Investigation the effect of conservation tillage on soil organic matter (SOM) and soil organic carbon (SOC) (The Review)

Sherwin Amini [1], Mohammad Amin Asoodar [2]

[1] M-Sc. Mechanization Engineering, Student of Khuzestan Ramin Agriculture and Natural Resources University, Khuzestan Iran
[2] Professor, Department of Agricultural Machinery and Mechanization Engineering, Khuzestan, Ramin Agriculture and Natural Resources University, Khouzestan, Iran
sherwinamini@yahoo.com

Abstract: Pores and organic matter take a multitude of forms in soil and their characteristics change in space and time following a change in tillage practices as a new "steady state" is approached. Information on the variation with depth (stratification) in the characteristics of pores and organic matter and the rates of changes in these characteristics are vital to interpreting the short- and long-term impacts of the reduction of using conventional tillage on the productivity and hydrology of agricultural soils. This information is also of value in estimating the effect of a reduction in tillage on the sequestration of carbon in agricultural soils. The influence of tillage on bulk density, macro porosity and organic matter content was found to be documented more extensively than the effects on pore size distribution, soil organic matter fractions and their interactions at different soil depths. Many of the reports documenting tillage-induced changes in soil porosity and organic matter were based on measurements at a specific time after initiating the tillage trial. The potential advantages of conservation tillage in organic farming are reduced erosion, greater macro porosity in the soil surface due to larger number of earthworms, more microbial activity and carbon storage, less run-off and leaching of nutrients, reduced fuel use and faster tillage. Conversion from conventional (CT) to no-tillage (NT) resulted in an immediate change in the placement of aboveground crop residue and the reduced fragmentation of the soil matrix may also slow the mineralization of SOC.
[Sherwin Amini, Mohammad Amin Asoodar. **Investigation the effect of conservation tillage on soil organic matter (SOM) and soil organic carbon (SOC).** *N Y Sci J* 2015;8(3):16-24]. (ISSN: 1554-0200). http://www.sciencepub.net/newyork. 3

Keywords: Conservation tillage, Soil organic matter, SOC

1. Introduction

Soil porosity and organic matter content play a critical role in the biological productivity and hydrology of agricultural soils. Pores are of different size, shape and continuity and these characteristics influence the infiltration, storage and drainage of water, the movement and distribution of gases, and the ease of penetration of soil by growing roots. Organic matter is composed of living biomass and materials that differ in stage of decomposition and degree of association with mineral material. These different forms of organic matter collectively represent a reservoir of nutrients that are critical to plant growth. Recently, a number of studies have shown that the amount of soil organic matter (SOM) increased at 0–20 cm soil depth with the application of conservation tillage. Frequent tillage destroys SOM fractions, and urges the transfer of SOM to deep soil layers. The elimination of tillage favored the accumulation of SOM. Conservation tillage covers a range of practices which conserve soil moisture and reduce soil erosion by maintaining a minimum of 30% of the soil surface covered by residue after drilling. Generally, conservation tillage includes a shallow working depth without soil inversion, i.e. no tillage or reduced or shallow tillage equipped with tines or discs. Shallow plowing, to no more than 10 cm, should be included in conservation tillage because burial of crop residues is usually incompleted. Conventional systems of tillage leave less than 30% of land by crop residues – and often none – on the soil surface after crop establishment. Conventional tillage is invariably deeper (20–35 cm) with inversion of the soil by moldboard plow, disc plow or spading machine.

Conservation tillage leaves an 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 (Franzluebbers, 2002a). Other beneficial aspects of conservation tillage are preservation of soil moisture and increase of soil biodiversity (Holland, 2004). Conservation tillage omitting annual deep plowing is accepted to reduce water erosion, to improve soil quality (Franzluebbers, 2002), to sequester carbon in soils and, thus, to alleviate global climate change (Lal et al., 1999). In the past decade, application of conservation tillage practices has considerably increased in several regions of Germany. About 25% of the national sugar beet crop was grown with conservation tillage in 2002. Although the environmental benefits are obvious, for the farmers cost reductions is the primary driving force to apply conservation tillage practices, predominantly consisting of non-inverting shallow-mixing tillage operations. The potential for reduction of machinery costs is especially high if these techniques are implemented for all crops grown on a farm during at least several consecutive years. Long-term conservation tillage may, however, decrease yields due to soil compaction in the lower layers of the previously plowed horizon (Ahl et al., 1998) or due to increased weed and slug infestation (El Titi, 2003a, 2003b), mostly caused by management decisions inappropriate for the local conditions.

Soil organic matter (SOM) is an important indicator of soil fertility and productivity because of its crucial role in soil chemical, physical and biological properties (Gregorich et al., 1994). Therefore, maintenance of satisfactory level of SOM is necessary for sustainable agroecosystems. There are two ways to increase soil organic C (SOC): (1) increase of C input, or (2) decrease of SOC loss and decomposition. Carbon input can be increased and decomposition decreased by adopting residue management and using conservation tillage (no-tillage or reduced tillage). However, short- and medium-term SOC changes are difficult to detect because of high background C content and its temporal and spatial variability (Bosatta and Agren, 1994). A suite of labile C fractions is typically required to assess SOM quality because of the multifunctional role of SOM (Haynes, 2005; Soon et al., 2007).

