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Review Article

Impact of Conservation Tillage on Soil Organic Carbon and Physical Properties –a Review

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Abstract

Soil conservation tillage (CT) systems are considered major component of sustainable agriculture involves reducing the tillage operations and plant remains at the soil surface in the ratio of at least 30%. In this review we summarized how conservation tillage affects soil compaction, aggregation, hydraulic conductivity, porosity, water storage and soil organic carbon. Water storage and movement of water are strongly influenced by soil structure. Contradictory results have been published on the effect of different tillage systems on soil physical and chemical properties. Several studies showed that conservation tillage leads to positive changes in the physical and chemical properties of a soil and provide the best opportunity for restoring and improving soil productivity however the magnitude of changes varies with the nature of the soil, tillage operations, soil water content and climate. Some studies stated a decrease in total porosity, water holding capacity, soil organic carbon and greater bulk density under no tillage system than the intensive tillage systems. On the other hand, in long term experiments, it has been well documented that soil can be managed to increase SOC and improve soil physical properties by adopting conservation tillage. Intensive tillage can deteriorate the soil quality, because it incorporates crop residue into the soil, disrupts soil aggregates, and increases soil aeration. However, short-term (<10 years) management effects on soil C and soil physical properties are complex and often vary. Moreover, there is need to examine the changes in soil physical properties and organic carbon in response to long term tillage and management practices (> 20 yr).

1. Introduction

Tillage is mechanical modification of soil structure, requires considerable expense of high-energy inputs to prepare the seed bed, to incorporate fertilizer, manure and residues into the soil, to alleviate compaction and to control weeds (Phillips et al., 1980; Leij et al., 2002). Excessive tillage practices without residue retention may adversely affect long-term soil productivity due to erosion and loss of organic carbon (Ahmad et al., 1996). Conservation tillage (CT) is defined as any tillage system that leaves at least 30% of the crop residue on the soil surface after planting. No tillage, shallow surface tillage, sub-soiling, minimum tillage and residue mulching are often included in this system (Jin et al., 2007). Conservation tillage is recognized having higher efficiency than conventional tillage in improving soil quality, crop productivity (Lal, 1989; Havlin et al., 1990). Reducing the intensity of soil tillage decreases the manpower and energy required for crop production (Zang et al., 2003; Osunbitan et al., 2005) and offers long-term benefits from improved soil structure (Wang et al., 2008), reduced fuel consumption, bio diversity, stability of ecosystem and energy use efficiency (Lal, 1995; Uri et al., 1998; Ogban et al., 2001; Franzluebbers, 2002; Holland, 2004; Iqbal et al., 2005). In Asia the adoption of conservation tillage is at a very low level (4%) (Table 1).

Globally soils contain 3.5% of the C reserves of the earth, compared with 1.7% in the atmosphere and 1.0% in biota (Lal et al., 1995). Soil can function as sink for atmospheric CO_2 in the global carbon cycle through appropriate soil and crop management (Lal et al., 1995; Paustian et al., 1995). Tillage increase soil CO_2 emission by enhancing plant nutrient availability, improving soil aeration, increasing soil and crop residue contact, (Logan et al., 1991; Angers et al., 1993), and increasing exposure of soil organic in inter and intra-aggregate zones to microbes for rapid oxidation (Reicosky

Table1: Worldwide area under conservation agriculture

Country	Area (mha)	Percentage (%)
USA	26.5	21.2
Brazil	25.5	20.4
Argentina	25.5	20.4
Australia	17.0	13.6
Canada	13.5	10.8
Russian Federation	4.5	3.6
China	3.1	2.5
Paraguay	2.4	1.9
Kazakhstan	1.6	1.3
Others	5.3	4.2
Total	124.8	100

Source: FAO, 2012

and Lindstrom, 1993; Beare et al., 1994; Jastrow et al., 1996). Long-term tillage study revealed that soil C stocks can be reduced by as much as 20–50% (Haas et al., 1957; Davidson and Ackerman, 1993; Murty et al., 2002). Tillage effects on soil CO_2 emission are complex and often vary (Mosier et al., 1991; Lauren and Duxbury, 1993).

