Chapter 9

An Appraisal of Conservation Tillage on the Soil Properties and C Sequestration

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Additional information is available at the end of the chapter

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1. Introduction

Soil is a fundamental natural resource on which civilization depends. Agricultural production is directly related to quality of soil. In view of the rapidly expanding global population and its pressure on the finite amount of land available for agricultural production; maintaining soil quality is essential not only for agricultural sustainability, but also for environmental protection. Maintenance of soil quality would reduce the problems of land degradation, decreasing soil fertility and rapidly declining production levels that occur in many parts of the world which lack the basic principles of good farming practices. Intensification of agricultural production has been an important factor influencing GHG emission and affecting the water balance. Currently, agriculture accounts for approximately 13% of total global anthropogenic emissions and is responsible for about 47% of total anthropogenic emissions of methane (CH_4) and 58% nitrous oxide (N_2O).

Soil tillage is one of the very important factors in agriculture that would affect soil physical properties and yield (Keshavarzpour and Rashidi, 2008). Among different operations, the soil tillage is considered one of the most important practices in agricultural production due to its influence on physical, chemical, and biological properties of the soil environment. The tillage would aim to create a soil environment favorable to the plant growth (Klute, 1982). Among different crop production factors, tillage contributes up to 20% (Khurshid et al., 2006). According to Lal (1979a, 1983), it is defined as physical, chemical or biological soil manipulation to optimize the conditions for germination, seedling establishment and crop growth. According to Antapa and Angen (1990), tillage is any operation or practice carried out to prepare the soil surface for the purpose of crop production. Ahn and Hintze (1990) state that tillage is nothing but physical loosening of the soil by a range of cultivation operations which could be either manually or mechanized. In the past, the soil tillage has been associated with an increased fertility, which originated from the mineralization of soil nutrients as a consequence of tillage operations. In the long term, this process would lead to a reduction of soil organic matter. Therefore, most soils degrade under prolonged intensive arable agriculture. This structural degradation of the soils would result in the formation of crusts and compaction and further would lead to soil erosion. Acharya and Sharma (1994) and Pagliai et al., (1995) reported that the structure of Ap horizon is largely influenced by the soil tillage system and the implements used for tillage operations. Soil tillage has a major influence on the water intake, storage, evaporation and absorption of water from the soil by plant roots, biological activity, and organic matter break down, which influence the soil aeration, soil moisture and soil temperature (Kathirval et al., 1992). 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. Some authors pointed out that the tillage treatments affected the soil physical properties, especially, when the same tillage system has been practiced for a longer time (Jordhal and Karlen, 1993; Mielke Wilhelm, 1998). The proper use of tillage could improve soil related constrains, while an improper tillage would cause destruction of the soil structure, accelerated erosion, depletion of organic matter and fertility, and disruption in cycles of water, organic carbon and plant nutrients (Lal, 1993). Appropriate tillage practices are those that would avoid the degradation of soil properties but would maintain crop productivity as well as ecosystem stability (Lal, 1981b, c, 1982, 1984b, 1985a; Greenland, 1981).

Conventional soil management practices resulted in losses of soil, water and nutrients in the field, and degraded the soil with low organic matter content and a fragile physical structure, which in turn led to low crop yield, low water and fertilizer use efficiency. Conventional tillage overturns the soil layer, which breaks the structure of soil and as a result, decreases the permeability of soil (Kribaa et al., 2001). Annual disturbance and pulverizing caused by the conventional tillage produced a finer and loose soil structure as compared to conservation and no-tillage method which would leave the soil intact (Rashidi and Keshavarzpour, 2007). This difference results in a change of number, shape, continuity and size distribution of the pores network, which would control the ability of a soil to store and transmit air, water and agricultural chemicals. This in turn would control erosion, runoff and crop performance (Khan et al., 2001).

According to the Conservation Technology Information Center in West Lafayette, Indiana, USA, conservation tillage could be defined as "any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce the erosion by water; or where.;p soil erosion by wind is the primary concern, with at least 1120 kg ha^{-1} flat small grain residue on the surface during the critical wind erosion period." No tillage, minimum tillage, reduced tillage and mulch tillage are terms synonymous with conservation tillage as observed by Willis and Amemiya, (1973); Lal (1973, 1974, 1976b); Phillips et al., (1980); Greenland (1981); Unger et al., (1988); Antapa and Angen (1990); Opara-Nadi (1990); Ahn and Hintze (1990).In recent years, interest in conservation tillage systems has increased in response to the need to limit the erosion and promote water conservation (Hulugalle et al., 1986; Unger et al., 1988). Conservation tillage provides the best opportunity for halting degradation, restoring and improving soil productivity (Lal, 1983; Parr et al., 1990). It has the potential to aggrade the soil quality and reduce the soil loss by providing protective crop residue on soil surface and improving water conservation by decreasing evaporation losses (Carter, 1991).Conservation tillage leads to positive changes in the physical, chemical and biological properties of a soil (Bescanca et al., 2006). 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). Soil organic matter was increased because of straw recycling, which can increase soil porosity (Lal et al., 1980 and Blanco et al., 2007). Many soil-surface modifications would influence the components in the WUE equation viz. manipulation of the soil surface by tillage and surface residue management or mulching, can increase soil water retention capacity, improve the ability of roots to extract more water from the soil profile, or decrease leaching losses (Hatfield et al., 2001). Soil physical properties that are influenced by conservation tillage include bulk density, infiltration and water retention (Osunbitan et al., 2005). The improved infiltration of rainwater into the soil increases water availability to plants reduces surface runoff and improves the groundwater recharge (Lipiec et al., 2005).Many studies showed that under edapho-climatic conditions, conservation tillage can lead to improvements in the water storage in the soil profile (Pelegrín et al., 1990; Moreno et al., 1997, 2001). Therefore, currently there is a significant interest and emphasis on the shift to the conservation tillage methods for the purpose of controlling erosion process (Iqbal et al., 2005). Under these conditions, improvements were also obtained in the crop development and yield, especially in dry years (Pelegrín, 1990; Murillo, 1998, 2001; Du Preez, 2001). Under arid or semi-arid climatic conditions, high temperatures limit the accumulation of organic carbon at the soil surface (Franzluebbers, 2002a, 2002b; Mrabet, 2002).

