Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(5): 2953-2958
Received: 24-07-2020
Accepted: 28-08-2020

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Effect of long term zero tillage on soil organic carbon and its fractions: A review

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DOI: https://doi.org/10.22271/phyto.2020.v9.i5ao.12791

Abstract
Soil tillage disruption is a major cause of loss of organic matter and a decline in the number and stability of soil aggregates as natural habitats are transformed into agriculture. Compared to conventional tillage, zero tillage cropping systems typically demonstrate increased aggregation and soil organic matter. To feed the rising population on a sustainable basis without degrading natural resources, there is a need to increase farm productivity and total food production. Although the country's green revolution technologies implemented during 1966-67 led to food protection, intensive agriculture, insufficient and imbalanced use of fertilizers, high yielding crop varieties, the use of heavy machinery, excess tillage, etc., resulted in degradation of soil health and quality for more than five decades and increased pollution of air, soil and water. There is a great lack of a systematic approach to relating tillage practices to chemical soil properties. The most significant pillar of conservation farming is zero tillage. The need for an hour is conservation farming. It is a win-win operation for farmers as well as for the environment. The goal of Tillage was to establish a soil environment conducive to plant growth, but to have negative effects on soil resources, structure and eventually on the environment in the long run. Zero tillage has the ability to enhance the chemical properties and environment of the soil in the long run. Keeping all of these under consideration, this analysis is compiled to create a perfect tillage scheme, i.e. zero tillage, which eliminates the adverse effects of tillage and retains soil resources and eventually contributes to sustainable agriculture. The magnitude of changes in soil organic matter in response to zero tillage, however, differs between soils and the stabilisation mechanisms of organic matter in zero tillage systems.

Keywords: Zero tillage, conventional tillage, soil organic carbon, dissolved organic carbon, light and heavy fractions

Introduction

Compared with conventional tillage, the deposition of soil organic matter under zero tillage confers major increases in soil quality, soil fertility and carbon sequestration. For some time, mechanisms by which zero tillage reduces the decomposition of soil organic matter have been established (Paustian *et al*., 1997) [45], but the ultimate mechanisms have not been well elucidated. It has been identified that their decomposition rate is reduced by the inclusion of organic materials within soil aggregates (Elliott and Coleman, 1988) [17]. Increases in aggregation were found in zero tillage systems concurrent with increases in organic carbon (Six *et al*., 2000) [58]. A loss of C-rich macroaggregates and a benefit of C-depleted microaggregates were found to induce tillage (Six *et al*., 2000) [58]. However, the overall C loss associated with tillage can't be explained by this reduction in macroaggregates. Six *et al*. (1998, 1999a) [56, 57] proposed that a primary mechanism that induces decreases in soil C is increased macroaggregate turnover under traditional tillage. In order to feed the growing population on a sustainable basis without degrading natural resources (soil and water) and the climate, there is a need to increase farm productivity and total food production. It is estimated that by 2050 the world population will be about 9.8 billion and 37 percent of which will reside in China and India (UN, 2017), requiring an estimated 59-98 percent rise in food demand (Valin *et al*., 2014) [67], placing more pressure on natural resources. Although green revolution technologies implemented in the country during 1966-67 led to food protection, intensive cropping, insufficient and imbalanced use of fertilisers, high yielding crop varieties, use of heavy machinery, excess lawning, etc., for more than five decades resulted in degradation of soil health, decrease in organic matter in the soil, decrease in chemical and physical soil, etc. Organic soil carbon is considered an important soil quality index and is considered to be a key factor in cycling plant nutrients and improving the physical, chemical and biological properties of the soil (Singh *et al*., 2008) [44]. Furthermore, there is a increasing concern now-a-days about elevated atmospheric CO_2 concentrations due to industrialization and other Anthropogenic activities.

