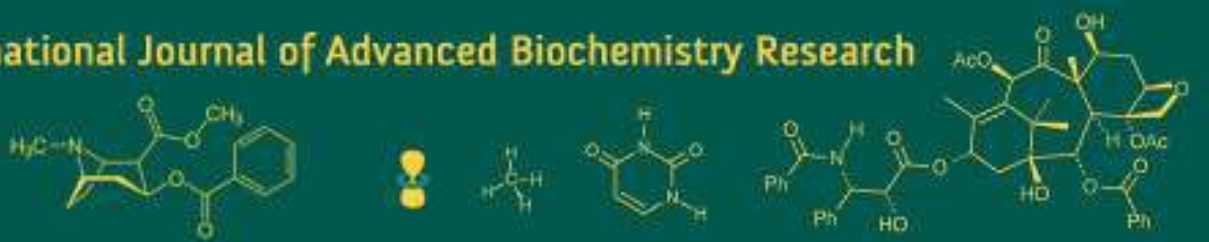


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A review on effect of conservation tillage practices on soil physical properties

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Abstract

A key element of sustainable agriculture is soil conservation tillage (CT) systems, which reduce tillage operations and leave at least 30% of the plants at the soil's surface. Soil aggregation, compaction, hydraulic conductivity, porosity, water storage, and soil organic carbon are all impacted by conservation tillage. In order to mix fertilizer, manure, and residues into the soil, reduce compaction, and manage weeds, tillage a mechanical modification of soil structure—requires a significant investment of high-energy inputs to prepare the seed bed. Because of erosion and the loss of organic carbon, excessive tillage techniques without residue retention may have a negative long-term impact on soil production. Any tillage method that leaves at least 30% of the crop residue on the soil's surface after planting is known as conservation tillage (CT).

This system frequently includes residue mulching, sub-soiling, shallow surface tillage, no tillage, and minimum tillage. It is acknowledged that conservation tillage is more effective than conventional tillage at enhancing crop productivity and soil quality. In addition to providing long-term benefits including enhanced soil structure, lower fuel consumption, biodiversity, ecosystem stability, and energy use efficiency, reducing the intensity of soil tillage also lowers the labor and energy needed for crop production.

Keywords: Conservation practices, tillage, sustainable agriculture, soil physical properties

Introduction

3.5% of the earth's carbon stores are found in soils worldwide, compared to 1.7% in the atmosphere and 1.0% in the biota (Lal *et al.*, 1995) [35]. With proper soil and crop management, soil can act as a sink for atmospheric CO₂ in the global carbon cycle (Lal *et al.*, 1995). By boosting plant nutrient availability, improving soil aeration, increasing soil and crop residue interaction, and exposing soil organic matter in inter and intra-aggregate zones to microorganisms for quick oxidation, tillage increases soil CO₂ emissions (Angers *et al.*, 1993; Jastrow *et al.*, 1996) [6, 28]. Soil C stores can be lowered by 20-50%, according to a long-term tillage research (Murty *et al.*, 2002) [45]. The effects of tillage on soil CO₂ emissions are complicated and frequently differ (Lauren and Duxbury, 1993) [37]. Jordhal and Karlen (1993) [30], Mielke Wilhelm (1998) [44] pointed out that the tillage treatments affected the soil physical properties when the same tillage system has been practiced for a longer time. In contrast to plow plowing (Tebrugge and During, 1999) [63] or decreased tillage (McVay *et al.*, 2006) [42], bulk density increased under no-till, which may have caused soil densification of the upper soil layers (Rasmussen, 1999) [50]. However, the impacts of tillage strategies on soil bulk density and total porosity were found to be inconsistent (Strudley *et al.*, 2008) [62]. Both conventional tillage and long-term zero-tillage can alter the organic matter content, aggregate stability, and pore volume, which in turn affects the soil's overall structure (Diaz-Zorita *et al.*, 2004) [14]. Kovac and Zak (1999) [33] discovered that various tillage treatments had an impact on the physical characteristics of the soil, but these changes were negligible. Also noted that when the same tillage system was used for a longer period of time, the physical characteristics of the soil were impacted by the tillage treatments.

Conservation tillage enhances the edaphic environment (Anikwe *et al.*, 2007) [7], controls soil temperature (Sarkar and Singh, 2007) [54], increases soil porosity and water infiltration rate during heavy rains (Glab and Kulig, 2008) [18], improves aggregate stability, which limits soil erosion (Franzluebbers, 2002) [16], and lowers runoff and soil erosion (Bhatt and Khera, 2006) [9].