World soils, an important pool of active C, play a major role in the global C cycle and contribute to changes in the concentration of GHGs in the atmosphere (Lal et al., 1998). Intensive agriculture is believed to cause some environmental problems, especially related to water use, water contamination, soil erosion and greenhouse effect (Houghton et al., 1999; Schlesinger, 1985; Davidson and Ackerman, 1993). Minimizing the increase in ambient CO2 concentration through soil C management, reduces the production of GHGs and minimizes potential for climate change. In fact, agricultural practices have the potential to store more C in the soil than agriculture releases through land use change and fossil fuel combustion (Lal et al., 1998).

Improved soil and crop management practices, such as reduced tillage and increased cropping intensity, however, would increase SOC as compared to conventional practices (Halvorson et al., 2002a; Sherrod et al., 2003; Sainju et al., 2007). Many studies have reported that implementation of minimum tillage has occasionally caused yield losses, especially in the no tillage method (Rao, 1996; Kirkegaard et al., 1995; Silgram and Shepherd, 1999). As Warkentin (2001) pointed out, the global experience with minimum tillage, or direct drilling, results in equal and even slightly smaller, harvests than traditional tillage (by using mouldboard plough). Since the late sixties, many studies of the effects of conservation tillage systems on soil properties and crop yield have been conducted in many parts of the world.

A complete review is beyond the scope of this presentation. The objective of this study is to give an overview of the early studies on conservation tillage systems, discuss some results from present-day studies and outline research needs and goals for the future aimed at enhancing and sustaining the crop production through conservation tillage systems.

2. Agriculture's contribution to greenhouse gas emissions

Agricultural eco-systems represent an estimated 11% of the earth's land surface and include some of the most productive and carbon-rich soils. As a result, they play a significant role in the storage and release of C within the terrestrial carbon cycle (Lal et al., 1995). The primary sources of greenhouse gases in agriculture are the production of nitrogen based fertilizers; the combustion of fossil fuels; and waste management (Fig. 1). Livestock enteric fermentation or the fermentation that takes place in the digestive systems of the ruminant animals, results in methane emissions. The major considerations of the soil C balance and the emission of greenhouse gases from the soil are: potential increase of CO_2 emissions from soil contributing to the increase of the greenhouse effect, the potential increase in other gas emissions (e.g., N_2O and CH_4) from soil as a consequence of land management practices and fertilizer use, and the potential for increasing C (as CO_2) storage into soils, which equals $1.3 – 2.4 X 10^9$ metric tons of carbon per year, and to help reduce the future increases of CO_2 in the atmosphere.

Carbon dioxide is removed from the atmosphere and converted to organic carbon through the process of photosynthesis. As organic carbon decomposes, it is converted back to carbon dioxide through the process of respiration. During 2005, agriculture accounted for 10 to 12 percent of the total global human caused emissions of greenhouse gases, according the Inter-governmental Panel on Climate Change (IPCC, 2007). In the United States, greenhouse gas from agriculture accounts for 8 percent of all emissions and has increased since 1990 (Congressional Research Service, 2008).Conservation tillage, organic fertilizers, cover cropping and crop rotations would drastically increase the amount of carbon stored in the soils.

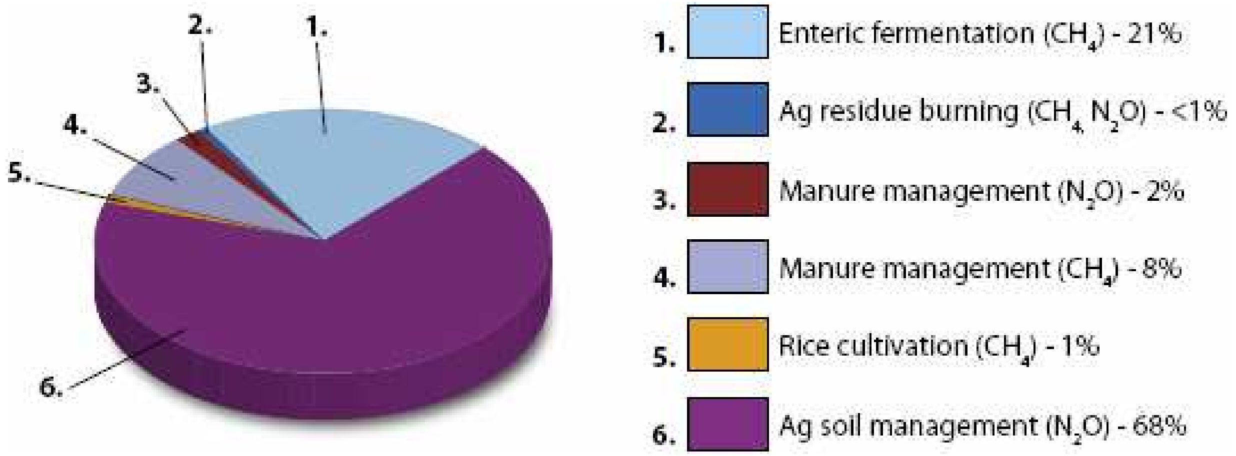

Figure 1. Agricultural green house gas emission (Average 2001-2006), Source: EPA, 2007

