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Review Paper

Role of Conservative Agriculture in the Sustainability of Soil Structure in Achieving Sustainable Management

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Abstract

Conservative agriculture is considered an alternative to tackle the need for increased agricultural production based on sustainable agriculture activities with the aim of increasing production and product stability along with preserving the environment. Tillage is one of the most important factors affecting soil structure. Appropriate tillage systems vary with local conditions, such as climate, soil type, type of plant residues, tensile strength, and so on. Understanding the components of the aggregate sustainability controller is very important for maintaining soil structure. This review paper discusses the role of tillage in aggregate stability and soil structure to reach conservative agriculture development. Considering the advantages of conservation tillage, it is better to use this kind of tillage for sustainable agriculture development. Based on the analysis of the available literature, it can be concluded that the conservation tillage also enhances soil structural stability through its positive effects on soil moisture and organic matter. Less soil disturbance, which is the characteristic of conservation tillage, has positive effects on soil properties and soil processes, which interact in a complex way, and they all together contribute to enhancing soil quality.

Keywords:
Aggregate stability; conservation tillage; conservative agriculture; soil characteristics

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INTRODUCTION

Sustainable agriculture

As a natural resource for the future of mankind, soils must be managed in a sustainable manner. Thus, to preserve agriculture for future generations, it is fundamental to develop production systems that conserve and enhance soil quality (Doran & Zeiss, 2000).

Farmers concerned about the environmental sustainability of their crop production systems and the ever-increasing production costs have begun to adopt and adapt improved system management. Practices, which have led to the ultimate vision of sustainable agriculture (Verhulst et al., 2010). To achieve sustainable agriculture in terms of production and environment, it is necessary to consider soil as the main production base. In fact, sustainable agriculture is a kind of agriculture that is in the interest of mankind, is more efficient in the use of resources, and should also be ecologically appropriate and economically justifiable (Celik, 2011).Tillage has been an integral component of crop production systems since the beginning of agriculture. The process of tilling or preparing the soil was greatly refined with the invention of the first plow by the Chinese in the sixth century B.C., and since then, various types of tillage equipment and systems have been developed for seedbed preparation and cultivation.

Conservative agriculture

Soil erosion reduces the potential fertility of farmlands by degrading and reducing the depth of surface soil. Nowadays, the introduction of agricultural equipment has enabled us to do soil tillage more readily, but this will destroy the soil structure and the amount of organic matter in the soil. Conservative agriculture (CA) is a type of farming that, in addition to product development, protects the environment and prevents the contamination of resources. CA can improve the physical properties of soil, especially the penetration and storage of water, porosity, and soil structure and can also reduce soil erosion and compaction, balance soil temperature, and ultimately improve yields.

CA has three main components: (i) no or minimum disturbance of soil by no or minimum tillage; (ii) permanent coating of soil surface by bio-residues; and (iii) proper crop rotation through diversity in annual products, using shallow products or appropriate plant species in perennial cropping systems (Indoria et al., 2017).