However, the kind of soil, climate, and cropping system may affect these advantages. Here, the goal is to evaluate the understanding of conservation tillage's effects on the organic carbon and physical characteristics of soil. Because it minimizes soil disturbance and leaves at least 30% of crop residue on the soil surface, conservation tillage (CT) is a fundamental component of sustainable agriculture. Although adoption of this strategy is still very low in Asia (around 4%), it improves soil health, decreases erosion, lowers fuel and labor costs, and increases long-term output. Any tillage method that leaves at least 30% crop residue on the soil's surface following planting is referred to as conservation tillage. Mulch tillage, strip tillage, minimum tillage, and no-till are common CT techniques. CT systems, which reduce tillage operations and leave plants at the soil's surface in a ratio of at least 30%, are regarded as a key component of sustainable agriculture. Soil aggregation, compaction, hydraulic conductivity, porosity, water storage, and soil organic carbon are all impacted by conservation tillage. In order to prepare the seed bed, add fertilizer, manure, and residues to the soil, reduce compaction, and manage weeds, tillage—a mechanical manipulation of soil structure—requires a significant investment of high-energy inputs (Leij *et al.*, 2002) ^[38]. Because of erosion and the loss of organic carbon, excessive tillage techniques without residue retention may have a negative long-term impact on soil production (Ahmad *et al.*, 1996) ^[2]. Any tillage method that leaves at least 30% of the crop residue on the soil's surface after planting is known as conservation tillage (CT). This system frequently includes residue mulching, limited tillage, sub-soiling, shallow surface tillage, and no tillage (Jin *et al.*, 2007) ^[29]. It is acknowledged that conservation tillage improves soil quality and crop productivity more effectively than conventional tillage (Havlin *et al.*, 1990) ^[21]. In addition to providing long-term benefits from improved soil structure (Wang *et al.*, 2008) ^[67], lower fuel consumption, biodiversity, ecosystem stability, and energy use efficiency (Lal, 1995; Iqbal *et al.*, 2005) ^[27, 35], reducing the intensity of soil tillage also reduces the labor and energy needed for crop production (Osunbitan *et al.*, 2005) ^[47]. The use of conservation tillage is extremely low in Asia (4%) (Table 1).

Table 1: 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		

Organic Matter

Soil organic matter stabilizes soil aggregates and provides food for soil organisms like bacteria, fungus, and mites, soil organic matter is crucial. Numerous studies show that various tillage techniques reduce bulk density and soil strength (Carter, 2002) ^[12], stabilize soil structure (Thomas *et al.*, 1996) ^[65], and improve labile SOC, soil aggregation,

and SOC distributions in aggregate size fractions. However, the immediate and long-term effects of disturbance on C mineralization are complicated and might differ according to local climate, soil type, and residue management techniques (Puget and Lal, 2005). The addition of organic matter, which has a higher porosity and a lower bulk density than mineral soils (Martin, 2000), would increase the porosity of the soil and increase its resistance to degradation (Zhang, 1994) ^[70]. In many tiny tillage plots compared to conventional tillage, Hunt *et al.* (1996) ^[26] observed the higher SOC content in the top few centimeters following nine years of CT. According to Moraru and Rusu (2010), after ten years of using the same soil tillage technique, 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 diverse soil types when compared to the classical approach. Singh *et al.* (2014) found similar outcomes. According to Reicosky (1997) ^[51], conservation tillage techniques lost an average of roughly 4.3 times more CO₂ than moldboard plows, which lost 13.8 times more CO₂ than untilled soil. According to Reicosky *et al.* (2002) ^[52], whether the stover was plowed back into the soil or the above-ground corn biomass was harvested for silage, 30 years of fall moldboard plowing decreased the SOC. Additionally, Hooker *et al.* (2005) ^[25] discovered that residue management had minimal impact on SOC in the surface soil layer during a tillage treatment. According to studies, as long as the soil is moldboard plowed, no residue management technique will raise the SOC concentration. During an 11-year trial, Campbell *et al.* (1999) ^[11] found very slight increases (0-3 Mg ha⁻¹) in C storage under no-tillage in the 0-15 cm soil depth. Numerous investigations have demonstrated that the total amount of soil organic carbon (C) has not increased much. Inadequate tilling weakens the soil's structure, increases soil erosion, and reduces soil nutrients and carbon stocks (Lal, 2002). Based on a global data set, West and Post (2002) ^[68] found that no-tillage (NT) practices generally enhanced soil C sequestration, although the response was delayed, peaking after 510 years. The results were consistent with those published by Franzluebbers and Arshad (1996) ^[17]. Conservation tillage has been shown to improve soil quality and the soil organic carbon pool (Ogle *et al.*, 2003).