Soils store a significant amount of carbon. It has been estimated that global soils contain approximately $1.5 X 10^{12}$ metric tons of carbon. As a component of the carbon cycle (Fig. 2), soils can be either net sources or net sinks of the atmospheric carbon dioxide. Changes in the land use and agricultural activities during the past 200 years have made the soils act as net sources of atmospheric CO_2. Evidence from the long-term experiments suggests that the carbon losses due to oxidation and erosion could be reversed with appropriate soil management practices that would minimize the soil disturbance and optimize plant yield through fertilization. The soil tillage systems would have considerable impact on the environment by influencing the soil structure, which would further substantially affect the water quality, nutrients, sediments, pesticides and air quality and greenhouse effect (Holland, 2004; Hobbs, 2007).

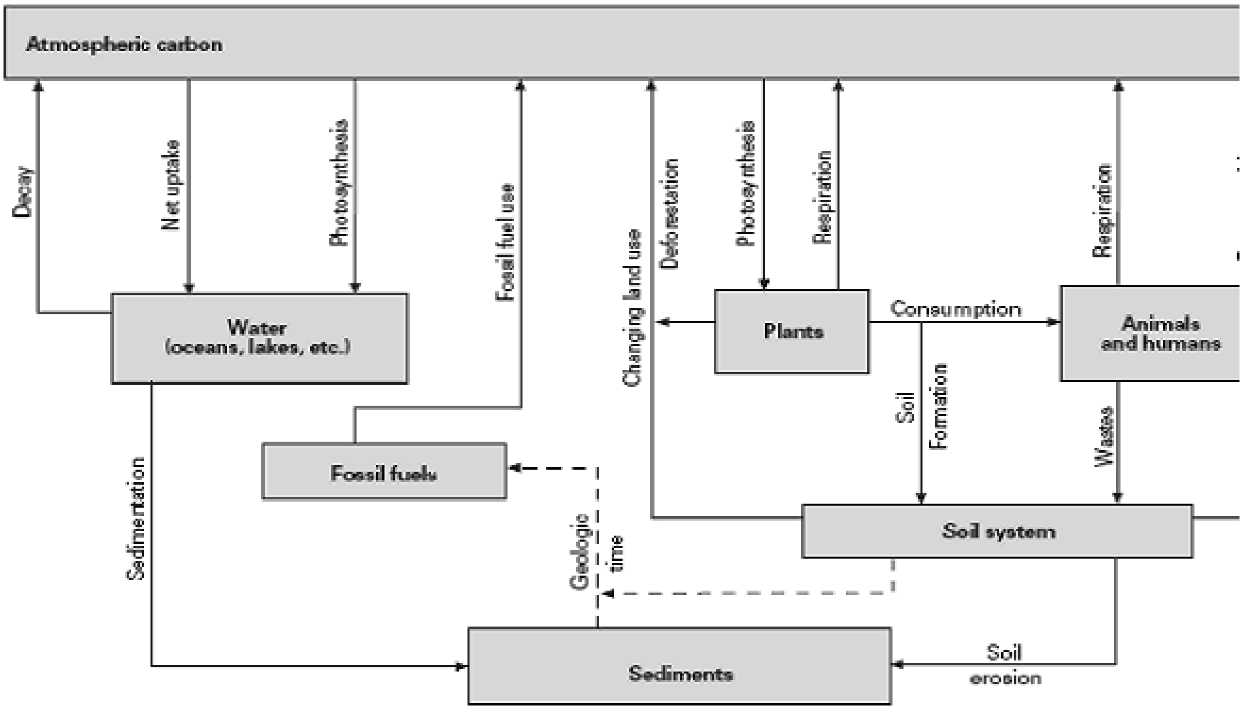

Figure 2. Carbon cycle aspects (modified from Paul and Clark)

3. Conservation tillage - the effects on soil properties

3.1. Organic matter

The amount of organic matter in a soil is often used as an indicator of the potential sustainability of a system. Soil organic matter plays a key role in nutrient cycling and can help improve soil structure. The soil organic matter is the second biggest carbon pool of the planet after the oceans. The soil organic matter is essential to control erosion, water infiltration and conservation of nutrients, and is related with the soil quality. Moist, hot and well-aerated conditions favour rapid decay of organic additions. If the rate of organic matter addition is greater than the rate of decomposition, the organic fraction in a soil will increase (Fig. 3). Reicosky (1997) reported that 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. Their results suggest that no form of residue management will increase SOC content as long as the soil is moldboard plowed. Hooker et al. (2005) also found that within a tillage treatment, residue management had little effect on SOC in the surface soil layer *(0-5* cm). Tillage tended to decrease the SOC content, although only no till combined with stover return to the soil resulted in an increase in SOC in the surface layer compared with moldboard plowed treatments. Walling (1990) reported that over the last 40 years the amount of organic matter being returned to the soil has declined, primarily as a consequence of more intensive soil cultivation, the removal of crop residues, the replacement of organic manures with inorganic fertilizer, and the loss of grass leys from rotations. In addition, organic matter is being eroded from arable land to rivers disproportionately to its availability. Over this period losses of soil C were estimated at 30–50% and a large proportion of arable soils now contain less than 4% C.