Contradictory results have been found as bulk density increased under no-till in relation to plow tillage (Tebrugge and During, 1999) or reduced tillage (Mc Vay et al., 2006), may induced soil densification of the upper soil layers (Rasmussen, 1999). However, inconsistent effects of tillage systems were observed on soil bulk density and total porosity (Strudley et al., 2008). Long-term zero-tillage or conventional tillage can change the volume of pores, aggregate stability and organic matter content and consequently the entire soil structure (Drees et al. 1994; Lal et al., 1994; Singh et al., 1994; Diaz-Zorita et al., 2004). Kovac and Zak (1999) found that the changes in soil physical properties were influenced by different tillage treatments but the changes were small and insignificant. Jordhal and Karlen (1993); Mielke Wilhelm (1998) pointed out that the tillage treatments affected the soil physical properties when the same tillage system has been practiced for a longer time. Conservation tillage improves edaphic environment (Anikwe et al., 2004; Aniekwe et al., 2007), moderates soil temperature (Sarkar and Singh, 2007; Sarkar et al., 2007), increases soil porosity and water infiltration rate during intense rains (Glab and Kulig, 2008), improve aggregate stability which restricts soil erosion (Franzluebbers, 2002) and reduces runoff and soil erosion (Bhatt and Khera, 2006). However these benefits may be dependent upon cropping system, climate and soil type. The objective here is to assess the knowledge gained regarding the impact of conservation tillage on soil organic carbon and physical properties.

2. Tillage Effects on Soil Properties

2.1. Organic matter

Soil organic matter is important because it provides stabilization to soil aggregates and food for soil organisms, including soil mites, bacteria and fungi. Many studies indicate that different tillage systems have a positive effect on labile SOC, soil aggregation, and SOC distributions in aggregates size fractions, stabilizes soil structure (Cochrane and Aylmore, 1994; Thomas et al., 1996), and decreases bulk density and soil strength (Sparovek et al., 1999 and Carter, 2002). However, the short and long-term influences of disturbance on C mineralization are complex and may vary depending on regional climate, soil type, residue management practice (Table 2), Paustian et al., 1997; Puget and Lal, 2005). Incorporation of organic matter having lower bulk density and greater porosity than that of mineral soils (Martin, 2000), would improve soil porosity and makes it more resistant to degradation (Zhang, 1994). Hunt et al. (1996) monitored the increased SOC content after 9 years of CT in the top few centimeters in numerous small tillage plots than conventional tillage. Moraru and Rusu, 2010, indicated that minimum tillage tended to increase soil organic matter content from 0.8 to 22.1%, in 0-30 cm soil depth, and permeability even across different soil types as compared to the classical system after ten years of applying the same soil tillage system (Table 3). Similar results were obtained by Singh et al., 2014 (Table 4). Reicosky (1997) reported that

Table 2: Effects of tillage systems on soil organic matter (SOM) and organic C

Soil components	Comparison of conservation tillage relative to conventional tillage	References
Organic matter	More in the tilled layer, Similar in the untilled layer	Andrade et al. (2003); Kay and Vanden Bygaart (2002)
Organic carbon	More in the tilled layer, Similar in the untilled layer, Similar throughout the topsoil	Tebru¨ gge and Du¨ ring (1999); Andrade et al. (2003); Balesdent et al. (2000). Deen and Kataki (2003). Anken et al. (2004)
Total carbon	More in the 0-5 cm layer but similar in the 5–20 cm layer under no tillage	Six et al. (1999)

Table 3: Effect of soil tillage system upon organic matter content (OM, %; 0-30 cm soil depth)

Type of soil	Soil tillage systems	Classic plough+ disc	Paraplow+rotary harrow	Chisel plow +rotary harrow	Rotary harrow
Chernozem cambic	OM, % Significance (%)	3.51 a wt.(100)	3.54 a ns(100.8)	3.87 a ns(110.2)	3.61 a ns(102.8)
Phaeozem tipic	OM, % Significance (%)	3.90 a wt.(100)	4.13 b *(106.0)	3.93 ab ns(100.9)	3.98 ab ns(102.2)
Haplic luvisols	OM, % Significance (%)	2.48a wt.(100)	2.94 ab *(118.6)	3.02 b *(122.1)	2.82 ab ns(113.9)
Fluvisol molic	OM, % Significance (%)	3.03 a wt.(100)	3.12 ab ns(103.1)	3.09 ab ns(102.0)	3.23 b ns(106.5)