Reducing the intensity of soil tillage decreases energy consumption and the emission of carbon dioxide, while increasing carbon sequestration (Holland, 2004). Reducing the intensity of tillage increases the sustainability of tillage systems by speeding up crop establishment and reducing labour demand (Davies & Finney, 2002). Organic production of field crops generally consumes up to 20% less energy than non-organic agriculture (Williams et al., 2006). However, environmental burdens, such as global warming potential or eutrophication, can be greater under organic farming (Williams et al., 2006). Thus conservation tillage may improve the environmental and economic performance of organic farming.

The International Federation of Organic Agriculture Movements standards (IFOAM, 2002) recommend that organic farmers should minimize loss of topsoil through minimal tillage, contour plowing, crop selection, maintenance of soil plant cover and other management practices that conserve soil' and 'should take measures to prevent erosion, compaction, salinization, and other forms of soil degradation'. Effectively, organic farmers are encouraged to adopt conservation tillage, especially if they are located in areas susceptible to erosion. Conservation tillage offers benefits that could improve the soil fertility, soil quality and the environmental impact of organic crop production. However, Koepke (2003) reported that organic farmers generally use the moldboard plow, working to a greater depth (Munro et al., 2002) or to a lesser depth (Watson et al., 2002) than in conventional agriculture.

2. Preservation of soil quality and fertility

2.1. *Residue distribution within the soil profile*

The different types of tillage system involve different stratification of the soil layers (Figure 1a–c). The soil is divided into three layers: the surface, the topsoil and the subsoil layers. The surface layer corresponds to the seedbed. The topsoil is historically the plow depth (20–40 cm). The subsoil is the undisturbed part of the soil profile below the topsoil. The tilled layer varying from 5 to 40 cm contains the crop residues. Less crop residue is left on the soil surface with reduced or shallow tillage than with no tillage. The reduced tillage method leaving least residues at the surface is shallow plowing. Furthermore, disc harrows incorporate more crop residues than chisel tines. The main impacts of the different tillage systems on seedbed quality are due to changes in the thickness, extent of soil inversion and extent of mixing of crop residue caused by the implement. The extent of residue incorporation is influenced by the degree of disintegration of the residues, e.g. straw length.

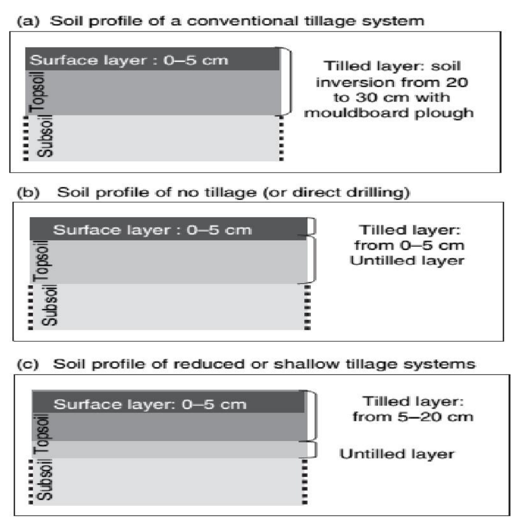

Figure 1 (a) Soil profile of a conventional tillage system, (b) soil Profile of no tillage (or direct drilling), (c) soil profile of reduced or shallow tillage systems.

The quantity of SOM in the whole topsoil varies due to the interacting influences of climate, topography, soil type and crop management history (fertilizer use, tillage, rotation and time) (Kay & VandenBygaart, 2002). Thus, in conservation tillage, SOM and microbiological activity are stratified in the soil profile, according to the burial depth of crop residues and manures (Needelman et al., 1999; Franzluebbers, 2002a). However, several authors have shown that there is no significant increase in the overall mass of soil organic carbon (C) (Table 2) or of soil microbial biomass (Table 1) in the whole topsoil in different tillage systems. SOM, organic C and soil microbial biomass increase in the tilled layer and are unchanged or decreased in the untilled layer below conservation tillage compared with conventional tillage (Table 1). Similarly, total N, organic N and mineralizable N, phosphorus (P) and potassium (K) follow the same pattern as C and SOM, with greater concentration in the soil surface layer (tilled layer) in conservation tillage, but without a significant increase in the whole topsoil. In a pan-European study, Ball et al. (1998) concluded that additional carbon fixation by the storage of organic matter and oxidation of atmospheric methane was very limited under reduced tillage and likely to last for a short period only. The authors also considered that soil nitrate was vulnerable to loss by denitrification, particularly in wet, fine-textured soils. However, less N is likely to be lost as a result of run-off and leaching than under conventional tillage. According to Sisti et al. (2004), the combined action of conservation tillage and the input of fresh organic matter as leguminous residues increased the soil C and, in the long term, improved the mineral N supply to crops. In a long-term study, Fließbach & Mäder (2000) and Pfiffner & Mäder (1997) showed that soil microbial biomass and its activity increased in organic farming compared with conventional management. Comparing properties of organically and conventionally managed soils of 28 sites on commercial farms, Munro et al. (2002) concluded that soils in organic systems contained more organic matter and total N than conventionally farmed soils. Frequent input of fresh organic matter, with no pesticide use, is the most probable cause of the increasing percentage of organic matter and biological activity found in organic systems. However, according to Shepherd et al. (2002) (cited in Stockdale et al. (2002)), few differences in organic matter content exist between organically and conventionally managed pastures in the UK. The main difference in SOM was found between conventional and organic arable land, where fresh organic matter was applied more frequently in organic systems. Moreover, no consistent difference was found in the quantity of nutrient reserves held in organic forms, between organically and conventionally managed soils (Stockdale et al., 2002).

