Effect of conservation tillage on soil fertility factors: A review

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Abstract

Increasing global demand for food led to intensification of agricultural practices, these practices such as tillage management that reduce soil degradation are needed to improve soil quality and maintain agricultural productivity. We reviewed the effects of conventional and zero-tillage on soil fertility factors in the way of agricultural sustainability. This review demonstrates that long-term tillage decrease soil organic matters which, plow system, disturb nutrient cycling, fertility and degrades soil quality. It has been reported that the use of chemical fertilizers alone to sustain high crop yield has not been successful due to enhancement of soil acidity, nutrient leaching and degradation of soil physical and organic matter status. Results have been showed that higher levels of soil organic C, microbial biomass C and N, potential N mineralization, total N, and extractable P were directly related to surface accumulation of crop residues promoted by conservation tillage management. No-tillage management increases soil organic matter and improves soil fertility and has potential for increasing the nutrient supply to crops through changes in the mineralization and immobilization of nutrients by microbial biomass.

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Introduction

History and importance of conservation tillage system

Even though plough system was invented in about 7000 years ago, plows that actually inverted the soil were not developed until the 17th century (Derpsch, 1998). At the end of 19th century use of conservation tillage were increased (Uria et al., 1998). Thereby, much soil and nutrient losing has been observed in over machinery system for example In Germany, annual P losses from agriculture ranging from less than 50 to more than 200 kg ha⁻¹ have been found (Buczko and Kuchenbuch, 2007). Loss 10% of initial soil organic matter (SOM) content with plow tillage had been reported by Rhoton (2000).

Using of plow and maintaining of 30% crop residue on the soil surface after harvest is called conventional tillage practices (CT) (Uria et al., 1998). Conservation tillage slows organic matter decomposition which results in a slower mineralization, or in an immobilization of the mineral N (Van Den Bossche et al., 2009). Long –term traditional tillage (TT) practices due to the soil erosion and loss of soil structure may significantly increase losing of soil organic matter (A’lvarez and A’lvarez, 2000; Nachtergaele et al., 2002).

By increasing of human population and extra using of lands and recognition of importance of sustainability in agricultural practices, hypothesis goes to minimal impact process such as no-till system which is improve soil quality and crop yield. Zero-tillage had significantly higher concentrations of soil pH, organic C, N, P, K, Ca and Mg for surface soil (0-15 cm depth) (Agbede, 2010). Some benefits of conservation tillage system such as no-tillage and mulch-till (Reddy et al., 2004) are a) increasing microbial biomass (MB) (Helgason et al., 2010), b) improving soil carbon (Lal et al., 2003), c) increasing mineralizable N (Spargo et al., 2011), d) increasing soil moisture (Ma et al., 2008), e) increasing (Six et al., 2004). Thus, efforts of conversion from plow-till to no-till practice could serve as the most effective factor in crop management for SOC sequestration and increased productivity (Jarecki and Lal, 2003).

By comparing of three no-till, ridge-till and plow-till in soil disturbance and residue cover; In no-till, the process may be nearer the interface of the soil surface and residue cover. In the plow-till treatment, residues are distributed through the soil profile, and are decomposed in a more homogeneous environment, with high soil–residue contact. Several beneficial agricultural effects of crop residue are reactivation of soil macro-and micro-founa in order to restoration of soil fertility instead of using chemical fertilizers (Michellon and Perret, 1994; Boyer et al., 1996). Ridge-till might be considered intermediate between the plow-till and no-till treatments in its modification of the decomposition environment for crop residues, with less homogenous residue distribution (Zibilske et al., 2002).

Indicators for conventional tillage cannot be the same as used in conservation tillage so, suitable indicators for this is required. One of these indicators which could develop other system characterizing indicators is soil properties monitoring which let to farmers to adapt their practices to the new states of the new system (Murillo et al., 2006). The main motivation for farmers to change their tillage system is the reduction of production coast (Cociu, 2010; Van den Putte et al., 2010). Precisely, the particulate organic matter (POM), particulate mineralizable N(PMN) and soil microbial biomass (SMB) and their stocks over the soil profile are known to be other suitable indicators in this sense(Gosai et al., 2009).