Bulk Density

According to numerous studies, using a zero tillage technique reduced porosity while increasing soil hydraulic conductivity, bulk density, and compaction (Strudley *et al.*, 2008) ^[62]. Comparing reduced tillage and direct drilling to conventional tillage, compaction in the upper soil layer was found to be higher in multiple studies (Thomas *et al.*, 2007) ^[64]. Al-Kaisi *et al.* (2005) ^[4] employed a variety of tillage techniques in the soil of the Corn Belt in the United States and discovered that, after seven years, the bulk density values of the chisel plow (CP) and no-tillage (NT) treatments did not differ appreciably. In a no-till system, Osunbitan *et al.* (2005) ^[47] found higher bulk density in the 5-10 cm soil depth. Other research, however, found that conventional tillage had higher to comparable BD than no tillage (Logsdon and Gambardella, 2000). He *et al.* (2009) ^[22] found that during the first five years of a long-term experiment, soil bulk density up to 30 cm depth was higher for NT than for traditional tillage (TT). However, the increase on conservation tillage plots plateaued after

roughly five years, while traditional tillage continued to increase. Bulk density on the TT plot was considerably higher than on the conservation tillage after ten years. Green *et al.* (2005) showed lower BD under NT compared to normal tillage in Maryland silt loam soil and sandy loam soil (Sharma *et al.*, 2011) [57]. According to Schjonning *et al.* (1994) [56], the NT system increased soil organic carbon and biotic activity while maintaining a noticeably higher amount of residue on the soil surface. Consequently, bulk density is reduced, especially close to the soil's surface. Additionally, Chen *et al.* (2009) [13] found that after 11 years at a soil depth of 0-15 cm, conventional tillage with residue removal had a greater bulk density than shallow tillage with residue cover and no-tillage with residue cover. In order to compare axle load on a clay loam soil, Abu-Hamdeh (2004) [11] investigated the effects of tillage treatments (moldboard ploughing MB, chisel ploughing CS, and disk plowing DP). 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. At all depths, the MB treatment resulted in the highest percentage increase in dry bulk density. In a 22-year study, Jabro *et al.* (2009) discovered that no-till (NT), spring till (ST), and fall and spring till (FST) tillage methods did not significantly affect BD on sandy loam soil. These results contrast with those published by Hill and Cruse (1985) [24] and McVay *et al.* (2006) [42], but they are consistent with those of Lampurlanes and Cantero-Martinez (2006) [36].

Soil Porosity

Tillage systems have an impact on porosity characteristics (Benjamin, 1993) [8] and are intimately linked to water movement, root growth, and soil aeration (Sasal *et al.*, 2006) [55]. Straw returning has been shown in long-term experiments to increase the soil's overall porosity (He *et al.*, 2009) [22]. On the other hand, minimal or no tillage would reduce the soil's porosity for aeration while increasing its capillary porosity; consequently, it would improve the soil's ability to hold water and improve its poor aeration (Glab and Kulig, 2008) [18]. According to Table 6, Glab and Kulig (2008) discovered that the macroporosity of soil with conventional tillage (14.79%) was considerably higher than that of soil with decreased tillage (6.55%). At the 010 cm layer, reduced tillage without mulch enhanced the macroporosity in the pore diameter range of 50 transmission pores content (0.078 cm³ cm⁻³). In a similar long-term study, He *et al.* (2009) [22] found that conservation tillage treatments improved the distribution of pore sizes in a spring wheatoat cropping system. Sur *et al.* discovered that more compacted soil, especially in no-tillage systems, had higher overall porosity. In contrast to ploughing in a semiarid location, Zhang *et al.* (2006) [71] reported a mere 1.6% increase in mesoporosity in the 0-10 cm soil layer in a short-term experiment, but Borresen (1999) [10] found no effect on total porosity and porosity size distribution. In comparison to conventional tillage, conservation tillage resulted in a decrease in the volume fraction of large pores and an increase in the volume fraction of small pores (Bhattacharya *et al.*). Zhang *et al.* (2003) [53] examined the mean aeration porosity between conventionally tilled soil and conservation tillage treatments at two locations in the top 0-0.30 m. The findings showed that conservation tillage (ST, sub-soiling with retention of all surface plant residues; NT, zero tillage and planting through the previous plant residues) improved soil porosity. This improvement was

most likely due to the positive effects of soil organic matter brought about by minimal tillage and residue cover.

