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Effect of long term zero tillage on soil chemical properties: A review

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Abstract

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. While green revolution technologies implemented in the country during 1966-67 led to food protection, intensive cultivation, insufficient and imbalanced use of fertilisers, high yielding crop varieties, use of heavy machinery, excess tillage, etc., resulted in deterioration of soil health and quality and increased air, soil and water pollution for more than five decades. There is a great lack of a systematic approach to relating tillage practises 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.

Keywords: Zero tillage, conventional tillage, nutrients available, sustainable farming

Introduction

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 efficient use of water and nutrients can be encouraged by improved soil conditions. Long-term conservation tillage improves the status of soil organic carbon and modifies soil pore geometry that ultimately affects basic physical parameters such as bulk density, aggregate stability, capacity for water retention, etc., and the status of soil fertility. The effects of conservation tillage, however, are highly variable across climate, soil type and depth, cropping method, and vary widely with the system's adoption period. 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) ^[60], requiring an estimated 59-98 percent rise in food demand (Valin *et al.* 2014) ^[61], 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 a key factor in cycling plant nutrients and improving the chemical properties of the soil. Moreover, nowadays, due to industrialization and other anthropogenic activities, there is a growing concern about elevated concentrations of CO₂ in the atmosphere. Almost three times the carbon contained in vegetation is contained in the upper 30 cm soil layer (Powlson *et al.* 2012) ^[46], 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) [21]. 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) [21]. 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) [30]. Tillage activity, on the other hand, is synonymous with soil ploughing with some tools and implements to manage weeds and build a favourable soil tilth for proper seed germination, emergence of seedling, and plant establishment and development (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) [53]. 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 plants. Conservation tillage is now considered a promising alternative to conventional tillage practise (Teklu, 2011) [56]. Conservation tillage is a promising alternative to traditional tillage practise.

Impact of zero tillage on soil chemical properties

Soil pH and EC

One of the significant factors determining soil fertility is pH, which may, however, be highly influenced by cultivation and crop residue management. For plant growth and development, soil reaction shows a clear assembly with nutrient availability. Long-term zero tillage adoption results in surface soil acidification that further impacts the supply and distribution within the rhizosphere of other nutrients. A substantial reduction of pH observed on silt loam soil at the upper soil of 0-7.5 cm under zero tillage (Dick *et al.* 1986) [18]. Soil acidity with zero tillage was found in Kentucky due to decomposition of organic residues at the surface with subsequent leaching into mineral soil of the resulting organic acids (Blevins *et al.* 1977) [12]. Kumar and Yadav (2005) [33] reported a marginal decline in soil pH relative to the initial traditional tillage values. However, the major impact of tillage on soil pH in both loam sand and sandy loam soil was not observed by Singh and Singh (2001) [51]. Due to the increased water movement in the soil and improved soil aggregate growth, Chatterjee and Lal (2009) [16] observed lower electrical

conductivity of soil under the zero tillage method compared with traditional tillage. In traditional tillage practises, the rise in pH may be attributed to more organic matter oxidation due to intensive tillage, which causes more soil CO₂ evolution and thus increased surface and subsurface soil pH. Organic matter decomposition under traditional tillage has induced organic acid production and increased pH (Hulugalle and Weaver, 2005) [29]. Miyazawa *et al.* (1993) [39] reported that by returning crop residues to the land, soil can be protected from acidification. But under zero tillage, there are contradictory results regarding pH. Karlen *et al.* (1994) [31] and Dick *et al.* (1986) [18] reported that acidification was caused by zero tillage with a substantial reduction in pH. This reduction in EC under zero tillage may be due to leaching of salts due to increased movement of water and plant uptake (Chatterjee and Lal, 2009) [16].