Intensive and conventional tillage led to a loss of soil fertility and reduction of soil water holding capacity and soil structural stability, by facilitating erosion by water and wind, and is reflected in a constant increase in the rates of fertilizers used by farmers to maintain crop productivity (Du Preez et al., 2001; Roldán et al., 2003; D’Haene et al., 2008). Conventional tillage leads to disruption of soil aggregates contributing to erosion and CO₂ increase in the atmosphere, contributing to global warming (Roldán et al., 2003).
More sustainable farming practices, using conservation tillage to improve residue cover with minimum or no-till, have been demonstrated in many environments (He et al., 2011). No-till has been adopted by many Latin American countries, based on results of field experiments carried out in developed countries (Tiscareño et al., 1999). Continuous long term (11 years) no tillage and residue cover practice in semi-arid North China Plain led to significant positive effects on soil properties (He et al., 2011).

Significant and positive effect of conservation tillage had been reported by researchers, no inter-row cultivation significantly increased cotton seed yield compared with conventional tillage (Blaise et al., 2003). Zero tillage with mulch and zero tillage without mulch increased grain yield of sorghum (Agbede and Ojeniyi, 2009). Winter wheat and summer maize yields tended to be 3.5% and 1.4% higher under NT than under CT (He et al., 2011). SOC and N had increased under NT and ZT compared with MT and CT (Lo´pez-Fando and Pardo, 2009). He et al. (2011) conducted a 2-year no-tillage experiment and established that no-tillage increased crop yields by 6.7–8.9% and water use efficiency by over 6.0% compared to conventional ploughing. Total N in NT was 51% and 60% higher than in MT and CT, respectively (Lo´pez-Fando, et al., 2012). Conservation tillage in contrast with fertilizers application rate reduced total phosphorous loading and suspended sediments (24 and 19% respectively) and planted with leguminous species improved some soil characters (Rolda’n et al., 2003). Conventional tillage as mouldboard plowing and disc plowing hasten N and C mineralization as tillage accelerates oxidation of organic matter by soil microorganisms (Lo´pez-Fando, et al., 2012). Therefore, agricultural practices are needed to improve soil quality and agricultural sustainability instead of soil degradation. In the way toward sustainability, conservation tillage with minimal soil disturbance beside crop rotation protects the soil against degradation (Balota et al., 2004).

Tillage and soil nutrient concentration

Nutrient addition had both positive and negative effect on soil microbial community, structure and function, C and N cycling and enzyme activities (Saiya-Cork et al., 2002; Sinsabaugh, 2003; Khan et al., 2007). Nutrient availability and concentrations could be affected by tillage practices (LavadoU et al., 1999). In some cases for example in the case of soybean higher concentration of Cu were observed in CT while high concentration of Zn was in ZT (LavadoU et al., 2001). Tillage influenced the depth distribution of macro and micronutrients but effects were primarily observed in surface soils (Wright et al., 2007). Bertol et al. (2007) and Lo´pez-Fando and Pardo (2009) reported that No-till treatments have higher P, K and organic carbon concentrations in the superficial 0–0.025 m soil layer. Conventional tillage releases more Na+ and K+ to the soil solution than the conservative techniques (Lozano-García et al., 2011). To show the importance of conservation tillage we discuss some issues such as NPK nutrient elements, microbial activities, soil organic carbon and soil PH which are the most effective factors in soil fertility.

Effects of tillage systems on N transformations have mainly been studied through measurements of net mineralization rates, as they are useful index of N availability for plant uptake (Go´mez-Rey et al., 2012). No-tillage had effective impact on mineralization rate while in comparing with minimum tillage (8.8 kg ha−1 per day), disk plowing (7.3 kg ha−1 per day) and no tillage showed the highest average N mineralization rate (11.5 kg ha−1 per day) (Salinas et al., 2002). Most of the N in crop residues is in organic form and is not directly available for plant growth. During decomposition of crop residues, this organically bound N is made available for crop or microbial growth through N mineralization (Lupwayi et al., 2006). A key role in mineralization, immobilization and denitrification processes is soil organic carbon level (Magill and Aber, 2000). Residue N concentration is generally positively correlated with net N mineralization, whereas the C:N ratio is negatively correlated with net N mineralization (Lupwayi et al., 2006). Differences in organic matter decomposition and N mineralization
are related to crop residue distribution within the plow layer (Salinas et al., 2002). The stocks of N had increased under NT compared with MT and CT. All stratification ratios were significantly higher in NT than in the other two tillage systems. Soil under NT had the highest average total nitrogen content (0.80 Mg ha$^{-1}$), MT had intermediate content (0.47 Mg ha$^{-1}$), and CT had the lowest content (0.41 Mg ha$^{-1}$) across locations (Salinas et al., 2002). Both no-till and ridge-till promoted significantly (p < 0.05) greater concentrations of soil organic N at the soil surface (Zibilske et al., 2002). Conservation tillage improves N availability to plants in the long-term (Rice et al., 1986) by increasing soil N retention and labile N pool (McCarty et al., 1995) in the upper soil layers.