Table 1 Effects of tillage systems on SOM, organic C and N, soil microbial biomass

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) Key & VandenBygaart (2002)
Organic carbon	More in the tilled layer Similar in the untilled layer Similar throughout the topsoil	Tebeugge & During (1999) and Andrade et al. (2003) Balesdent et al. (2000) and Deen & Kataki (2003) Anken et al. (2004)
Total carbon	More in the 0-5 cm layer similar in the 5-20 cm Layer under no tillage	Six et al. (1999)
Microbial biomass	More in the tilled layer Similar in the untilled layer More active microbial biomass in the 0-5 cm layer under no tillage No difference in total soil microbial biomass in the 0-5 cm layer under no tillage	Stockfisch et al. (1999) and Key & VandenBygaart (2002) Aon et al. (2001) and Key & VandenBygaart (2002) Alvarez & Alvarez (2000)
Microbial diversity	More fungi than bacteria in crop residue at soil surface	Kladivko (2001)
Micro-organisms	*Specific effects:* More Anecid species More endogeic species during a short period If plough pan is present in conservation tillage: less endogeic species *Effect on quantity:* More Earthworms. Nematodes Depends on tillage depth and intensity (no tillage > reduced tillage) and also on time and soil type	Rasmussen (1999) Chan (2001). Kladivko (2001) and birkas et al. (2004) Chan (2001)

Table 2 Effects of tillage systems on N, P and K

Soil components	Comparison conservation vs. conventional tillage	References
Total nitrogen	More in the tilled layer with shallow tillage Similar in the untilled layer	Stockfisch et al. (1999)
Organic nitrogen	More in the tilled layer Similar in the untilled layer	Balesdent et al. (2000) Balesdent et al. (2000) and Aon et al. (2001)
Mineralizable nitrogen	More in the tilled layer Similar in the whole topsoil	Six et al. (1999) and Balesdent et al. (2000) Six et al. (1999)
Mineralizable nitrogen	More in the tilled layer Similar in the untilled layer More in the tilled layer after 10 years Less in the whole topsoil after 10 years More in the whole topsoil in long term Less in the whole topsoil in short term	Kandeler et al. (1998) and Young & Ritz (2000) Ahl et al. (1998) Andrade et al. (2003)
Available phosphorus	More in the tilled layer Similar in the untilled layer	Rasmussen (1999)
Available potassium	More in the tilled layer under shallow tillage Similar in the untilled layer	Rasmussen (1999)

The quantity and quality of crop residues and animal manures will determine the amount of N which becomes available (Berry et al., 2002). Hence, although we expect that the combined effects of organic farming and conservation tillage could improve the SOM content and consequently the soil nutrient reserves in organic stockless system, further research on the combined effects is required. The number of earthworms and their activity increase in conservation compared with conventional tillage (Table 1). Plowing disrupts earthworm soil habitats, especially deep burrowing species (anecic), and exposes earthworms to predation and desiccation (Holland, 2004). In the same way, the increase of fresh organic matter in organic farming is an additional resource stimulating trophic and burrowing activity of earthworms (Gerhardt, 1997; Glover et al., 2000; Shepherd et al., 2000). Thus, both organic farming and conservation tillage improve the activity of earthworms. This is especially important in arable systems where generally earthworm activity is much reduced compared with grassland.

3. *Aggregate stability*

One of the main objectives of conservation tillage is to reduce soil erosion (Holland, 2004). Soil organic matter, concentrated near the soil surface with conservation tillage (Table 1), and especially labile organic matter (Ball et al., 2005), encourages microbial activity leading to increased soil aggregate stability (Table 3) and improved soil structure. In the same way, fungal hyphae, more abundant in the surface layer in conservation tillage (Table 1), play an important role in aggregating and stabilizing soil structure. Also, with no tillage, crop residues at the soil surface prevent surface crusting (Azooz & Arshad, 1996). This improved aggregate stability tends to enhance infiltration rate which in turn results in less run-off containing dissolved nutrients and adsorbed P.