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) [24]. 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) [13]. 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) [55]. The SOC level can be sustained or even increased by better farming management practises along with other added benefits in terms of better physical condition, fertility and soil water conservation (Stockmann *et al.* 2013) [54]. Tillage operations that are mainly conducted for the preparation of seed fields, weed control, introduction of residues, play a dominant role in reducing the level of SOC and altering the physical conditions of the soil (Victoria *et al.* 2012) [62]. 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 micro organisms (Al-Kaisi and Yin, 2005) [4]. It has been estimated that traditional tillage activities have removed about 75 percent of the SOC stock of native land (Lal *et al.* 2007) [36]. The SOC level of the soil can be increased by zero tillage, which is a mitigation choice for the level of CO₂ in the atmosphere. 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 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 zero tillage soil disturbance favoured the formation of macro-aggregates and covered the intra-aggregate SOC (Six *et al.* 2000a)^[52]

¹. Owing to slow decomposition, crop residue maintained on the soil surface increased the SOC amount (Guo *et al.* 2015)^[25]. Conservation agriculture had a beneficial impact on biological activities and/or physical structure development such as earthworm macro-aggregates, suggesting a special SOC dynamics (Brouder and Gomez-Macpherson, 2014)^[14]. 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)^[20]. With the period of conversion from traditional tillage to zero tillage, soil organic C was found to increase, especially in a few centimetres of surface soil (Hermle *et al.* 2008)^[27]. In shallow or zero tillage, an accumulation of organic matter near the soil surface is typically observed due to a decrease in ploughing depth (Moreno *et al.* 2006)^[40]. Even after years of traditional tillage, the implementation of zero tillage management led to a rise in SOC across the Great Plains in a wide range of soils and climates (Baker *et al.* 2007)^[8]. 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)^[20]. 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)^[59]. In zero and shallow-tilled plots compared to traditional tillage, Gosai *et al.* (2009)^[23] recorded greater organic matter content. 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)^[15]. Failure to increase SOC sequestration by zero tillage practises relative to traditional tillage systems was also stated (Ogle *et al.* 2005)^[41]. Zero tillage has increased surface SOC content in many fine-textured soils at the cost of SOC deposited within the rooting zone (Kay and VandenBygaart, 2002)^[32]. 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)^[38] found that, with larger aggregates and more soil organic carbon, zero tillage with residue cover had greater aggregate stability. By implementing zero tillage, higher soil organic carbon sequestration has also been observed (Panday *et al.* 2008)^[42]. 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)^[11]. Hooker *et al.* (2005)^[28] 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 moldboard ploughed treatments, only zero till combined with stover return to the soil resulted in an increase in SOC in the surface layer. Improved land and crop management methods have improved SOC relative to

traditional methods, such as decreased tillage (Andruschkewitsch *et al.* 2013)^[5]. 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)^[49]. Dong *et al.* (2009)^[19] 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 practises, improved crop management practises, such as zero tillage and straw mulch techniques, will increase the SOC and the SOC fractions (Andruschkewitsch *et al.* 2013)^[5]. Zotarelli *et al.* (2005)^[66] reported that by influencing soil aggregates and aggregate-associated C, soil disturbance showed major influences on SOC safety. Freixo *et al.* (2002)^[22] found that topsoil organic carbon of 0-5 cm decreased by 60 percent after 13 years of traditional tillage farming, whereas zero tillage conditions decreased 43 percent. Under zero tillage, soil organic C storage is always greater than traditional tillage due to residue accumulation at the soil surface (Piovanelli *et al.* 2006)^[45]. Soils administered with ZT change SOM, microbial species and nutrient availability and their roles (Thomas *et al.* 2007)^[58]. 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)^[34].

Available nutrients (N, P, K and micronutrients) in soil and their uptake by plants