OM: organic matter; wt: witness; ns: not significant; *positive significance, a, ab, b, c: Duncan's classification (the same letter within a row indicates that the means are not significantly different)

Table 4: Carbon stock (Mg ha^{-1}) and C sequestration rate (Mg ha^{-1} $year^{-1}$) in surface (0.4 m depth) soils under conventional (CT) and zero (ZT) tillage

Soil texture	Carbon stock		C sequestration rate in ZT over CT after 15 years
	CT	ZT	
Sandy loam	18.75	22.32	0.24
Loam	19.84	26.73	0.46
Clay loam	23.83	33.07	0.62

moldboard plow lost 13.8 times more CO_2 as the soil not tilled while conservation tillage systems averaged about 4.3 times more CO_2 loss. Reicosky et al. (2002) found that 30 years of fall moldboard plowing reduced the SOC whether the above ground corn biomass was removed for silage or whether the stover was returned and plowed into the soil. Hooker et al. (2005) also found that within a tillage treatment, residue management had little effect on SOC in the surface soil layer. Studies indicated that no form of residue management will increase SOC content as long as the soil is moldboard plowed. Campbell et al. (1999) reported very small increases (0-3 Mg ha^{-1}) in C storage under no-tillage in the 0-15 cm soil depth over an 11 years experiment. Several studies have shown that there is no significant increase in the overall mass of soil organic carbon (C) (Table 6). Inappropriate tilling deteriorates the soil structure and can promote soil erosion and deplete the soil nutrients and C stocks (Lal, 2002; Reicosky et al., 1997). On the basis of global data set, West and Post (2002) concluded that soil C sequestration was generally increased by no-tillage (NT) practices, but had a delayed response, with peaks in 5–10 years. The finding was in agreement with the results reported by Franzluebbers and Arshad (1996). Positive effect of conservation tillage on soil quality and soil organic carbon pool are well established (Paul et al., 1997; Paustian et al., 1997a; Paustian et al., 1997b; Lal et al., 1998; Ogle et al., 2003).

2.2. Bulk Density

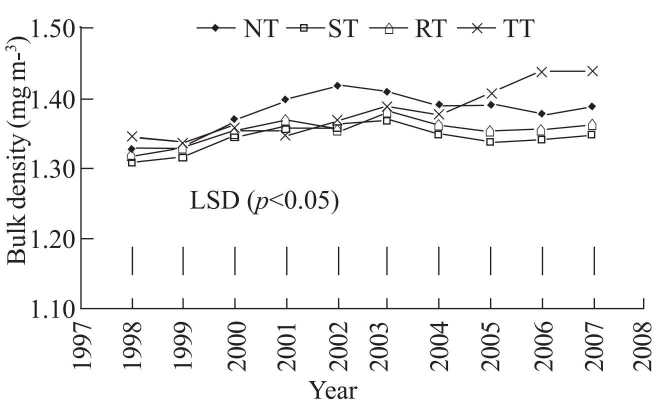
Many researchers reported that soil hydraulic conductivity, bulk density and compaction increased and porosity decreased because of the application of a zero tillage system (Munkholm et al., 2001; Strudley et al., 2008; Lipiec et al., 2006; Glab and Kulig, 2008). In several studies compaction was higher in the upper soil layer under reduced tillage and direct drilling when compared to the conventional tillage (Ozpinar and Cay, 2005; McVay et al., 2006; Boydaş and Turgut, 2007; Thomas et al., 2007). Al-Kaisi et al., 2005 used wide range of tillage systems in the Corn-Belt in the United States soil and found that bulk density values of no-tillage (NT) and chisel plow (CP)

Table 5: Tillage effects on BD at different soil depths (cm)