Organic matter plays an important role in the maintenance of soil structure. Shepherd et al. (2002) assessed soil structure in over 90 arable fields managed under organic and conventional systems. They found that the potential for structural improvement in soils under organic production was greater than in conventional soils due to the greater biological and earthworm activity enhanced by regular application of organic matter, improving aggregate stability and biological porosity. Helfrich (2003) found that increasing the duration of the ley phase in an organic ley-arable rotation increased aggregate stability. Voorhees & Lindstrom (1984) (cited in Munkholm et al., 2001) considered that a period of about 3–5 years from adoption of conservation tillage is required to improve the friability of the surface layer of fine-to-medium-textured soils.

4. *Total organic matter*

Soil inversion by moldboard plowing tends to concentrate plant residue at the bottom of the plow layer (Allmaras et al., 1996); however annual inversion results in a progressive homogenization of soil organic carbon (SOC) in the plow layer (Yang and Wander, 1999; McCarty et al., 1998; Wander et al., 1998). Shallow tillage will also homogenize SOC within the depth of tillage (Franzluebbers and Arshad, 1996b), but may result in some stratification of SOC with depth (Yang and Wander, 1999). The degree of stratification is usually a function of intensity of disking and plowing, with the amount of surface residue remaining after tillage acting as the most important variable (Duiker and Lal, 1999).

Table 3 Effects of tillage systems on soil porosity and aggregate stability

Soil components	Comparison of conservation tillage vs. conventional tillage	References
Aggregate stability	More stable in surface layer More clay decreases differences between tillage system	Ball et al. (1996), Arshad et al. (1999) and Stenberg et al. (2000) Tebugge & During (1999)
Total porosity	Greater or no difference in surface layer (0-5 cm) with no tillage No difference in tilled layer with shallow tillage Less in the untilled layer and the whole topsoil	Guerif (1994) and Rusmussen (1999) Ball & O'Sullivan (1987) and Key & VandenBygaaret (2002)
Soil bulk density	Smaller or no difference in surface layer (0-5 cm) with no tillage Greater in the untilled layer and the whole topsoil No difference or higher in the subsoil	Tebrugge & During (1999) Arshad et al. (1999), Rasmussen (1999) and Deen & Kataki (2003) Tebrugge & During (1999)
Pore size	More micro and mesopores in conservation tillage	Guerif (1994) and Key & VandenBygaart (2002)
distribution	Fewer pores with diameter from 30 or 100 µm More boipores (diameter 100-500 µm) Fewer irregular and elongated shaped pored > 1000 µm Greater connectivity of vertical biological porosity in long term	Chan (2001) Ball & O'Sullivan (1987) and Key & vandenBygaart (2002) Chan (2001) and Anken et al. (2004)

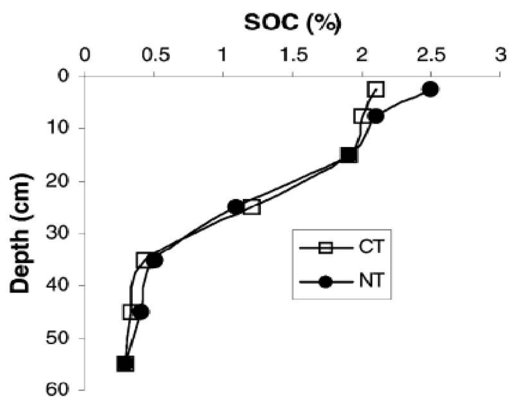

Fig. 3. SOC concentration as a function of soil depth in NT and CT at the end of 22 years in a silt loam in southern Ontario.