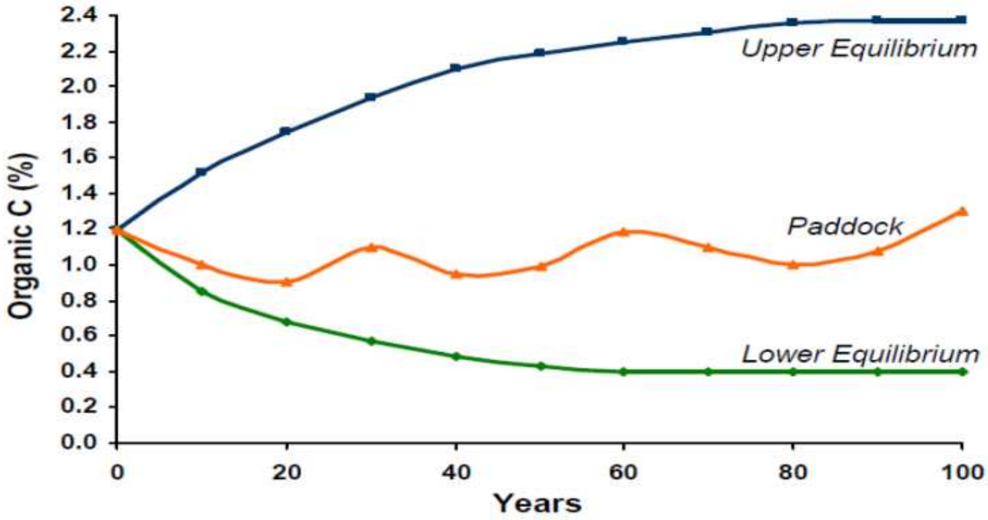

Figure 3. Organic carbon levels over time under different management systems

Murillo et al., (2001) compared the traditional tillage (TT) and conservation tillage (CT) under rainfed conditions in south-west Spain. The results indicated that CT improved the soil quality by reaching a greater soil resistance 'SR' (> 2) than that in TT (< 2). This fact could be due to the better water infiltration and storage in the soil profile under CT that would facilitate the uptake of water and nutrients by the plant in the periods of most droughts. In general, in any edapho-climatic context, a high stratification ratio is a good index of soil quality, since ratios above 2 are not common in the degraded systems (Franzluebbers, 2002a, 2002b; Mrabet, 2002). Application of conservation tillage to sandy loam and loamy soil type in the dryland, central rift valley of Ethiopia for five years, markedly improved the organic matter content, N concentration and soil moisture content (Worku, B. et al., 2006).

3.2. Bulk Density (BD)

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. These results reflect a more compact soil layer at the 0-10 cm depth than at the 10-20 cm depth. According to Lhotsky (1991), soil BD above 1.50 Mgm^{-3} in the plough horizon on medium heavy soils has a negative effect on the growth and development of agricultural crops and was regarded as the threshold value of adverse soil compaction. Sharma et at (2011) observed that intensive tillage condition increased the bulk density (4.7 %) of a sandy loam soil as compare to the reduced tillage in rainfed condition. Osunbitan et al. (2005) observed greater bulk density in no-till system in the 5 to 10 cm soil depth. Logsdon et al. (1999) found no differences in bulk density between the different tillage systems. Jabro et al., (2009) in a 22 years study on a sandy loam soil found that the tillage practices [no-till (NT), spring till (ST), and fall and spring till (FST)] apparently had not significantly influenced the soil BD and only slight differences were observed in BD (Table 1). These findings are in agreement with those of Anken et al., (2004), and Lampurlanes and Cantero-Martinez (2003) but differ from results reported by Hill and Cruse (1985) and McVay et al., (2006). Based on 8 years studies Zhang et al., (2003) reported that the mean soil bulk density was 0.8-1.5% lower in ST (sub-soiling with retention of all surface plant residues) and NT treatments (consisted of zero tillage; planting was through the previous plant residues.) than in CT (consisted of manually removing all plant residues from the soil surface, followed by mouldboard ploughing). The crop residue retention has been reported to 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 in the ST and NT plots under investigation.

Parameter	BD (Mg m^{-3})	GWC (g g^{-1})
Tillage		
NT	1.59	0.141
ST	1.58	0.139
FST	1.61	0.135
Soil depth (cm)		
0 - 5	1.49^{a}	0.144
5 - 10	1.68^{b}	0.136
10 – 15	1.60^{c}	0.135
Tillage (T)	0.439	0.515
Soil depth (D)	0.0001	0.253
T × D	0.990	0.161

Table 1. Effect of tillage and depth on bulk density (BD), and gravimetric water content (GWC)