Soil Water Storage

The most significant aspect affecting soil compaction processes is soil water content (Akram and Kemper, 1979) [3]. The rate of soil water infiltration can also be used to track the level of soil compaction, particularly in the topsoil. As evidenced by rising soil bulk density and strength and falling soil water penetration rate, increases in soil water and external load together increased soil compaction (Hamza and Anderson, 2011) [19]. Water flow through the soil typically slows significantly as bulk density increases. According to numerous studies, applying surface mulch can increase the amount of precipitation water stored in soil by decreasing evaporation, boosting infiltration, and minimizing runoff (Sharma *et al.*, 2011) [57]. Alvarez *et al.* 2009 discovered that reduced tillage systems had higher rates of water infiltration than plow tillage. Because of residue retention, no-till management has higher soil water contents (Nielsen *et al.*, 2005) [46] and higher water use efficiencies (Hatfield *et al.*, 2001) [20] than tillage management. Meek *et al.* (1989) [43] found that modest packing of the soil prior to the first flood irrigation increased the infiltration rate in the field by 17% when compared to no packing. According to Barzegar *et al.* (2002), when the application rate of wheat straw rose from 0 to 15 Mg ha⁻¹, the infiltration rate and water retention increased linearly. During the dry years of 1999, 2003 and 2006, He *et al.* (2009) [22] found that NT plots had higher WUE than traditional plots. This was linked to improvements in aggregations and macrospore connectivity, which had an impact on near-zero infiltration rates and hydraulic conductivity (Strudley *et al.*, 2008) [62]. According to Rasmussen, 1999, in some cases, increases of soil water content had been observed under no-till (Nielsen *et al.*, 2005) [46] or lower infiltration rates.

Soil Structure

Aggregate stability is the best measure of soil quality from an agricultural perspective (Karlen and Stott, 1994) [32]. According to research, tillage intensity affects soil aggregation (Feiza *et al.*, 2008) [15]. Water-stable aggregates and organic matter are more prevalent when tillage is reduced (Belesdent *et al.*, 2000). No-till (NT) soils have more macroaggregates than plow-till (PT) soils due to a decrease in the breakdown of surface soil aggregates caused by residue cover of the soil surface and the lack of tillage (Oyedele *et al.*, 1999) [48] (Mikha and Rice, 2004). According to Kahlon *et al.* (2013) [31], under no till (NT), reduced till (RT), and plow till (PT), mean weight diameter (MWD, mm) grew from 0.36 to 1.21, 0.29 to 0.84, and 0.25 to 0.62 respectively, with increase in mulch rate from 0 to 16 Mg ha⁻¹. According to Zotarelli *et al.* (1999) [72], the MWD of the aggregates was on average 0.5 mm higher under NT than under PT. Additionally, the rate of macroaggregate turnover (formation and degradation) is decreased under NT compared with PT (Six *et al.*, 1998, 2000a) [59, 60], and aggregate stability is decreased with PT. Throughout the soil profile, conservation tillage plots had a higher percentage of macro-aggregates (1337%) than traditional tillage plots, whereas traditional tilled soils had a higher percentage of micro-aggregates (2559%) (He *et al.*, 2009) [22]. Reduced tillage or the addition of straw

considerably decreased the quantity of the smallest particles (less than 0.25 mm). According to studies, macroaggregates (>0.25) have a higher C enrichment than microaggregates (<0.25 mm) (Six *et al.*, 2000b) ^[61].

Saturated Hydraulic Conductivity

The capacity of the saturated hydraulic conductivity, or Ks, to both drain extra water from the root zone and transfer the water required for plants to the root zone (Topp *et al.*, 1997) ^[66]. According to Reynolds *et al.* (2003) ^[53], a Ks value between 5×10^{-3} and 5×10^{-4} cms⁻¹ indicates rapid uptake and redistribution of crop-available water, decreased surface runoff and soil erosion, and rapid drainage of excess soil water. Compared to tilled fallow, Ks values were considerably higher in fallow soil that had been chisel-tilled and disc-ploughed (Kribba *et al.*). In 2006, Lampurlanes and Cantero-Martinez compared three tillage systems (subsoil tillage, minimum tillage, and no-tillage) on two soils under three field conditions (continuous crop, fallow, and crop after fallow). They discovered that during one of two years of continuous crop, soil under no-tillage had lower hydraulic conductivity than soil under subsoil tillage or minimum tillage because of a decrease in soil porosity. However, after 28 years of tillage on a silt loam soil in Ohio, Mahboubi *et al.* (1993) ^[40] discovered that no-tillage produced higher saturated hydraulic conductivity than conventional tillage. In a long-term experiment, Kahlon *et al.* (2013) ^[31] discovered that when the mulch rate increased from 0 to 16 Mg ha⁻¹, greater Ks were detected in NT treatments compared to PT treatments. Long-term conservation tillage has been shown to improve soil physical qualities (Lal *et al.*, 1994; Mahboubi *et al.*, 1993) ^[34, 40]. In tilled soils, Ks were observed to drop during the growing season (Logsdon *et al.*, 1993) ^[39] as a result of root growth that gradually plugs pores and soil structural disintegration and surface sealing (Ankeny *et al.*).

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