Almost three times the carbon contained in vegetation is contained in the upper 30 cm soil layer (Powlson *et al*., 2012) [49], which is considered most prone to CO2 loss. Estimates of total C sequestration capacity in the world's soils, however, vary widely from 0.4 to 1.2 Gt C year-1. There is also the ability to increase the stock of C in soils (FAO, 2011). There is therefore a increasing concern about the implementation of technologies and management practises that have the potential to increase the content of organic carbon in the soil. Conservation agriculture (CA) has been found to have sufficient capacity to improve soil organic carbon and soil productivity. In this era of climate change, the CA is a resource-saving agricultural crop production system that aims to achieve reasonable benefit along with high and sustained levels of production while at the same time protecting the environment (FAO, 2010) [18]. The three interlinked principles of conservation agriculture are: I continuous minimum mechanical soil disturbances, (ii) preservation of permanent organic soil coverage, and (iii) diversified crop rotations (FAO 2010) [18]. One component of conservation agriculture, zero tillage, refers to soil management systems that result in crop residues covering at least 30 percent of the soil surface (Jarecki and Lal, 2003) [28]. Tillage activity, on the other hand, is synonymous with soil ploughing with certain instruments and implements to monitor weeds and create a favourable soil tilth for proper germination of seeds, emergence of seedlings, and plant establishment and growth (Lal, 1979; Klute 1982; Ahn and Hintze, 1990) [1]. Tillage has been found to compact sub-surface soil in the current mechanised agriculture scenario, limiting root penetration and production, nutrient and water availability, and thus plant growth and yield. The mechanical inversion of the soil does not take place when the tillage is not used over the years, and hence the soil-plant system enters a physical balance. In addition, as a result of reduced soil organic carbon, intensive tillage operations typically increase soil erosion, environmental contamination and soil degradation (Srinivasan *et al*., 2012) [59]. With the advent of herbicides for weed control, several scientists have advocated the adoption of zero tillage to minimise organic matter oxidation, sub-surface compaction and better soil condition for root penetration and proliferation, increasing the availability of nutrients and water resulting in better growth and yield of pants. Conservation tillage is now considered a promising alternative to conventional tillage practise (Teklu, 2011) [62]. Conservation tillage is a promising alternative to traditional tillage practise. As they save energy and provide optimal soil conditions for sustainable crop production and reduced cultivation costs, conservation tillage practises like zero tillage or limited soil disturbance and residue retention on the soil surface are becoming economically and ecologically viable options. Better root growth and productive use of water and nutrients can be encouraged by improved soil physical condition. Long-term conservation tillage improves the status of soil organic carbon and modifies soil pore geometry, which ultimately affects basic physical parameters such as bulk density, aggregate stability, water retention capacity, etc. However, the effects of conservation tillage are highly variable across environment, soil type and depth, cropping system, and vary widely with the period of adoption.