Systems without tillage can result in P stratification with high concentrations near the surface, and thus increase the potential for P losses during runoff events (Simard et al., 2000; Sharpley, 2003). A few studies indicated that P content in the soil surface is more than depth, however, there are varieties of results that determine the exact P content depth for example in the surface soil layer (0–50 mm), extractable P content was approximately 50% greater with NT and MT than with plowing when averaged across sites while disk plow resulted in greater extractable soil P in the 50–100 and 100–150 mm soil depths, at Casas Blancas (Salinas et al., 2002). Rhoton (2000) also found a higher amount of P in the 2.5 cm depth under no-tillage. Concentrations of P, Mg, and Ca at the soil surface tended to be higher in NT than in DT, especially in the mid-rows of the 76 cm wide-row systems. Conservation tillage, especially no-tillage, results in vertical stratification of plant nutrients in the soil profile (Philip et al., 2002). Soil samples showed significant P and K stratification under conservation tillage. Calcium-acetate lactate (CAL) soluble P and K concentration in 0–15 cm soil depth increased by 24% and 118%, respectively (Deubel et al., 2011). Reduced tillage increased plant-available P, NO3 and Zn in surface soil, which may have contributed to higher lint yields than CT continuous cotton (Wright et al., 2007). In the 0–20 cm layer, higher concentrations of P and K under NT and ZT than under MT or CT were also found (Lo`pez-Fando and Pardo, 2009). The apparent “mining” of P from lower soil depths and retention in upper depths in conservation-tillage systems is probably due to immobilization of P, which promotes the organic P cycle, and to the chelation effect of organic compounds on soluble P. Results indicate an increased capacity of soils managed with conservation tillage to supply P from organic sources (Zibilske et al., 2002). One review indicated that conservation tillage practices can result in reducing P losses by 6.1 kg ha$^{-1}$ year$^{-1}$, and was the most cost effective practice to reduce P losses (Sharpley et al., 2001). Conservation tillage generally results in greater amounts of P and K in the upper soil layer (Martin-Rueda et al., 2007). The CT significantly increased P as did the addition of manure. However, with manure, K was significantly increased in all tillage treatments (Anwar et al., 2007).