Conversion from CT to NT results in an immediate change in the placement of aboveground crop residue and the reduced fragmentation of the soil matrix may also slow the mineralization of SOC. Crop residue that was mechanically distributed throughout the tillage zone under CT remains at the soil surface under NT. Leaching of organic solutes and redistribution by soil faunal activities become the primary physical transport mechanisms under reduced tillage. Initial changes in SOC under NT would be expected to primarily reflect changes in the placement of C, with C being gained in the vicinity of the soil surface and lost at lower depths. The balance between the two processes could change with time. In a silt loam from Ontario, SOC under NT for 22 years was greater than under CT at a depth of 0–5 cm, but not different below 5 cm (Fig. 3). Tillage-induced changes in bulk density extended to 10 cm and calculations on an equivalent mass basis resulted in significant accumulation of SOC (3 Mg ha^{-1}) to a depth of 10 cm (Yang and Kay, unpublished data). During the first 3 years of converting a silt loam in Maryland from CT to NT management SOC increases at 0–5 cm, but decreased at 12.5–20 cm (McCarty et al., 1998). There was no detectable change in SOC content to 20 cm on an equivalent weight basis. From six different cool, humid soils of eastern Canada, SOC was not different between CT and NT comparisons of 3–11 years at a depth of 0–60 cm (Angers et al., 1997). Soil organic C in the top 10 cm was greater than under CT, but was lower at a depth of 20–40 cm and not different at a depth of 40–60 cm. At a depth of 0–15 cm, SOC increased significantly in a silt loam from Ohio between 18 and 32 years after implementing NT, but decreased slightly at 22.5–30 cm (Dick and Durkalski, 1998). Total SOC to a depth of 30 cm at the end of 32 years was significantly greater (1.7 Mg ha^{-1}) under NT than under CT. Variability in processes across landscapes may alter the storage potential of SOC with conservation tillage. VandenBygaart et al. (2002) found that erosion/deposition within landscape units on several farms in southern Ontario had a very strong influence on the dynamics of SOC. At shoulder slope landscape positions where there had been a history of soil loss during CT, there was primarily a gain in SOC stored in the profile at the end of 15 years of NT. However, in depositional, concave landscape positions where there was evidence of soil deposition during CT, a majority of the sites had lost SOC since NT had been implemented. Therefore, SOC dynamics under conservation tillage are affected by previous soil loss and redistribution and extrapolations beyond research domains should be minimized. The storage potential of SOC with conservation tillage may also be influenced by management decisions made in previous years. In a side-by-side comparison of CT and NT for 19 years on a private farm in southern Ontario, SOC in the profile (on an equivalent mass basis) was 70 Mg ha^{-1} greater under NT than CT (Yang and Kay, 2001b). Tile drainage had been installed 7 years before the tillage comparison had been initiated. Soil organic C was declining in both tillage treatments at the end of 6 years. The remarkably large difference in SOC was not due to sequestration of SOC, but rather a reduction in the rate of SOC mineralization under NT.

Research indicates that SOC accumulates near the soil surface and is lost at lower depths soon after a conversion from CT to NT practices. More information is required on how the balance between these processes changes with time in soils of different texture, drainage and under different climates. In addition, more information is required on the depths at which these processes are dominant. Information on how these processes interact with processes that vary across landscapes will be particularly critical to estimations of C budgets arising from widespread adoption of conservation tillage.

Recently the influence of tillage on various fractions of soil organic matter has been investigated. Effects of tillage on organic matter fractions have been based on segregation by particle-size (Angers et al., 1993), particle density (Alvarez et al., 1998), fractions in soil aggregate size classes (Beare et al., 1994; Bajracharya et al., 1997), and in biological (Angers et al., 1993; Franzluebbers et al., 1995; Needelman et al., 1999) and chemical (McCallister and Chien, 2000) fractions of soil. A reduction in tillage would be expected to initially affect microbial biomass and relatively undecomposed crop residue. Soil microbial biomass C in the 0–5 cm depth under NT for 4 years increased 10–23% compared with shallow tillage, but this increase was gradually offset with time by a decline at lower depths (Carter, 1986). Needelman et al. (1999) found that NT affected the vertical distribution, but not the overall amount of SOC and particulate organic matter (POM) under NT for 5 years compared with CT in soils from Illinois. Concentration of SOC and POM in the upper 5 cm of soil was greater under NT than under CT, but lower in the 5–15 cm depth. Similar results were observed by Wander et al. (1998). Yang and Kay (2001b) found there was about twice as much total loose POM and occluded POM in the top 5 cm of a soil under NT for 19 years compared with CT at a private farm in southern Ontario. However, at 10–20 cm depth POM was lower under NT than under CT.

Texture may have a significant effect on the protection of organic C fractions when soils are converted to NT. At the end of 19 years, sequestration of SOC occurred primarily in the POM fraction in a sandy loam (Yang and Kay, 2001b). However, in the clay loam portion of the field, sequestration of SOC was dominant in the heaviest or humic fraction of the soil. POM tended to accumulate more under NT than under CT in soils with higher clay content in northern Alberta and British Columbia (Franzluebbers and Arshad, 1997).

Based on this review, POM and total SOM become concentrated near the soil surface in NT systems, presumably due to the lack of incorporation of crop residue by tillage. The distribution of microbial biomass C may be related to the placement of crop residue. More research is needed on the changes in forms of organic matter that are most humified or most closely associated with the mineral fraction following a change in tillage practices. This information is critical to understand SOC dynamics and potential sequestration upon conversion to conservation tillage. More information is needed on the influence of texture and climate on the changes in SOC fractions with conservation tillage.