Impact of zero tillage on soil organic carbon and its fractions

Soil organic carbon

In soil fertility, soil organic carbon (SOC) plays a crucial role. Due to its crucial role in the chemical, physical and biological properties of the soil, it is an important measure of soil fertility and productivity (Gregorich and Janzen, 1994) [22]. For sustainable agro-ecosystems, maintenance of a satisfactory level of SOM is therefore necessary. There are two ways of increasing SOC: (1) increasing the input of C, or (2) reducing the loss and decomposition of SOC. By implementing residue management and using conservation tillage, carbon production can be increased and decomposition decreased (no tillage or limited tillage). However, due to elevated background C content and its temporal and spatial variability, short and medium-term SOC shifts are difficult to detect (Bosatta and Agren, 1994) [7]. Increased atmospheric greenhouse gas concentrations and consequent climate change have contributed to an overriding interest in organic carbon sequestration in agricultural soils. SOC is the primary component of soil organic matter (SOM) and is formed on or below the soil surface by the decomposition of different organic materials. The rate of SOM turnover and decomposition is largely determined by the interactions between different components of the soil (physical, chemical and biological) and the environment, such as temperature and humidity (Taylor *et al*., 2009) [61]. The SOC level can be sustained or even increased by better agricultural management practises along with other added benefits in terms of better physical condition, fertility and soil water storage (Blanco and Lal, 2010; Stockmann *et al*., 2013) [60]. Tillage practises mainly carried out for the preparation of seed beds, weed control, introduction of residues, play a dominant role in reducing the level of SOC and altering the physical conditions of the soil (Baker *et al*., 2007; Victoria *et al*., 2012) [4, 68]. Compared to normal movement of soluble, particulate or colloidal carbon, tillage physically integrates the carbon as crop residue into the soil. However, the soil aggregates are killed by continuous traditional tillage and the covered SOC is exposed to the atmosphere, which then undergoes rapid decomposition by aerobic microorganisms (Al-Kaisi and Yin, 2005) [2]. It has been calculated that conventional tillage activities have removed about 75% of the SOC inventory of the native soil (Lal *et al*., 2007) [34]. The SOC level of the soil, which is a mitigation choice for the level of CO_2 in the atmosphere, can be increased without laundering. This mechanism is called 'carbon sequestration' and the source-sink relationship of carbon in cultivated land is influenced by various agricultural management practises (Lin *et al*., 2002) [37]. In C-sequestration, SOC turnover time may have a dominant function and is influenced by soil mineralogy and climatic conditions (rainfall, temperature and radiation). In comparison to unfertilized soils, plant root biomass and root exudates increase the SOC content of fertilised soils (Kuzyakov, 2002; Chaudhary *et al*., 2012). In the form of cover crop under zero tillage, residue mulch or live mulch improves the degree of SOC and improves the process of C-sequestration. Minimal no-tillage soil disturbance favoured the formation of macro-aggregates and preserved the intra-aggregate SOC (Six *et al*., 2000a) [55]. Due to slow decomposition, retained crop residues on the soil surface increased the SOC level (Feng*et al*., 2010; Johansen *et al*., 2012; Boeckx *et al*., 2011; Brouder and Gomez-Macpherson, 2014; Tits *et al*., 2014; Chaplot *et al*., 2015; Guo *et al*., 2015) [8, 23]. Conservation agriculture had a beneficial influence on biological activities and/or physical structure development such as earthworm macro-aggregates, suggesting a special SOC dynamics (Brouder and Gomez-Macpherson, 2014; Tits *et al*., 2014) [8] increased Plaza-Bonilla *et al*., 2013; Higashi *et al*., 2014; Villami and Nafziger, 2015; Arai *et al*., 2013) [47]. Due to higher oxidation rates, the tillage is known to cause rapid loss of SOM material. This results in a degradation of the physical properties of the soil and a potential decline in crop production in the long term (Du Preez *et al*., 2001) [16]. With the period of conversion from traditional tillage to no tillage, soil organic C and total N were found to increase, especially in