Zero tillage plays a major role in the supply of nutrients and their uptake by plants. Nutrient availability near the soil surface was improved by the Zero tillage (Bhatt *et al.* 2016; Antil and Narwal, 2007)^[10, 6]. The addition of more organic matter in the form of crop residues, which is the main source of nitrogen and the presence of more microbes and microbial activities, has resulted in higher nitrogen availability under zero tillage. Alijani *et al.* (2012)^[3] stated that an increase in soil nitrogen was caused by reduced tillage. Conservation tillage activities such as zero tillage have increased the supply of nitrogen, according to Habtegebrial *et al.* (2007)^[26]. With deeper layers, the nitrogen available has decreased (Sharma *et al.* 2015)^[48]. In comparison to pearl millet, the N uptake was higher by 16.7 and 13.1 percent and P uptake by 22.2 and 16.5 percent when wheat was grown after cowpea and cluster bean, respectively. Compared to wheat grown after pearl millet alone, Balyan (1997)^[9] observed higher N uptake in wheat grown after legume crops either alone or as an intercrop during kharif. The amount of potassium content in maize was 0.26 and 0.26 Cmol / kg, respectively, for surface and zero tillage (Ali, 2018)^[2]. N and P uptake by wheat sown after cowpea and cluster bean was statistically at par with each other and significantly greater after pearl millet than that raised bed (Singh *et al.* 2003)^[50]. Parihar *et al.* (2018)^[43] stated that it could have improved soil fertility and improved crop growth, yield, and nutrient content by using legumes as the preceding crop. Recycling of nutrients from sub-surface to surface layers and enhanced nutrient availability in the rhizosphere of shallow rooted crops are caused by the rotation of deep-rooted legumes in the cropping systems. Due to the insertion of legumes into cropping systems, Aziz *et al.* (2015)^[7] and Parihar (2014)^[43] have also recorded increased nitrogen content. Das *et al.* (2014)^[17] published comparable findings. The higher availability of zero tillage phosphorus was due to the addition of more organic matter in the form of crop residues, which increased the availability of phosphorus

due to the release of organic acids during organic material decomposition. Alijani *et al.* (2012) ^[3] stated that soil phosphorus was increased by reduced tillage. Conservation tillage activities such as zero tillage have increased the availability of phosphorus, according to Habtegebrail *et al.* (2007) ^[26], Sharma *et al.* (2015) ^[48] and Kumar *et al.* (2012) ^[34] have reported the decrease in usable phosphorus with soil depth. Increased phosphorus content due to the insertion of legumes into cropping systems has also been documented by Aziz *et al.* (2015) ^[7]. Higher soil organic matter can be due to the rise in usable phosphorus under zero tillage practises. Under zero tillage activities, Kushwah *et al.* (2016) ^[35] observed greater usable phosphorus. Similar to the N and P available, greater potassium abundance under zero tillage was due to the addition of more organic matter in the form of potassium-sourced crop residues. Alijani *et al.* (2012) ^[3] stated that an increase in soil potassium was caused by reduced tillage. Under zero tillage activities, Kushwah *et al.* (2016) ^[35] and Roldan *et al.* (2003) ^[47] observed greater usable potassium. Higher soil organic matter can be due to the rise in usable potassium under zero tillage practises. Crop residue has had a beneficial impact on available soil potassium (Yadvinder-Singh and Sidhu, 2014) ^[65]. In the 0-40 cm soil layer with residue retention, Wei *et al.* (2015) noted an increase in usable potassium. Similarly, in the 0-15 cm soil layer under zero tillage and maize residue retention, Villamil and Nafziger (2015) ^[63] found significantly higher exchangeable potassium than traditional tillage and without residue in the continuous maize cropping system. With deeper layers, the potassium available has decreased (Sharma *et al.* 2015) ^[48]. The addition of more organic matter in the form of crop residues, which are the main source of Fe, Mn and Zn, resulted in higher availability of micronutrients (Fe, Mn and Zn) except for Cu under zero tillage. In contrast with traditional tillage, crop residues under zero tillage led to greater organic matter addition under zero tillage. Soil moisture was higher under zero tillage, which may be an explanation for the greater availability of these nutrients (Walters *et al.* 1992) ^[64]. With deeper layers, the nutrients available have decreased (Sharma *et al.* 2015; Kumar *et al.* 2012) ^[48, 34].

Conclusion

Finally, we concluded that long-term practises of zero tillage could boost the chemical properties of the soil and conserve soil resources for sustainable agriculture. 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 strategy is to improve soil quality by restoring SOC stock, improving the productivity of inputs for usage, narrowing the yield gap and implementing sustainable agroecosystem intensification systems. The 1960s Green Revolution improved food production, but due to intensive cultivation, heavy farm machinery, excessive irrigation usage, and indiscriminate use of fertilisers and pesticides, there were strong confrontational impacts on the climate, including depletion of SOC stock, increased risks of soil erosion and salinization degradation, and deterioration of physical properties of the soil. 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 chemical properties of the soil, 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.

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