Conclusions

The maintenance of soil organic matter levels and the optimization of nutrient cycling are essential to the sustained productivity of agricultural systems. Both are related closely to the bioturbating activities of macrofauna and the microbially-driven mobilization and immobilization processes, which the activities of large invertebrates also encourage. Maintaining soil organic matter content requires a balance between addition and decomposition rates. As changes in agricultural practices can engender marked changes in both the pool size and turnover rate of soil organic matter, it is important to analyse their nature and impacts. Crop production worldwide has generally resulted in a decline in soil organic matter levels and, consequently, in a decline of soil fertility. Converting grasslands and forestlands to arable agriculture results in the loss of about 30 percent of the organic C originally present in the soil profile. On reasonably fertile soils with reliable water supply, yields in long-term arable agricultural systems have been maintained at very high levels by applying substantial amounts of fertilizer and other soil amendments. In low-input agricultural systems, yields generally decline rapidly as nutrient and soils organic matter levels decline. However, restoration is possible through the use of fallow lands, mixed crop-livestock and agroforestry systems, and crop rotations, conservation tillage.

Traditional mold-board plow and disc-tillage cropping systems tend to cause rapid decomposition of soil organic matter, leave the soil susceptible to wind and water erosion, and create plow pans below the cultivation depth. By contrast, reduced- or zero-tillage systems leave more biological surface residues, provide environments for enhanced soil activity, and maintain more intact and interconnected large pores and more soil aggregates, which are better able to withstand raindrop impact. Water can infiltrate more readily and rapidly into the soil with reduced tillage and this helps protect the soil from erosion. In addition, organic matter decomposes less rapidly under reduced-tillage systems. No-tillage systems have proved especially useful for maintaining and increasing soil organic matter.

Corresponding author
Sherwin Amini
M-Sc. Mechanization Engineering, Student of Khuzestan Ramin Agriculture and Natural Resources University, Khuzestan Iran
Tel: +93-56-678812
E-mail: sherwinamini@yahoo.com

References

1. Ahl, C., Joergensen, R.G., Kandeler, E., Meyer, B. & Woehler, V.1998. Microbial biomass and activity in silt and sand loams after long-term shallow tillage in central Germany. Soil & Tillage Research, 49, 93–104.
2. Allmaras, R.R., Copeland, S.M., Copeland, P.J., Oussible, M., 1996. Spatial relations between oat residue and ceramic spheres when incorporated sequentially by tillage. Soil Sci. Soc. Am. J. 60, 1209–1216.
3. Alvarez, C.R. & Alvarez, R. 2000. Short-term effects of tillage systems on active soil microbial biomass. Biology and Fertility of Soils, 31, 157–161.
4. Alvarez, C.R., Alvarez, R., Grigera, M.S., Lavado, R.S., 1998. Associations between organic matter fractions and the active soil microbial biomass. Soil Biol. Biochem. 30, 767–781.
5. Andrade, D.S., Colozzi-Filho, A. & Giller, K.E. 2003. The soil microbial community and soil tillage. In: Soil tillage in agroecosystems (ed. A. El Titi), pp. 51–81. CRC Press, Boca Raton, FL.
6. Andraski, B.J., D.H. Mueller, and T.C. Daniel. 1985. Phosphorus losses in runoff as affected by tillage. Soil Sci. Soc. Amer. J. 49:1523-1527.
7. Angers, D.A., Bolinder, M.A., Carter, M.R., Gregorich, E.G., Drury, C.F., Liang, B.C., Voroney, R.P., Simard, R.R., Donald, R.G., Beyaert, R.P., 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. Soil Till. Res. 41, 191–201.
8. Angers, D.A., N'dayegamiye, A., Coˆte´, D., 1993. Tillage-induced differences in organic matter of particle size fractions and microbial biomass. Soil Sci. Soc. Am. J. 57, 512–516.
9. Anken, T. & Irla, E. 2000. Minimum tillage and mechanical weed control in winter wheat. In: Proceedings of The World Grows Organic: 13th International IFOAM Scientific Conference, Basel (eds. T. Alfo¨ ldi, W. Lockertz & U. Niggli) pp. 409. Vdf, Zu¨ rich.
10. Anken, T., Weisskopf, P., Zihlmann, U., Forrer, H., Jansa, J. & Pehacova, K. 2004. Long-term tillage system effects under moist cool conditions in Switzerland. Soil & Tillage Research, 78, 171–183.
11. Aon, M.A., Sarena, D.E., Burgos, J.L. & Cortassa, S. 2001. (Micro)-biological, chemical and physical properties of soils subjected to conventional or no-till management: an assessment of their quality status. Soil & Tillage Research, 60, 173–186.
12. Azooz, R.H. & Arshad, M.A. 1996. Soil infiltration and hydraulic conductivity under long-term no-tillage and conventional tillage systems. Canadian Journal of Soil Science, 76, 143–152.
13. Bajracharya, R.M., Lal, R., Kimble, J.M., 1997. Soil organic carbon distribution in aggregates and primary particle fractions as influenced by erosion phases and landscape position. In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), Soil Processes and the Carbon Cycle. CRC Press, Boca Raton, FL, pp. 353–367.
14. Balesdent, J., Chenu, C. & Balabane, M. 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil & Tillage Research, 53, 215–230.
15. Ball, B.C. & O'Sullivan, M.F. 1987. Cultivation and nitrogen requirements for drilled and broadcast winter barley on a surface water gley (gleysol). Soil & Tillage Research, 9, 103–112.
16. Ball, B.C., Bingham, I., Rees, R.M., Watson, C.A. & Litterick, A. 2005. The role of crop rotations in determining soil structure and crop growth conditions. Canadian Journal of Soil Science, 85, 557–577.
17. Ball, B.C., Tebru¨ gge, F., Sartori, L., Gira´ ldez, J.V. & Gonza´ lez, P.1998. Influence of no-tillage on physical, chemical and biological soil properties. In: Experiences with the applicability of no-tillage crop production in the west-European countries, review papers, summaries and conclusions of the concerted action (eds F. Tebru¨ gge & A. Bo¨ hrnsen), pp. 7–27. Justus-Liebig University, Giessen, Germany.
18. Beare, M.H., Hendrix, P.F., Coleman, D.C., 1994. Water-stable aggregates and organic matter