3.3. Soil porosity

Porosity is a measure of the total pore space in the soil. This is measured as a volume or percent. The amount of porosity in a soil depends on the minerals that make up the soil and the amount of sorting that occurs within the soil-structure. For example, a sandy soil will have larger porosity than silty soil because the silt will fill in the gaps between the sand particles. Porosity characteristics differ among tillage systems (Benjamin, 1993). Soil porosity characteristics are closely related to the soil physical behavior, root penetration and water movement (Pagliai and Vignozzi 2002; Sasal et al. 2006). Previous researches showed that the straw returning could increase the total porosity of soil (Lal et al., 1980), while 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). However, Børresen (1999) found that the effects of tillage and straw treatments on the total porosity and porosity size distribution were not significant. Allen et al., (1997) indicated that the minimal tillage could increase the quantity of big porosity. Zhang et al., (2003) compared the mean aeration porosity at two locations viz, Dazing and Changping in China in the top 0-0.30 m between conservation tillage treatments and conventionally tilled soil. The results illustrated 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 (Table 2). The increased porosity is especially important for the crop development since it may have a direct effect on the soil aeration and enhances the root growth (Oliveira and Merwin, 2001). The improved root growth would hence increase plant water as well as nutrient uptake. Within the conservation tillage treatments, ST produced more aeration porosity than NT, but the effect on capillary porosity appeared to be reversed in the 0-0.30 m soil layer. Husnjak and Kosutic (2002) reported that higher BD reduced the total porosity and changed the ratio of water holding capacity to air capacity in favour of water holding capacity. Total porosity below 45% on medium heavy soils had a negative effect on the plant growth (Lhotsky, 1991).

Treatment	Total porosity	Aeration porosity (> 60 [micro]m)	Capillary porosity (> 60 [micro]m)
Dazing			
ST	52.36 a	42.64 a	9.72 a
NT	51.86 a	41.19 a	10.67a
CT	45.58 b	37.24 b	8.34 a
Changping			
ST	54.25 a	46.32 a	7.93 a
NT	53.01 a	42.99 a	10.02a
CT	45.74 b	39.59 b	6.15 a

Table 2. Soil porosity for ST, NT, and CT treatments at 0-0.30 m depth in Dazing and Changping (Values within a column followed by the same letter are not significantly different at $p < 0.05$)

4. Infiltration rate and gravimetric water content

Infiltration is the process by which water on the ground surface enters into the soil. Infiltration is governed by two forces viz; gravity, and capillary action. Tillage disturbs the natural channels that have formed in a soil. The increase in porosity when soil is tilled may not result in an increase in the infiltration rate because of disruption of the vertical continuity of the pores (Kooistra et al., 1984). The plant roots are important in forming new channels (Parker and Jenny, 1945). Tillage plays a vital role in the conservation of soil moisture at different depths in the rainfed cultivation. It would also improve the soil condition by altering the mechanical impedance to root penetration, hydraulic conductivity and water holding capacity (Dexter, 2004). Lal (1978) measured the infiltration rates of 480 mm h^{-1} for no-till and 150 mm h^{-1} for the ploughed treatment after a field had been planted with maize *(Zea mays* L.) for 5 years. They found that surface residues prevented surface seal in the no-till treatments. Meek et al., (1989) measured a 17% increase in the infiltration rate in the field when soil was packed lightly before the first flood irrigation compared with no packing. Compacting loads of 335 kPa at field capacity on a sandy loam soil reduced infiltration rates to < 1% of the rate obtained when the soil was compacted air dry (Akram and Kemper, 1979). Increases in the bulk density usually result in large decreases in water flow through the soil. Antapa and Angen (1990) reported that retaining crop residues on the soil surface with conservation tillage would reduce evapo-transpiration, increase infiltration rate, and suppress weed growth. Numerous studies shown that the soil moisture and efficiency of moisture use tended to be higher under reduced tillage systems than conventional tillage system. Abu-Hamdeh (2004) observed that mould board plough caused a maximum decrease in the infiltration rate, while with Chiesl plough, CS treatment had the lowest effect. Sharma et al. (2011) observed increase in soil moisture content (12.4%, 16.6%) in minimum tillage (MT) in maize and wheat rotation respectively,in rainfed farming as compared to conventional tillage (Fig 4 & 5).

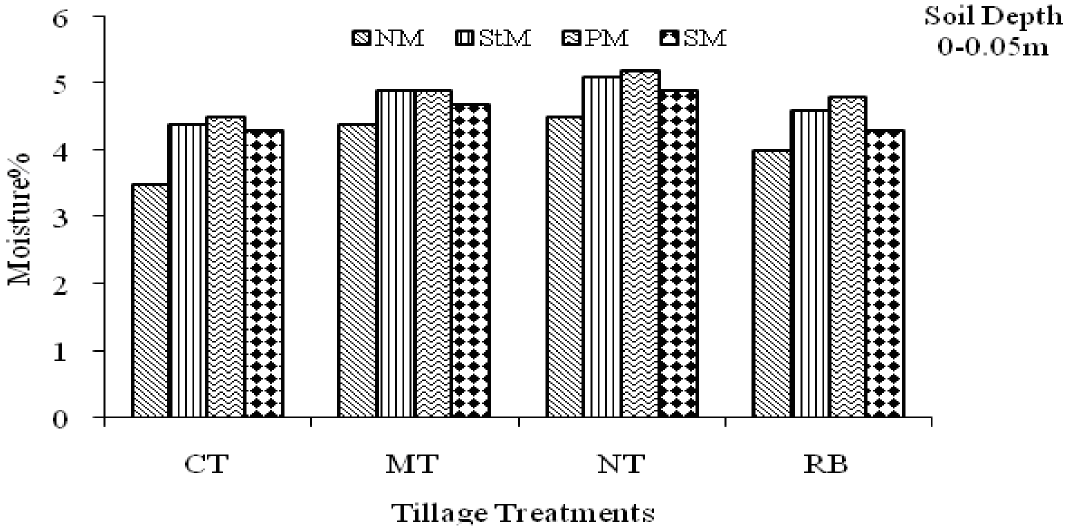

Figure 4. Effect of tillage and water management practices on soil water content at maize harvesting (CT= Conventional tillage,MT= Minimum tillage, NT= No till, RB= Raised bed; NM No mulch nad SM=straw mulch)