a few centimetres of surface soil (Bowman *et al*., 1999, Hermle *et al*., 2008) [25]. In shallow or minimum tillage, an accumulation of organic matter near the soil surface is usually observed due to a decrease in ploughing depth (Hernanz *et al*., 2002; Moreno *et al*., 2006) [42]. After years of CT, even the implementation of no-till management led to a rise in SOC across the Great Plains in a wide variety of soils and climates (West and Post, 2002; Baker *et al*., 2007) [4]. In arid and semi-arid areas where SOM material is often lost because of its harsh climatic conditions, conservation tillage has improved the organic matter content and water storage (Du Preez *et al*., 2001) [16]. In semi-arid regions, however, variations in soil organic C between traditional and zero tillage systems are typically limited since conventional tillage is less intensive and shallower than in wet regions (Unger, 1991) [65]. Gosai *et al*. (2009) [21] recorded higher organic matter content compared to moulboard tillage in zero and shallow-tilled plots. After 11 years of continuous cultivation, the carbon storage of zero tillage at 0-15 cm surpassed that of traditional tillage by 0, 1.6 and 3.9 Mg ha-1 in sandy loam, silt loam and clay loam soils, respectively (Campbell *et al*., 1996a) [9]. Also reported was the failure of ZT practises to increase SOC sequestration relative to CT systems (Ogle *et al*., 2005) [43]. No tillage on the surface has increased SOC content in many fine-textured soils at the cost of SOC deposited within the rooting zone (Kay and VandenBygaart, 2002) [31]. Conservation tillage, such as zero tillage, has the ability to sustain both soil fertility and crop fertility as it has a major effect on the organic carbon content of the soil due to crop residue retention. Madari *et al*. (2005) [39] found that, with larger aggregates and more soil organic carbon, zero tillage with residue cover had greater aggregate stability. By introducing zero tillage, higher soil organic carbon sequestration has also been observed (Dick *et al*., 1991 and Panday *et al*., 2008) [13, 44]. After rice and wheat harvesting, the soil organic carbon content in the 0-15 cm soil depth was higher under zero tillage than under traditional tillage, but soil organic carbon content remained almost unchanged in both traditional and zero tillage in the 15-30 cm soil layer after 4 years of cropping (Bhattacharyya *et al*., 2008) [5]. Hooker *et al*. (2005) [26] also discovered that residue control had little impact on SOC in the surface soil layer (0-5 cm) during tillage treatment. Tillage appeared to decrease the SOC material, although, as opposed to tomold board ploughed treatments, only no till combined with stover return to the soil resulted in an increase in SOC in the surface layer. Compared to traditional methods, enhanced soil and crop management methods, such as reduced tillage, increased SOC (Sainju *et al*., 2007; Zhang *et al*., 2007; Andruschkewitsch *et al*., 2013) [14, 3]. Long-term zero laying increased the surface layer soil carbon stock by 19.0, 34.7 and 38.8 percent over traditional laying in sandy loam, loam and clay loam soil over 15 years (Singh *et al*., 2014) [53]. Dong *et al*. (2009) [14-15] stated that, relative to the total SOC, the impact of tillage and residue management was greater on SOC fractions, such as dissolved organic C, microbial biomass C and particulate organic matter C. Compared to traditional methods, improved crop management practises, such as no-tillage and straw mulch strategies, will lift the SOC and SOC fractions (Andruschkewitsch *et al*., 2013; Blanco-Canqui and Lal, 2007; Mishra *et al*., 2010; Sainju *et al*., 2007) [3, 34]. Zotarelli *et al*. (2005) [69] reported that by influencing soil aggregates and aggregate-associated C, soil disturbance showed major influences on SOC safety. Freixo *et al*. (2002) [19] found that 0-5 cm of topsoil organic carbon decreased by 60 percent after 13 years of CT farming, while ZT conditions decreased by 43 percent. Due to residue accumulation at the soil surface, soil organic C storage is always higher under ZT than CT (Piovanelli*et al*., 2006) [46]. Soils administered with ZT change SOM, microbial species and nutrient availability and their roles (Thomas *et al*., 2007) [63]. Residues on the soil surface are maintained by the no tillage system and the SOC has therefore increased compared to intensive tillage systems (Kumar *et al*., 2012) [33].