Conservative agriculture and tillage

Proper tillage improves soil structure and increases porosity. It can also lead to a better distribution of aggregate and the reduction of soil compaction (Speratti et al, 2015). The overall effect of tillage depends on soil type, soil moisture, type of tillage equipment, and the number of replications of tillage operations. The most important disadvantage of long-term tillage is the destruction of soil structure due to the reduction of soil organic matter and humus content (Jiang et al., 2011). So, sever tillage is one of the main factors in reducing the amount of organic matter in soils, which changes the health of the soil undesirably. Depending on soil softness, it affects many physical properties of soil such as bulk density, soil penetration resistance, penetration rate, storage capacity, soil moisture, air flow, and soil heat (Mohanty et al., 2007). In conventional tillage (CT), plant residues replace surface soil with deep plowing. The results are the reduction in soil porosity and the loss of organic matter. Regardless of maintaining soil sustainability, conventional tillage causes problems such as soil compaction due to the use of machinery and equipment, soil erosion due to the removal of plant residues, energy consumption, and high costs. The presence of crop residues increases the activity of various soil microorganisms that are effective in the formation of stable aggregates. It can also reduce compression and crusting on the surface and soil degradation. Generally, in CA, crop residues improve physical properties and reduce the negative effects of conventional tillage (Indoria et al., 2017). Because it reduces the impact of raindrops on soil particles, acts as an insulator for soil and thus reduces evaporation, reduces the effect of wind erosion, increases water productivity, and reduces surface runoff damage. Therefore, covering fields with crop residues in CA can improve productivity in the long run. The positive effect of the coverage of the crop residues in a region depends on the biophysical factors such as soil type, topography, intensity and amount of rainfall, wind speed, temperature, soil surface cover, and the dominant crop pattern (Indoria et al., 2017). According to the FAO definition, conservation tillage refers to "*a set of operations that put crop residues on the surface to increase water penetration and reduce erosion*" (FAO, 2007). Conservation tillage operations can be seen as a step towards CA and sustainable development agriculture. In contrast to the negative effects of the traditional method, the use of reduced tillage (RT) and no-tillage (NT) methods in conservation tillage has several advantages including reducing the movement of agricultural machinery, soil tillage, and amount of water consumed; saving fuel, energy consumption, and inputs; saving time; stabilizing moisture and temperature; reducing production costs; improving aggregate stability, soil organic matter, soil ventilation, water penetration, and field capacity; reducing water requirements and environmental pollution; the presence of plant residues in the surface layers; reducing bulk density and crusting; and controlling erosion (Mrabet, 2002; Indoria et al., 2017).

The effect of conservative agriculture on soil physical properties

Many research works have reported the impact of CA on the physical properties of soil. Most have reported the reduction of moisture and surface runoff of the soil, the increase in the penetration of soil water, and the decrease in the evaporation; while other desirable changes, such as improvement in soil structure, soil porosity and organic matter, occur over the long run (Indoria et al., 2017). CA reduces the effect of many restrictions related to the degradation of soil physical properties, such as soil compaction, soil destruction, soil crusting, and the reduction of soil organic matter. Some important physical parameters of soil affected by CA are described below.

a- Soil structure and aggregate

The evaluation of soil structure is often dependent on the measurement of the sustainability of its building blocks (aggregates). Aggregate stability creates interactions between the environment, management operations, and user patterns (Zhang et al., 2008) which is defined by such features as size, shape, empty space, pore connection, water retention capacity, organic and inorganic matters, and the ability to maintain plant's root (Verhulst et al., 2011). According to researchers, for a proper culture bed, the aggregate size should not be less than 0.5 mm and greater than 6 mm (Bronick & Lal, 2005). Aggregate stability is defined by using mean weight diameter (MWD) (dry and wet), geometric mean diameter (GMD), and water- stability aggregate (WSA%). Aggregate stability depends on soil texture (Bronick & La, 2005), soil biological activity (Oades, 2005), and the use of inputs. Tillage operation due to soil disturbance and the impact on the amount of organic matter and its distribution across the soil profile can be effective in aggregate stability and ultimately in MWD. Several studies have reported the effects of tillage on soil structural properties, especially the stability and distribution of aggregate size in different soils and climates (Curaqueo et al., 2011; Jemai et al., 2012). The difference in aggregate stability under different uses depends on human activities and cultivation operations (Zhang et al., 2008). In CA, aggregate stability often leads to the following: (i) maintaining organic residues on the soil surface, which reduces aggregate separation and degradation; (ii) organic matter decomposition increases the aggregate formation process; (iii) it does not increase soil fungi and microbes; (IV) increasing soil compaction makes the aggregate more resistant to changes (Indoria et al., 2017). Here, the effect of three CA bases on aggregate stability is investigated.