**Tillage and soil microbial activities**

Increasing global demand for food is leading to the intensification of agricultural practices and increasing demands on natural soil resources. As the primary organisms responsible for biogeochemical cycling, soil microbial communities catalyse a range of processes, such as nutrient cycling, which are important to the productivity and sustainability of soil ecosystems (Bissett et al., 2013). Soil microbial biomass is the living part of soil organic matter. It generally comprises <10% of organic matter in soil, however, it performs important functions for plant production in an ecosystem (Salinas et al., 2002). Many factors such as temperature, pH, moisture content, clay content, organic matter inputs and heavy metal concentration are known to affect microbial biomass in soil (Singh et al., 2007; Khan et al., 2007). Soil microbial biomass through the process of immobilization and mineralization controls the flow of C, N and P in terrestrial ecosystems (O’Donnel et al., 2001). Soil quality is largely governed by SOM, which is dynamic and responds effectively to changes in management. The level of SOM is determined by biological, chemical and physical properties of soil.
that control microbial activity (Cole et al., 1987). In this way, soil enzyme activities and microbial biomass have been shown to be sensitive indicators of differences between sustainable cropping systems (Kennedy and Papendick, 1995). Microbial biomass often responds quickly to changes in soil management and is known to be an indicator of soil quality (Roldán et al., 2003). Conservation tillage, especially no-tillage can improve the substrate availability and the microbial nutrient (Roldán et al., 2003). Drijber et al. (2000) similarly reported that cropped sites always showed higher MB than fallowed sites in the wheat system they investigated. In general, the long-term effects of soil management practices on the size and activity of the microbial biomass have been found to be closely related to changes in total soil organic matter content (Haynes and Beare, 1996). The level of SOM is determined by biological, chemical and physical properties of soil that control microbial activity (Cole et al., 1987). In this way, soil enzyme activities and microbial biomass have been shown to be sensitive indicators of differences between sustainable cropping systems (Kennedy and Papendick, 1995). Microbial biomass often responds quickly to changes in soil management and is known to be an indicator of soil quality (Roldán et al., 2003). Total organic C and available P showed significant correlation with microbial biomass C and microbial biomass P respectively while total N showed significant correlation with microbial N (Roldán et al., 2003). Microbial biomass has been shown to be a sensitive indicator of differences in sustainable cropping systems (Anderson and Domsch, 1989). Soil microbial properties, such as microbial biomass and soil enzymes, have been used to predict soil biological status and the effect of farm managements as it relates to soil quality (Eivazi et al., 2003). Microbial biomass is a sensitive indicator of N fertilizer management affects on soil quality (McCarty, 1995). Reported that microbial biomass and potentially mineralizable nitrogen in the 0–7.5 cm surface layer of no till soils were 34% higher than those of ploughed soils, although the opposite was true at 7.5- to 15-cm depth (Doran, 1987). Gupta et al. (1994) found higher values of microbial biomass in the first 5 cm of the soil profile under NT than under TT after one year of conservation management. Wright et al. (2005) found MBC to be greatest under no-till management but only in the surface 2.5 cm with little tillage effect to 20 cm (Wright et al., 2005). Conversion of CT to conservation reserve program (CRP), no tillage for 4 (NT4) and 28 (NT28) years increased MBC in the 0–5 cm depth by 40, 6 and 78%, respectively (Melero et al., 2009). The CT soil has reduced C concentrations from oxidation of labile SOM due to tillage (Purakayastha et al., 2008). The contents of active carbon (AC) and microbial biomass carbon (MBC) in the long-term trial and contents of active carbon (AC) in the short-term trial were higher for conservation tillage (CT) than traditional tillage (TT) at 0–5 cm depth for both sampling periods (Melero et al., 2009). In a Brazilian oxisol there was a consistent increase in biological activity and N mineralization with no-till management (Green et al., 2007). Similar increases with depth have been observed in arid wheat based systems where total soil N (TSN) increased by38–68% (Dou and Hons, 2006). Interestingly, the CT soil mineralized as much N as the NT systems but had less TSN than NT (Purakayastha et al., 2008). Wright et al. (2005) found an increase of MBC and mineralizable N in the surface soil with corn and cotton cropping sequences for twenty years under no-till and minimum tillage systems but little change in MBC concentration in the 2.5 to20 cm depths. Previous reports in NT systems have observed the stratification of residue near the soil surface and the increased surface distribution of organic matter and MBC (Madejon et al., 2007). The distribution of MBC may be related to the placement of crop residues. A’lvarez et al. (1995) observed marked stratification in total soil microbial biomass and activity as a consequence of the application of NT to previously tilled soils in long-term experiments.