Jabro et al. (2009), in a long term study evaluated that tillage, soil depth and their interaction had no significant effect on the soil water content (Table 1). Not surprisingly, NT plots resulted in wetter soil to a depth of 10 cm in this study. The NT plots had greater grvimatric water content (GWC, 0.141 g g^{-1}), followed by ST having 0.139 g g^{-1}, and followed by FST with a mean of 0.135 g g^{-1}. Zhang et al., (2009) showed soil mean GWC values averaged across three tillage systems were 0.144, 0.136, and 0.135 g g^{-1} at 0 to 5 cm, 5 to 10 cm, and 10 to 15 cm depths, respectively. The soil GWC generally was found to decrease with soil depth across the three tillage practices. This could be attributed to greater residues and organic matter in the soil surface than the subsurface proportions of the soil.

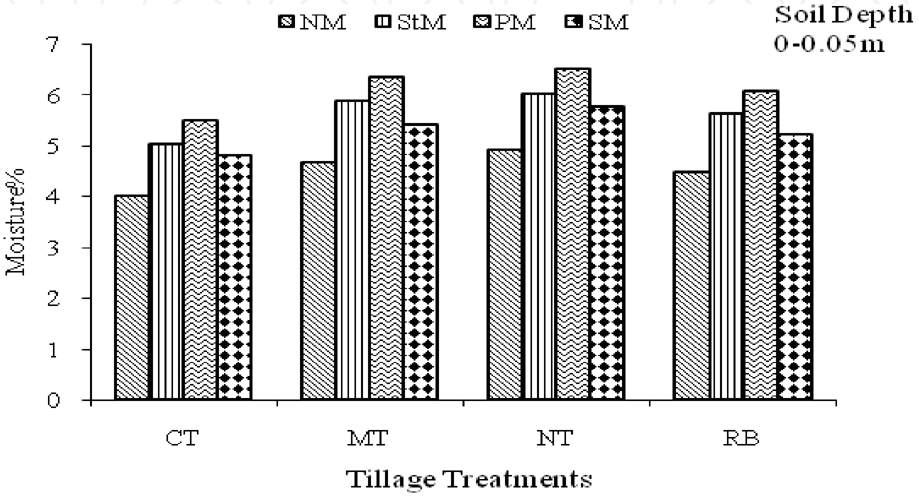

Figure 5. Effect of tillage and water management practices on soil water content at wheat harvesting (CT= Conventional tillage,MT= Minimum tillage, NT= No till, RB= Raised bed; NM No mulch nad SM=straw mulch)

5. Hydraulic conductivity (Ks)

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient. Iqbal et al., (2005) reported that the mean increase in saturated hydraulic conductivity observed was 4.5, 9.1 and 34.1% in the minimum, conventional and deep tillage treatments, respectively compared to zero tillage indicating that deep tillage increases the saturated hydraulic conductivity compared to other tillage methods. Kribba et al., (2001) reported that hydraulic conductivity values were significantly different between treatments of fallow soil tilled with chisel and disc ploughed fallow, and both treatments yielded higher values than untilled fallow. 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. 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. Jabro et al., (2009) reported that the Soil K_s was slightly influenced by tillage and varied from 3.295 mm h^{-1} for intensive tillage (FST) to 5.297 mm h^{-1} for no tillage

(NT), thus, soil K_s decreased with increased intensity of soil manipulation by tillage practices (Fig. 6). 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. Patel and Singh (1981) reported that if the bulk density in a course-textured soil was increased from 1.7 to 1.9 Mg m^{-3}, hydraulic conductivity decreased by a factor of 260.

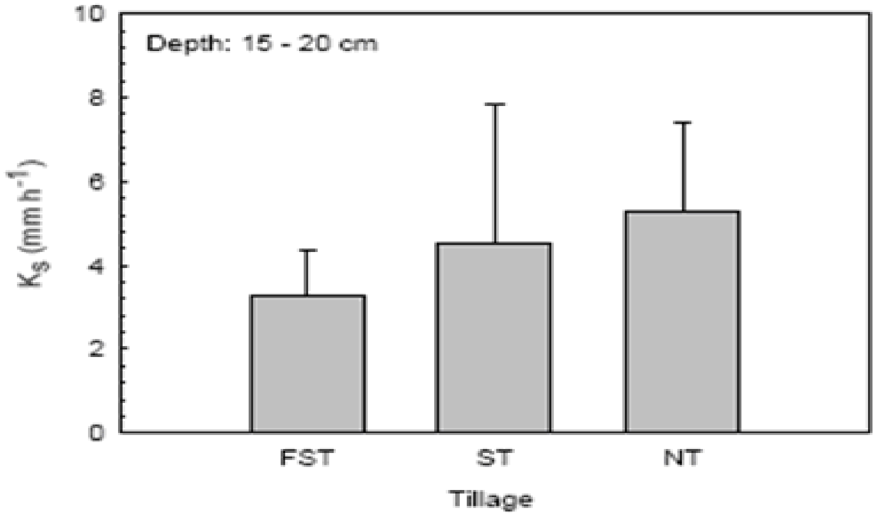

Figure 6. Soil saturated hydraulic conductivity, K_s, as affected by three tillage practices.