Soil depths			0-5	5-10	10-15	15-30	30-60
Two-tillage treatments	CNW	No-tillage	1.19[ab]	1.23[a]	1.31[a]	1.30[a]	1.31[a]
		Chisel plow	1.03[b]	1.29[a]	1.33[a]	1.27[a]	1.30[a]
	GPS	No-tillage	1.14[a]	1.22[a]	1.26[a]	1.35[a]	1.31[a]
		Chisel plow	1.11[a]	1.23[a]	1.29[a]	1.31[a]	1.30[a]
	KFC	No-tillage	1.22[a]	1.44[a]	1.40[a]	1.48[a]	1.44[a]
		Chisel plow	1.24[a]	1.28[a]	1.40[a]	1.45[a]	1.43[a]
	M	No-tillage	1.10[a]	1.17[a]	1.10[a]	1.09[a]	1.10[a]
		Chisel plow	0.99[a]	1.19[a]	1.14[a]	1.13[a]	1.14[a]
	OMT	No-tillage	1.22[a]	1.31[a]	1.31[a]	1.36[a]	1.34[a]
		Chisel plow	1.01[a]	1.25[a]	1.26[a]	1.32[a]	1.29[a]

BD: bulk density; CNW: Clarion–Nicollet–Webster; GPS, Galva–Primghar–Sac; KFC, Kenyon–Floyd–Clyde; M: Marshall; OMT: Otley–Mahaska–Taintor. Values in column within each soil association of the two-tillage treatments experiment or within the five-tillage treatments experiment followed by the same letter are not significantly different at $p<0.05$

treatments were not significantly different after 7 years (Table 5). Osunbitan et al. (2005) observed greater bulk density in no-till system in the 5 to 10 cm soil depth. In contrast, other studies reported greater to similar BD in conventional tillage compared to no tillage (Logsdon and Gambardella, 2000; Unger, 1996). In a long term experiment, He et al. (2009) reported that soil bulk density up to 30 cm depth was greater for NT than for traditional tillage (TT) during the first 5 years of the experiment, however, the increase on the conservation tillage plots plateaued after about 5 years, while traditional tillage kept increasing (Figure 1). After 10 years, bulk density on the TT plot was significantly greater than on the conservation tillage. Lower BD under NT than conventional tillage has also been reported by Green et al. (2005) in silt loam soil in Maryland and in sandy loam soil (Sharma et al., 2011). The NT system maintained a significantly greater amount of residue on the soil surface increase soil organic carbon and biotic activity (Lal, 1989; Karlen et al., 1994; Tiarks et al., 1974; Schjonning et al., 1994)., thereby decreasing bulk density, particularly near the soil surface. Chen et al. (2009) also indicated higher bulk density under conventional tillage with residue removal than shallow tillage with residue cover, and no-tillage with residue cover after 11 years at 0-15-cm soil depth. Abu-Hamdeh (2004) studied the effect of tillage treatments (moldboard ploughing MB; chisel ploughing CS; and disk ploughing DP) for comparison of axle load on a clay loam soil. He reported that the dry bulk density from 0 to 20 cm was affected by the tillage treatments and from 20 to 40 cm by axle load. The MB treatment caused the maximum percentage increase of dry bulk density at all depths. Jabro et al., (2009) in a 22 years study found that the tillage practices [no-till (NT), spring till (ST), and fall and spring till (FST)] had no significant difference on BD on a sandy loam soil. These findings are in agreement with those of Lampurlanes and Cantero-Martinez (2003) but differ from results reported by Hill and Cruse (1985) and McVay et al., (2006).



NT: no-tillage with straw cover; ST: sub-soiling with straw cover; RT: Roto-tilling with straw cover; TT: traditional ploughing

Figure 1: Mean bulk density for the four treatments in the 0–30 cm soil profile

Table 6: Macroporosity (>30 μm) and differential porosity of investigated soil for tillage and mulch treatments

Treatments	Total porosity (cm^3 cm^{-3})	Macroporosity (cm^3 cm^{-3})	Pores (cm^3 cm^{-3}) Transmission	Storage	Residual
0-10 cm					
RZ	0.466 [b]	0.147 [b]	0.078 [b]	0.236[a]	0.096[a]
RM	0.508[a]	0.197[a]	0.112[a]	0.234[a]	0.091[a]
CZ	0.503[a]	0.190[a]	0.108[a]	0.237[a]	0.089[a]
CM	0.514[a]	0.201[a]	0.115[a]	0.228[a]	0.090[a]
10-20 cm					
RZ	0.458[a]	0.142 [b]	0.076[b]	0.220[a]	0.094[a]
RM	0.463[a]	0.149 [b]	0.082[b]	0.214[a]	0.092[a]
CZ	0.508[a]	0.210[a]	0.121[a]	0.217a	0.087[a]
CM	0.512[a]	0.210[a]	0.12[a]	0.217[a]	0.087[a]