Dissolved organic carbon, light and heavy fractions

The SOC strongly affects the consistency and productivity of the soil and can be categorised into fractions based on their chemical properties and time of residence (Mc Lauchlan *et al*., 2006). The light fraction of SOC, also known as the labile fraction, plays a key role in the understanding of soil quality changes (Kapkiyai *et al*., 1999) [29]. The sand fraction-related SOC is a labile pool of C and is thus affected by land use and management (Shrestha and Lal, 2007) [34], while the clay fraction-related SOC is more stable (heavy fraction) and has been found to be altered more by physical and chemical processes than by changes in land use. This labile fraction (LF) of SOM consists of micro-organisms, plant and soil fauna living at various decay levels and the products of their decomposition, and of non-humic organic substances which can be easily decomposed, such as carbohydrates, polysaccharides, proteins, organic acids, amino acids, waxes, fatty acids and other non-specific compounds (Poirier *et al*., 2005) [48]. The LF consists of a heterogeneous blend of recent residues of plants, small animals and micro-organisms that may be present at different stages of decomposition. In agricultural soils, this pool of soil organic matter is typically about many times greater than that of soil microbial biomass (Liang *et al*., 1998) [36]. SOC fractions, including dissolved organic C (DOC), microbial biomass C (MBC) and particulate organic matter C (POMC), are considered to be more susceptible than the total SOC (Dong *et al*., 2009) [14-15] markers of treatment-induced changes. The effects of various management activities on labile SOC pools have been documented in several studies (Plaza-Bonilla *et al*., 2013) [47]. Chen and Weil (2011) [9] stated that SOC changes were responsive to labile organic C fractions, with sensitivities decreasing in the order of POMC > DOC > MBC. The DOC is a large soil C pool and affects many chemical and biological processes (Chantigny, 2003) [10] and can imply short-term responses to crop management practises. Due to the preservation of soil surfaces, it usually decreases with depth (Qualls and Haines, 1992) [50]. The contribution to the DOC pool of crop residues and root exudates, however, is not fully known. By generating residues of variable quantity and consistency, cropping systems have varying effects on DOC pools (Lorenz and Lal, 2005) [38]. Chantigny (2003) [10] stated that under CT regimes, burial of crop residues increased soil C and DOC levels as residues experienced physical breakdown, resulting in higher levels of decomposition and DOC. Guo *et al*. (2015) [23] reported that ZT treatments increased the concentration of dissolved organic carbon (DOC) by 29.5% and 14.1% in the > 0.25 mm aggregate and < 0.25 mm aggregate in the 0-5 cm soil layer, relative to CT treatments, respectively. Larney *et al*. (1997) [35] recorded that no tillage significantly increased SOC by 8 percent and increased organic carbon light fraction (LFOC) by 15 percent after 16 years of spring wheat-fallow rotation relative to traditional tillage, but the increase in LFOC under ZT was not statistically significant, suggesting a higher variability of LFOC. The interaction between clays and slower decomposing carbon inputs to form soil aggregates can be facilitated by the lower disturbance in ZT systems. However, under ZT, faunal populations and microbial biomass (in particular fungal biomass) are also higher and these species play an important role in soil aggregation (Rillig and Mummey, 2006) [51]. In addition, in ZT systems, the root system has been considered an important agent for stabilising macroaggregates, while new C inputs from surface residues do not seem to contribute as much to C pools associated with macroaggregates (Gale *et al*., 2000) [20].

Conclusion

Due to the unparalleled increase in the world population and rapid economic growth, the number of food-insecure individuals may increase. In addition, due to growth in popularity, soil depletion, urbanisation, and other competing uses, the per capita cropland region is also declining. The stratagem is therefore to balance food production demand with the need for soil regeneration and reduction of the environmental footprint of agroecosystems. By following sustainable practises such as zero tillage, this can be done. The goal is to generate more from less soil, less water usage, less fertiliser and pesticide production, and less energy consumption. In order to transform scientific information into effect, the much needed paradigm change will also entail defining and enforcing effective policies. Zero tillage, properly applied, is one of the best solutions with the ability to enhance all physical properties of the land, preserve soil and water, and retain productivity. By designing site-specific packages and informing the agricultural community and the general public about the merits of zero tillage and stewardship of soil resources, its implementation can be strengthened. Finally, we concluded in a nut shell that long-term zero tillage practises could boost the organic carbon stocks of the soil and conserve soil resources for sustainable agriculture. Compared to traditional tillage in soils, the sum of macroaggregates and the mean residence time of total soil carbon upgrades at zero tillage.

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