6. Soil structure

Good soil structure is important in allowing crop plants to yield well and resist erosion caused by the action of rainfall, melting snow in the early spring and wind. Conservation tillage practices were associated with a greater percentage of macro-aggregates (> 0.25 mm) than conventional tillage (Zhang et al., 2009). Mean macro-aggregates in 0-0.30 m soil depth at Daxing were 22.1% and 12.0% greater under ST (shallow tillage) and NT (no tillage) than CT, and the improvements at Changping were 18.9% under ST and 9.5% under NT (Table 3). These results were consistent with the increase in aggregation occurring as a result of greater biological activity in minimum tilled soils, demonstrated by Tisdall and Oades (1982), and with a 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).

7. C sequestration

Soil carbon or organic matter in general, is important because it affects all soil quality functions (Fenton et al., 1999). The sequestration of atmospheric C in the soil and biomass would not only reduce greenhouse effect, but also helps to maintain or restore the capacity of a soil to perform its production and environmental functions on a sustainable basis. Thus, there is a great interest in the research on sequestration of atmospheric C into the soils for maintaining or restoring soil fertility and mitigating carbon dioxide emissions to the atmosphere.

Location	Soil depth (m)	Soil Treatment	Aggregate size classes (mm)			
			> 2	2-1	1-0.25	< 0.25
Daxing	0-0.10	ST	13.11 a	23.14 a	20.09 a	43.66 a
		NT	11.56 a	18.26 a	19.37 a	50.81 a
		CT	6.42 b	10.37 b	26.35 b	56.86 b
	0.10-0.20	ST	20.42 a	13.74 a	19.73 a	46.11 a
		NT	17.05 a	13.21 a	19.35 a	50.39 a
		CT	10.03 b	12.36 a	21.72 a	55.89 b
	0.20-0.30	ST	19.76 a	17.34 a	27.15 a	35.75 a
		NT	18.52 a	16.35 a	26.35 a	38.78 a
		CT	12.35 b	17.28 a	26.04 a	44.33 b
Changping	0-0.10	ST	7.23 a	13.16 a	40.63 a	38.98 a
		NT	13.11 b	23.14 b	20.09 b	43.66 b
		CT	11.56 b	18.26 b	19.37 b	50.81 b
	0.10-0.20	ST	12.53 a	12.30 a	38.96 a	36.21 a
		NT	8.95 b	11.36 a	38.02 a	41.67 b
		CT	5.97 b	10.28 a	37.96 a	45.96 b
	0.20-0.30	ST	9.59 a	11.48 a	38.26 a	40.67 a
		NT	7.53 b	10.23 a	37.12 a	45.12 b
		CT	6.85 b	9.55 a	35.23 a	48.38 b

Table 3. Soil wet stable aggregate size classes for ST, NT, and CT treatments at 0-0.10, 0.10-0.20, and 0.20-0.30 m depths (%) at Daxing and Changping
(Values within a column followed by the same letter are not significantly different at $p < 0.05$)

Maintaining or increasing SOC under dryland cropping systems remains a challenge in the northern Great Plains (Aase and Pikul, 1996). This is because the crop biomass yields and C inputs are often lower in drylands than in the humid regions due to limited precipitation and a shorter growing season. As a result, it often takes more time to enrich SOC (Halvorson et al., 2002a; Sherrod et al., 2003). Many studies have identified the potential of soils cultivated with different conservation practices (e.g., no-till) to sequester large amounts of carbon (C). It is estimated that conservation tillage practices across the United States may drive large-scale sequestration in the order of 24–40 Tg C yr^{-1} (Tg: teragram; 1 Tg = 1012 g), and that additional C sequestration of 25–63 Tg C yr^{-1} can be achieved through other modifications of the traditional agricultural practices. In the northern Great Plains, traditional farming systems, such as conventional tillage with wheat -fallow, have resulted in a decline in soil organic C (SOC) by 30 to 50% of their original levels in the last 50 to 100 years (Haas et al., 1957; Mann, 1985; Peterson et al., 1998). The data in Fig. 7 indicate the yield of wheat decreased with reduction in the SOC pool and increased with increase in the SOC pool.Intensive tillage increases the oxidation of SOC (Bowman et al., 1999; Schomberg and Jones, 1999). Halvorson et al., (2002a) observed that no-till with continuous cropping increased C sequestration in the drylands of the northern Great Plains by 233 kg ha^{-1} yr^{-1} compared to a loss of 141 kg ha^{-1} yr^{-1} in conventional tillage. The use of no-till has allowed producers to increase cropping intensity in the northern Great Plains (Aase and Pikul, 1995; Aase and Schaefer, 1996; Peterson et al., 2001) because no-till conserves surface residues and retains water in the soil profile more than the conventional tillage (Farhani et al., 1998). The reduced tillage and increased cropping intensity could conserve C and N in a dryland soil; and crop residues better than the traditional conventional tillage with wheat- fallow system in northern Great Plains (Sainju et al., 2007). The no tillage practice on Indiana crop land stores five times more carbon than conventional tillage. It is also of particular importance to reduce tillage on organic soils. Because of their high carbon content, these soils were found to emit more C when disturbed as compared to mineral soils (Table 4).