fractions in conventional and notillage soils. Soil Soc. Am. J. 58, 777–786.
19. Birkas, M., Jolankai, M., Gyuricza, C. & Percze, A. 2004. Tillage effects on compaction, earthworms and other soil quality indicators in Hungary. Soil & Tillage Research, 78, 185–196.
20. Bosatta, D.A., A˚ gren, G.I., 1994. Theoretical analysis of microbial biomass dynamics in soils. Soil Biol. Biochem. 26, 143–148.
21. Chan, K.Y. 2001. An overview of some tillage impacts on earthworm population abundance and diversity – implications for functioning in soils. Soil & Tillage Research, 57, 179–191.
22. Davies, D.B. & Finney, J.B. 2002. Reduced cultivation for cereals: research, development and advisory needs under changing economic circumstances. Home grown cereals authority research review, 48, 57.
23. Deen, W. & Kataki, P.K. 2003. Carbon sequestration in a long-term conventional versus conservation tillage experiment. Soil & Tillage Research, 74, 143–150.
24. Dick,W.A., Durkalski, J.T., 1998. No-tillage production agriculture and carbon sequestration in a Typic Fragiudalf soil of northeastern Ohio. In: Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), Management of Carbon Sequestration in Soil. CRC Press, Boca Ration, FL, pp. 59–71.
25. Duiker, S.W., Lal, R., 1999. Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. Soil Till. Res. 52, 73–81.
26. El Titi, A. 2003. Implications of soil tillage for weed communities. In: Soil tillage in agroecosystems (ed. A. El Titi), pp. 147–185. CRC Press, Boca Raton, FL.
27. Flieكbach, A. & Ma¨ der, P. 2000. Microbial biomass and size-density fractions differ between soils of organic and conventional agricultural systems. Soil Biology & Biochemistry, 32, 757–768.
28. Franzluebbers, A.J. 2002a. Soil organic matter stratification ratio as an indicator of soil quality. Soil & Tillage Research, 66, 95–106.
29. Franzluebbers, A.J. 2002b. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil & Tillage Research, 66, 197–205.
30. Franzluebbers, A.J., Arshad, M.A., 1996b. Soil organic matter pools with conventional and zero tillage in a cold, semiarid climate. Soil and Till. Res. 39, 1–11.
31. Gerhardt, R.A. 1997. A comparative analysis of the effects of organic and conventional farming systems on soil structure. Biological Agriculture and Horticulture, 14, 139–157.
32. Glover, J.D., Reganold, J.P. & Andrews, P.K. 2000. Systematic method for rating soil quality of conventional, organic, and integrated apple orchards in Washington State. Agriculture, Ecosystems & Environment, 80, 29–45.
33. Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M., Ellert, B.H., 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can. J. Soil Sci. 74, 367–385.
34. Guerif, J. 1994. Influence de la simplification du travail du sol sur l'etat structural des horizons de surface: conse´quences sur leurs proprie´te´s physiques et leurs comportements me´caniques. In: Simplification du travail du sol (eds. G. Monnier, G. Thevenet & B. Lesaffre INRA), pp. 13–33. INRA Edition, Paris.
35. Haynes, R.J., 2005. Labile organic matter fractions as central components of the quality of agricultural soils: an overview. Adv. Agron. 85, 221–268.
36. Helfrich, M. 2003. Protected soil organic matter under organic farming. I. Assessment of aggregate stability and organic matter distribution within aggregates. Diploma thesis for the Technischen Universita¨ t Carolo-Wilhelmina Braunschweig, Germany.
37. Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems & Environment, 103, 1–25.
38. IFOAM 2002. IFOAM basic standards for organic production and processing. IFOAM, Germany, pp. 13–40.
39. Kandeler, E., Tscherko, D. & Spiegel, H. 1998. Long-term monitoring of microbial biomass, N mineralisation and enzyme activities of a chernozem under different tillage management. Biology and Fertility of Soils, 28, 343–351.
40. Kay, B.D. & VandenBygaart, A.J. 2002. Conservation tillage and depth stratification of porosity and soil organic matter. Soil & Tillage Research, 66, 107–118.
41. Kladivko, E.J. 2001. Tillage systems and soil ecology. Soil & Tillage Research, 61, 61–76.
42. Koepke, U. 2003. Conservation agriculture with and without use of agrochemicals. In: Proceedings of the Second World Congress on Conservation agriculture, Iguassu Falls, Parana´ , Brazil 13pp. FAO, Rome.
43. Lal R., Soil compaction and tillage effects on soil physical properties of a mollic ochraqualf in Northwest Ohio, J. Sustain. Agric. 14 (1999) 53–65.
44. McCallister, D.L., Chien, W.L., 2000. Organic carbon quantity and forms as influenced by