Means in columns for particular soil layer followed by the same letters are not significantly different (P-p< 0.05) conventional tillage and mulch (CM), conventional tillage but zero mulching (CZ), reduced tillage and mulch (RM) and reduced tillage but zero mulching (RZ)

2.3. Soil porosity

Tillage systems affect the porosity characteristics (Benjamin, 1993) and are closely related to the soil aeration, root growth and water movement (Pagliai and Vignozzi, 2002; Sasal et al., 2006; Oliveira and Merwin, 2001). In long term experiment it has been well documented that straw returning could increase the total porosity of soil (Lal et al., 1980; He et al., 2009), however, minimal and no tillage would decrease the soil porosity for aeration, but increase the capillary porosity; as a result, it enhances the water holding capacity of soil along with bad aeration of soil (Wang et al., 1994; Glab and Kulig, 2008,). Glab and Kulig, (2008) found the macroporosity of soil with conventional tillage (14.79%) was significantly higher in comparison with reduced tillage (6.55%), Table 6. Reduced tillage increased the macroporosity in pore diameter range of 50–500 μm. The lowest transmission pores content (0.078 cm^3 cm^{-3}) was noticed at the reduced tillage without mulch at the 0–10 cm layer. Similarly in long term experiment, He et al. (2009) reported that in a spring wheat–oat cropping system conservation tillage treatments had positive effects on pore size distribution.

Sur et al. (2001) found increased in total porosity in more compacted soil particularly in no tillage system. However in short term experiment Zhang et al. (2006) found an increase in mesoporosity in the 0–10 cm soil layer of only 1.6% compared to ploughing in semiarid area while Børresen, (1999) found no effect on total porosity and porosity size distribution. The effect of conservation tillage was to reduce the volume fraction of large pores and to increase the volume fraction of small pores relative to the conventional tillage (Bhattacharya et al., 2008). Zhang et al. (2003) compared the mean aeration porosity at two locations in the top 0-0.30 m between conservation tillage treatments and conventionally tilled soil. The results indicated an improvement in the soil porosity under conservation tillage (ST, sub-soiling with retention of all surface plant residues; and NT consisted of zero tillage and planting was through the previous plant residues) was most probably related to the beneficial effects of soil organic matter caused by minimum tillage and residue cover.

2.4. Soil water storage

Soil water content is the most important factor influencing soil compaction processes (Lal, 1978; Akram and Kemper, 1979). Soil water infiltration rate also can be used to monitor soil compaction status, especially of the topsoil. Combined increases in soil water and external load increased soil compaction, as indicated by increasing soil bulk density and soil strength and decreasing soil water infiltration rate (Hamza and Anderson, 2003 and 2011). Increases in the bulk density usually result in large decreases in water flow through the soil. Much research has shown that use of surface mulch can result in storing more precipitation water in soil by reducing runoff, increasing infiltration and decreasing evaporation (Ji and Unger, 2001; Smika and Unger, 1986; Antapa and Angen, 1990; Abu-Hamdeh, 2004; Soane and Van Ouwerkerk 1994; Sharma et al., 2011). Alvarez and Steinbach 2009 found water infiltration rate were higher in reduced tillage systems than under plow tillage. The increase of soil water contents under no-till (Martens, 2000; Nielsen et al., 2005) and also higher water use efficiencies (Hatfield et al., 2001) due to residue retention, than under managements with tillage application. Meek et al. (1989) reported 17% increase in the infiltration rate in the field when soil was packed lightly before the first flood irrigation compared with no packing. Barzegar et al., (2002) observed that infiltration rate and water retention increased linearly with increase in wheat straw application rate from 0 to 15 Mg ha^{-1}. He et al., 2009 observed increased WUE in NT plots than in the traditional plots during the dry years of 1999, 2003 and 2006 (Table 7) associated to improvement in aggregations and macrospore connectivity, which affects near-zero infiltration rates and hydraulic conductivity (Strudley et al., 2008). In some cases, increases of soil water content had been observed under no-till (Nielsen et al., 2005, Sharratt, 1996; Gregorich et al., 2008), similar (Ankeny et al., 1990) or lower infiltration rates (Gantzer and Blake, 1978; Go´mez et al., 1999; Rasmussen, 1999).

