower soil temperature than the plough soil.

Conclusion

Tillage and residue management significantly influence the soil physical properties which in turn affects crop growth and productivity to a large extent. Conservation tillage (zero tillage, minimum and reduced tillage) along with residue retention on soil surface produced soil micro-climate much conductive for crop growth. Crop residue on soil surface reduces its bulk density and compaction making it easier for seed germination and emergence. Residue retention or incorporation increases soil organic carbon, aggregate stability and better regulation of soil hydrothermal regime. Therefore, conservation tillage along with residue management on a long-term basis increases crop yield by improving soil physical properties.

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