tillage and cropping sequence. Commun. Soil Sci. Plant Anal. 31, 465–479.
45. McCarty, G.W., Lyssenko, N.N., Starr, J.L., 1998. Short-term changes in soil carbon and nitrogen pools during tillage management transition. Soil Sci. Soc. Am. J. 62, 1564–1571.
46. Munkholm, L.J., Schjonning, P. & Rasmussen, K.J. 2001. Noninversion tillage effects on soil mechanical properties of a humid sandy loam. Soil & Tillage Research, 62, 1–14.
47. Munro, T.L., Cook, H.F. & Lee, H.C. 2002. Sustainability indicators used to compare properties of organic and conventionally managed topsoils. Biological Agriculture and Horticulture, 20, 201–214.
48. Needelman, B.A., Wander, M.M., Bollero, G.A., Boast, C.W., Sims, G.K. & Bullock, D.G. 1999. Interaction of tillage and soil texture: biologically active soil organic matter in Illinois. Soil Science Society of America Journal, 63, 1326–1334.
49. Pfiffner, L. & Mader, P. 1997. Effects of biodynamic, organic and conventional production systems on earthworm populations. Entomological Research in Organic Agriculture. Biological Agriculture and Horticulture, 15, 3–10.
50. Rasmussen, K.J. 1999. Impact of ploughless soil tillage on yield and soil quality: a Scandinavian review. Soil & Tillage Research, 53, 3–14.
51. Shepherd, M., Hatley, D. & Gosling, P. 2002. Assessing soil structure in organically farmed soils. In: Proceedings of UK Organic Research 2002: the COR Conference, Aberystwyth (ed. J. Powel), pp. 143–144. Organic Centre Wales, Institute of Rural Studies, University of Wales, Aberystwyth.
52. Sisti, C.P.J., Dos Santos, H.P., Kohhan, R., Alves, B.J.R., Urquiaga, S. & Boddey, R.M. 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil & Tillage Research, 76, 39–58.
53. Six, J., Elliott, E.T. & Paustian, K. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Science Society of America Journal, 63, 1350–1358.
54. Soon, Y.K., Arshad, M.A., Haq, A., Lupwayi, N., 2007. The influence of 12 years of tillage and crop rotation on total and labile organic carbon in a sandy loam soil. Soil Till. Res. 95, 38–46.
55. Stenberg, M., Stenberg, B. & Rydberg, T. 2000. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. Applied Soil Ecology, 14, 135–145.
56. Stockdale, E.A., Shepherd, M., Fortune, S. & Cuttle, S. 2002. Soil fertility in organic farming systems – fundamentally different? Soil Use and Management, 18, 301–308.
57. Stockfisch, N., Forstreuter, T. & Ehlers, W. 1999. Ploughing effects on soil organic matter after twenty years of conservation tillage in Lower Saxony, Germany. Soil & Tillage Research, 52, 91–101.
58. Tebrugge, F. & During, R.A. 1999. Reducing tillage intensity: a review of results from a long-term study in Germany. Soil & Tillage Research, 53, 15–28.
59. Wander, M.M., Bidart, M.G., Aref, S., 1998. Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. Soil Sci. Soc. Am. J. 62, 1704–1711.
60. Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R. & Rayns, F.W. 2002. Managing soil fertility in organic farming systems. Soil Use and Management, 18, 239–247.
61. Williams, A.G., Audsley, E. & Sandars, D.L. 2006. Energy and environmental burdens of organic and non-organic agriculture and horticulture. 'What will organic farming deliver?' COR 2006. Aspects of Applied Biology, 79, 19–23.
62. Yang, X.M., Kay, B.D., 2001b. Impacts of tillage practices on total, loose- and occluded-particulate, and humified organic carbon fractions in soils within a field in southern Ontario. Can. J. Soil Sci. 81, 149–156.
63. Yang, X.M., Wander, M.M., 1999. Tillage effects on soil organic carbon distribution and storage in a silt loam soil in Illinois. Soil Till. Res. 52, 1–9.
64. Young, I.M. & Ritz, K. 2000. Tillage, habitat space and function of soil microbes. Soil & Tillage Research, 53, 201–213.

2/21/2015