Table 7: Water use efficiencies (WUE) in different tillage

Year		DW (mm)				WUE (kg ha^{-1} mm^{-1})			
		NT	ST	RT	TT	NT	ST	RT	TT
1998	159.1	81.8	83.3	80.3	77.8	4.9^{a}	5.0^{a}	4.6^{a}	4.5^{a}
1999	190.0	69.5	67.7	72.2	75.9	5.1^{a}	4.7^{ab}	4.6^{ab}	4.3^{b}
2000	274.9	55.4	62.2	46.8	47.9	4.3^{a}	4.1^{a}	4.1^{a}	4.2^{a}
2001	268.9	52.8	50.2	49.8	55.8	4.2^{a}	3.9^{a}	4.1^{a}	3.8^{a}
2002	254.9	54.1	53.4	60.8	58.3	4.8^{a}	4.9^{a}	4.4^{a}	4.2^{a}
2003	167.2	79.9	80.8	74.7	72.1	5.4^{a}	4.8^{ab}	4.8^{ab}	4.4^{b}
2004	309.7	49.8	52.8	44.3	46.8	4.2^{a}	4.4^{a}	4.3^{a}	4.2^{a}
2005	286.4	78.8	71.8	70.1	73.8	4.1^{a}	3.9^{a}	3.8^{a}	3.6^{a}
2006	206.1	66.0	63.5	66.9	68.8	5.2^{a}	4.9^{ab}	4.6^{ab}	4.1^{b}
2007	192.6	83.4	70.8	82.6	71.0	4.9^{a}	4.9^{a}	4.6^{a}	4.2^{a}
Mean	231.0	67.2	65.7	64.9	64.8	4.7	4.6	4.4	4.2

Values within a row followed by the same letters are not significantly different ($p<0.05$); DW: Change in stored soil water of the soil profile (0–100 cm depth) from planting to harvest; NT: No-tillage with straw cover; ST: Subsoiling with straw cover; RT: Rototilling with straw cover; TT: traditional ploughing

2.5. Saturated hydraulic conductivity

The saturated hydraulic conductivity, *Ks* is an indicator of the soil's ability to transmit the water needed for plants to the root zone, as well as drain excess water out of the root zone (Topp et al., 1997). A *Ks* value in the range 5×10^{-3} cms^{-1} to 5×10^{-4} cms^{-1} may be considered "ideal" for promoting rapid infiltration and redistribution of needed crop-available water, reduced surface runoff and soil erosion and rapid drainage of excess soil water (Reynolds et al., 2003). *Ks* values were significantly higher in fallow soil tilled with chisel and disc ploughed than untilled fallow.

(Kribba et al., 2001). Lampurlanes and Cantero−Martinez, 2006 compared three tillage systems (subsoil tillage, minimum tillage and no-tillage) under three field situations (continuous crop, fallow and crop after fallow) on two soils and found soil under no-tillage had lower hydraulic conductivity than under subsoil tillage or minimum tillage during 1 of 2 years in continuous crop due to a reduction of soil porosity. However, Mahboubi et al., (1993) found that no-tillage resulted in higher saturated hydraulic conductivity compared with conventional tillage after 28 years of tillage on a silt loam soil in Ohio. Kahlon et al. 2013 in a long term experiment found higher Ks were measured in NT than PT treatments with increase in mulch rate from 0 to 16 Mg ha^{-1}. Lal et al. (1994); Mahboubi et al. (1993) showed beneficial effects of long-term conservation tillage on soil physical properties. *Ks* were found to decrease during the growing season in tilled soils (Messing and Jarvis, 1993; Mwendera and Feyen, 1993; Logsdon et al., 1993) due to soil structural breakdown and surface sealing, and root growth that progressively blocks pores (Ankeny et al., 1990; Suwardji and Eberbach, 1998). Whereas, Chang and Landwell (1989) did not observe any changes in the saturated hydraulic conductivity after 20 years of tillage in a clay loam soil in Alberta. Heard et al., (1988) reported that saturated hydraulic conductivity of silt clay loam soil was higher when subjected to 10 years of tillage than no-tillage in Indiana. They attributed the higher hydraulic conductivity of tilled soil to the greater number of voids and abundant soil macropores caused by the tillage implementation. Iqbal et al., (2005) reported that deep tillage increase the *Ks* as compared to the no tillage. Furthermore, previous research demonstrated that continuous tillage of 11 years had developed a compacted layer that impeded water movement at a depth of approximately 10 to 15 cm (Pikul and Aase, 1999, 2003). Soil macropores and aggregations under NT formed by decayed roots can be preserved under NT whereas conventional tillage breaks up the continuity of these macropores. Macropores generally occupy a small fraction of the soil volume but their contribution to water flow in soil is high.