**Tillage and soil organic carbon (SOC)**

It has been well established that agricultural soils can be a sink for carbon (C) through the formation of soil organic matter (West and Post, 2002). Carbon (C) is an indispensable necessity for soil fertility; it is strongly correlated with nitrogen (N) and fuels the
microbial engine that drives the nitrogen cycle (Korschens, 1998). Soil organic matter (SOM) is an important indicator for soil fertility. It is strongly affected by tillage as well as temperature, moisture, soil texture, plant residue quantity and quality (Berner et al., 2008). While conventional tillage in the long run does alter soil structure and increase the loss of soil carbon, the magnitude of these effects is a function of the intensity of tillage, the frequency of tillage and the quantity and quality of fertilizer and organic residue returned to the soil. Conservation tillage has the potential for converting many soils from sources of atmospheric carbon to carbon sinks (Rasmussen and Collins, 1991). Conservation tillage may increase the amount of organic carbon in the soil by providing an environment where fungal decomposition is greater than bacterial decomposition. Fungal decomposition results in more recalcitrant decomposition products than bacterial decomposition (Holland and Coleman, 1987). An increase in conservation tillage has two identifiable effects with regard to carbon emissions. First, no tillage results in an increase in carbon retention in the soil because less organic matter is lost to oxidation from mixing of the soil and soil temperatures tend to be lower, which slows oxidation from mixing of the soil. The lower soil temperature slows decomposition. Second, conservation tillage is more energy efficient than conventional tillage, as fewer machinery operations are required less fossil fuel (gasoline and diesel fuel) is used thus carbon emissions are reduced. The amount and kind of crop residues have an effect on organic carbon levels in the soil (Uria et al., 1998). Soil organic matter plays a crucial part in all aspects of soil quality (soil structure, soil water relations, chemical fertility and biodiversity) and therefore is a key indicator for the integrated evaluation of soil quality (Carter, 2002). Crop residue type plays an important role in C sequestration and organic matter cycling due to differences in C/N ratio or quality of residue (Potter et al., 1998). In addition to the total SOC pool, there also occur qualitative changes in SOC fractions under the NT systems. In general, the SOC recalcitrance decreases under NT systems, indicating that crop residues added are only partially decomposed, exceed microbial metabolic rate, and form less humified SOC fractions (Bayer et al., 2000; Tivet et al., 2013). Several studies (i.e., Ball et al., 1996; Beare et al., 1997), showed an enrichment of microbially derived carbohydrates under NT versus CT. Management practices such as no-tillage (NT) have been frequently recognized for their effect on SOC storage (A´ lvaro-Fuentes et al., 2012). Numerous studies have been conducted to assess the changes in SOC pool following the conversion of NV into agricultural lands managed under CT, and upon conversion of CT to NT systems. Conversion to NT systems increases the SOC pool at least in the soil surface layer (Batlle-Bayer et al., 2010). In addition, incorporation of forage species into crop rotations seems to increase hot-water extractable organic C (HWOEC) in the 0–5 cm depth, probably due to higher root inputs and the stimulation of microbial activity that follows (Lienhard et al., 2013). The short-term (10 years) effects of management on soil organic carbon (SOC) are complex and vary with soil conditions such as soil texture, climate, cropping system and kind of crop residue, as well as with the management itself (Al-Kaisi et al., 2005; Mun¨oz et al., 2007). Compared with CT, ST and NT had significantly higher SOC concentration (Awale et al., 2013). Generally, the soil organic matters (SOM) in all treatments were generally higher under conservation than under conventional tillage (Vogeler et al., 2009). NT practices generally increase the sequestration of soil carbon (C), but this increase might not be apparent for approximately five to ten years (West and Post, 2002; Franzluebbers and Arshad, 1996). However, Franzluebbers and Arshad (1996) noted that there was little or no detectable increase in SOC content in the first two to five years after implementing conservation tillage. Weil et al. (2003) found active carbon (AC) to be a more sensitive indicator of soil management than TOC. The increase in TOC under CT in the long-term has been observed by other researches (Melero et al., 2008). To short-term studies, several authors have found an increase of TOC in the top layer when using NT in the first three years of transition from TT to NT (McCarty et al.,
In reduced tillage or no tillage systems, carbon sequestration takes 25–30 years to reach a new steady state (Alvarez, 2005). These soils contained up to 12 t ha⁻¹ more C_{org} under conservation tillage than under conventional tillage (Alvarez, 2005). Twenty years after conversion from conventional tillage to no tillage, soils contained 16% more C_{org} under a temperate wet climate and 10% more under a temperate dry climate (Berner et al., 2008). According to Mikha and Rice (2004), NT greatly enhances C accumulation within soil aggregates and increased tillage intensity in many conventional tillage systems; such as plowing, chisel plowing. Tillage can greatly modify edaphic factors and thereby influences the rate of C mineralization (Huggins et al., 2007; Curtin et al., 2012). Therefore, measurement of a suite of SOC fractions and elucidation of the interactive relationships among different SOC fractions would perhaps more reflect tillage and N management induced changes in soil quality (Strosser, 2010). SOC content was greater under NT than under CT and RT (A’Ivaro-Fuentes et al., 2009). The CT significantly increased P as did the addition of manure. However, with manure, K was significantly increased in all tillage treatments (Anwar et al., 2007).

**Conclusion**

By increasing of global concerns about the impact of agricultural practices on environment, the use of conservation tillage has been increased, thereby many of conservation methods have been designed to attain environmental objective instead of productivity criteria. This review indicated that each production practices neither conventional tillage or conservation tillage may had positive and negative effect on environment that may involve land, water, air and health status of wildlife. The conclusion suggest that the use of conservation tillage reduced soil erosion, energy use, leaching, run off of agricultural chemicals and stand stock of macro-aggregate protected soil organic carbon compared with conventional tillage. Higher levels of soil organic C, microbial biomass C and N, potential N mineralization, total N, and extractable P were directly related to surface accumulation of crop residues promoted by conservation tillage management. No-tillage management increases soil organic matter and improves soil fertility and has potential for increasing the nutrient supply to crops through changes in the mineralization and immobilization of nutrients by microbial biomass.

**References**


Agbede TM. 2010. Tillage and fertilizer effects on some soil properties, leaf nutrient concentrations, growth and sweet potato yield on an Alfisol in southwestern Nigeria. Soil & Tillage Research 110, 25–32.


Al-Kaisi MM, Yin XII, Licht MA. 2005. Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. Agriculture, Ecosystem, Environment 105, 635–647.


Cociu AI. 2010. Tillage system effects on input efficiency of winter wheat, maize and soybean in rotation. Romanian Agricultural Research. 27, 81–87.


Rice CW, Smith MS, Blevins RL. 1986. Soil nitrogen availability after long-term continuous no-