Management system	**Tons of Carbon stored /acre**
Cropland	0.107 tons C/acre
CRP/Grassland conversion	0.397 tons C/acre
Trees/Wetland conversion	0.209 tons C/acre
Cultivation of organic soils	-3.52 tons C/acre
By tillage systems	
Intensive Tillage	0.042 tons C/acre
Moderate Tillage	0.169 tons C/acre
No- Tillage	0.223 tons C/acre

Table 4. Carbon stored in Indiana Croplands in 1999 (Smith et al 2002).

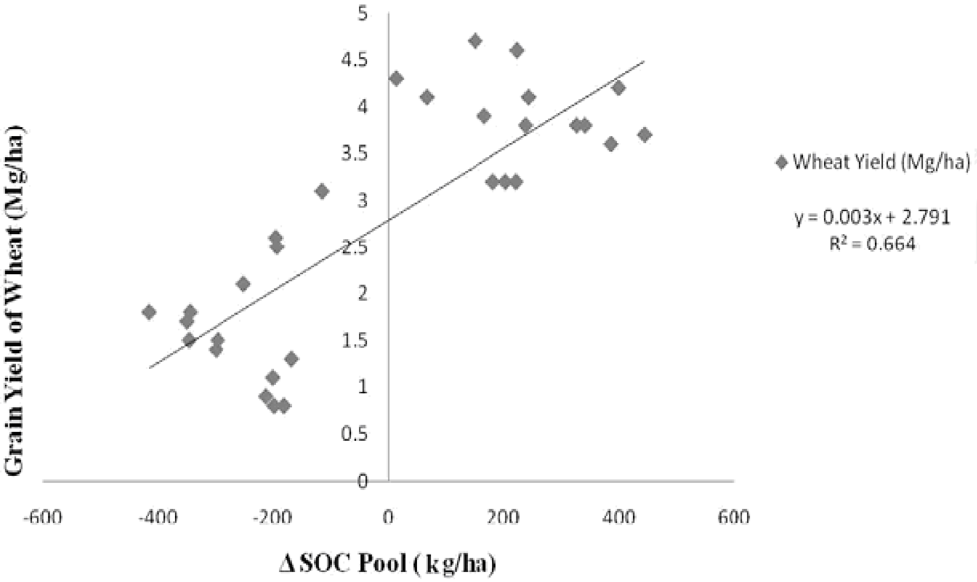

Figure 7. Effect of changes in soil organic carbon (ΔSOC) pool in the root zone on grain yield of wheat in Australia (redrawn and recalculated from Farquharson et al., 2003).

There exists a strong relationship between the agronomic production and the SOC pool, especially under low-input agriculture (none or low rate of fertilizer input). An optimal level of the SOC pool is an essential determinant of soil quality because of its positive impact on the soil structure and aggregation, water and nutrient retention, biotic activity including the microbial biomass, erosion control, nonpoint-source pollution abatement, C sequestration, increase in the use efficiency, and increase in biomass production. The increase in aggregation and available water capacity are among important benefits of SOC (Emerson, 1995; Huntington, 2003).

8. Conclusion

In future, soil conservation efforts would need greater focus in the Peninsular and central India because of their projected high runoff and soil losses associated with global climate change. A decreasing trend of runoff and soil loss is ordered when we move from tropics to temperate region. A significant tenet of organic agriculture is to build up soil fertility by increasing the levels of organic carbon compounds in a soil. This is primarily achieved by using photosynthesis to convert atmospheric carbon dioxide, and by using management techniques that convert these plant materials into soil organic matter. ‘Sufficient organic material should be regenerated and/or returned to the soil to improve, or at least maintain, humus levels. Conservation and recycling of nutrients is a major feature of any organic farming system’ (National Standard 2005). Data from the Rodale Institute’s long-term comparison of organic and conventional cropping systems (Rodale, 2003) confirms that the organic methods are effective at removing CO_2 from the atmosphere, and for fixing it as beneficial organic matter in the soil.The ambiguous nature of research findings document the need for additional studies of the effect of long-term tillage on soil physical properties under various tillage practices in order to optimize the productivity and maintain sustainability of soils. Moreover, there are a few studies that have examined the changes in soil physical properties in response to long term tillage and frequency management (> 20 yr) in the northern Great Plains. Global cereal production must be increased by ~50% by 2050. The crop yields in sub-Saharan Africa and South Asia have either stagnated or declined since the 1990s because of the widespread use of extractive farming practices and problems of soil and environmental degradation. Most degraded and depleted soils of agro-ecosystems contain a lower soil organic carbon (SOC) pool than in those under natural ecosystems. Thus, restoring the SOC pool is essential for improving soil quality, eco-efficiency and numerous ecosystem services. Increasing the SOC pool in the root zone can enhance agronomic production. Thus, the concept of eco-efficiency is important to produce more and more from less and less. Eco-efficiency is related to both “ecology” and “economy,” and denotes both efficient and sustainable use of resources in the farm production and land management (Wilkins, 2008). Eco-efficiency is increased by those farming systems that would increase agronomic production by using fewer resources through reduction in losses of input, apart from sustaining and enhancing the production potential of land. Yet it is not enough to develop agricultural practices that would merely minimize the adverse environmental impact. Because of the increasing population and rising standards of living, it is essential to develop those agricultural practices that would maximize agricultural production and also enhance ecosystem services (Firbank, 2009).

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