2.6. Soil Structure

From the agricultural point of view, the most suitable indicator of soil quality is aggregate stability (Karlen and Stott, 1994). Research indicates that soil aggregation depends on tillage intensity (Feiza et al., 2008). Reduced tillage increases the amount of water stable aggregates and organic matter (Belesdent et al., 2000). Reduction in the breakdown of surface soil aggregates as a result of residue cover of soil surface and the absence of tillage (Oyedele et al., 1999) increase the macroaggregates in no till (NT) compared with plow till (PT) soils (Cambardella and Elliott, 1993a; Beare et al., 1994a, b; Six et al., 2000b; Mikha and Rice, 2004). Kahlon et al., 2013 reported that mean weight diameter (MWD, mm) increased from 0.36 to 1.21, 0.29 to 0.84, 0.25 to 0.62 under no till (NT), reduced till (RT) and plow till (PT), respectively, with increase in mulch rate from 0 to 16 Mg ha^{-1} (Table 8). The rate of macroaggregate turnover (formation and degradation) is also reduced under NT compared with PT (Six et al., 1998, 2000a), and aggregate stability is decreased with PT. Zotarelli et al., (2005) reported that the MWD of the aggregates was on average 0.5 mm greater under NT compared with that under PT. Soils from conservation tillage plots contained more macro-aggregates (13–37%) than those under traditional tillage throughout the soil profile while the percentage of micro-aggregates was 25–59% greater in traditional tilled soils (He et al., 2009). Straw incorporation or reduced tillage significantly reduced the amount of the smallest <0.25 mm aggregates. Studies revealed that macroaggregates (>0.25 mm) are more enriched in C than microaggregates (<0.25 mm) (Elliott, 1986; Cambardella and Elliott, 1993a, b; Puget et al., 1995; Six et al., 2000b).

Table 8: Mulch and tillage effects on mean weight diameter (mm) and water stable aggregates (%)

Tillage	Mulch rate (Mg ha^{-1})					
	0		8		16	
	Soil depth (cm)					
	0-10	10-20	0-10	10-20	0-10	10-20
MWD (mm)						
NT	0.36	0.23	0.64	0.51	1.21	0.65
RT	0.29	0.21	0.57	0.45	0.84	0.53
PT	0.25	0.19	0.44	0.37	0.62	0.47
LSD (<0.05) Tillage=0.07; Mulch=0.02; Depth=0.01; Tillage×mulch=0.04; Tillage×mulch×depth=0.05						
WSA (%)						
NT	52.1	31.7	68.7	43.9	77	54.3
RT	43.7	26.8	58.6	36.5	66.6	46.1
PT	39.5	21.7	50.9	30.6	59.5	38.5

LSD ($p<0.05$) for Tillage=5.6, Mulch=3.1, Depth=0.62, Tillage×mulch=1.07; NT: No till; RT: Reduced till; PT: plow till

3. Conclusion

Long term studies show that conservation agriculture minimizes soil disturbance, encourages build-up of organic material, preserves the soil structure, increases biodiversity and conserves soil water. Lower intensity of tillage leaves organic mulch at the soil surface, which reduces run-off, increases the surface soil organic matter (SOM) promoting greater aggregate stability which restricts soil erosion. However, ambiguous nature of research findings documents the need for additional studies of the effect of long-term tillage on soil organic carbon and physical properties.

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