Effect of tillage

The type and severity of the effect of soil tillage method on soil physical quality depend on management type, usage time, tillage type, soil type, tillage depth, and climatic conditions of the area. NT operations and residues conservation improve the distribution of aggregates, keep water, and reduce erosion (Zuber et al., 2015). In a 9-15-year study of the sandy loam soil in Nigeria, the highest and lowest amounts of aggregate stability indicators were obtained in NT and CT operations by using the water-stability aggregate, respectively. The results show that NT and RT operations outperform CT operations in improving aggregate stability (Sauwa et al., 2013). The researchers noted that virgin soil had more stable aggregates than cultivated soils (Gajici et al., 2010). The effects of tillage on soil aggregates are: 1) Physical disruption of the soil structure resulting from tillage causes the aggregate to break down and increase the amount of aggregate change and decrease the stability. 2) Tillage causes the roots to crush; this is the main basis for the creation of fine aggregates. 3) Crop residues on the soil surface in CA protect against the effects of raindrops. 4) During the tillage, changes occur in the amount of soil organic matter, and these changes affect the stability of large aggregates (Verhulst et al., 2011). RT operation reduces the risk of soil erosion compared with deep plowing, improves the stability of aggregates, and maintains more soil moisture. Organic matter, plant residues, and non-manipulation of soil in NT compared with CT increase the stability of aggregates and improve soil quality, organic matter, aggregate stability, the amount of soil nutrients, and yield (Mrabet, 2002). Abdollahi & Munkholm (2013) studied soybean during a ten-year period and showed that NT operations increased the stability of small and large aggregates and the amount of organic matter in the soil in the long run. There was also a great correlation between the stability of aggregates and soil texture (AlKaisi et al., 2014). Pinheiro et al. (2004), in a series of studies on four no-tillage, plowing with plows, conventional tillage and barren land, concluded that aggregates larger than 2 mm were an appropriate index to study the effect of tillage type on the stability and consistency of the aggregates. In this study, there was a significant difference between MWD and GMD at depths of 0-5 and 5-10 cm. An investigation into the effects of different treatments of CT on a four-year wheat-maize system in Urmia showed that the highest crop yield was due to subsoiling operations (Tabiezad et al., 2017). The subsoiling operations and tillage with rotary had a significant effect on MWD. On the other hand, subsoiling operations and tillage with chisel had a significant effect on the WSA. Emadi et al. (2009) reported that although aggregates with a diameter of less than 0.5 mm were dominant in agricultural soils, MWD in the virgin soil was more than that in the agricultural soils with large aggregates (diameter greater than 1 mm). The results of Mousavi Booger et al. (2014)'s study on the effects of three tillage methods (no-till, min-till, and conventional-till) and three bread wheat cultivars assigned to the main and subplots, respectively showed that no-till was significantly different from the other two methods in aggregate particle size distribution along with increasing aggregate stability index such as mean weight diameter, geometrical mean of particle diameter, and water stable aggregate index. Sauwa et al. (2013) on the physical properties of sandy loam soil in Maiduguri, Nigeria after 9-15 years of management showed that NT and RT treatments have promoted the physical quality of the soil versus the CT treatment. They recommended that other reduced tillage systems such as animal traction and ridge tillage be tried to assess their efficacy in improving soil physical quality.

Balan et al. (2010) showed that tillage treatments had significant effects on water stable aggregates (WSA) and the distribution of soil aggregate size. For 0-10 cm WSA and the distribution of macro-aggregates (> 0.25 mm) were observed greater for conventional tillage than in other tillage treatments. Under this depth, the relative proportion of macro-aggregates was more in NT. Those two physical properties increased with the increase in soil depth and also from sowing time until wheat maturity. In general, both physical characteristics improved with increasing depth. It can be said that tillage without plowing can increase the water-stability aggregate (Brtoval & Badalikoca, 2011). Jiang et al. (2011) showed that CT tillage reduced the amount of aggregates whose diameters were greater than 2 mm. Investigations show that no-till practices seem to favor increasing aggregate stability and carbon stock accumulation in various dry aggregate. NT operations increased GMD and MWD at all three depths of 0-5, 15-5, and 30-15 cm in the one-year rotation period (Manasseh & Ya`u, 2014). A study by Brtoval & Badalikoca (2011) showed that in a 4-year wheat-maize rotation period, RT increased the water-stability aggregate (WSA) and crop yield. During the NT operation along with keeping residues, conventional tillage with a return of residues, and a shallow plow with rotary, aggregates with a size of greater than 2 mm were increased. Also, in the range of 25-0.25 mm, the MWD stability index and the SOC value in large and small aggregates were increased. The results showed that reducing soil disruption, increasing the return of residues, and combining these two methods could reduce erosion and increase the amount of organic carbon in the soil (Liu et al., 2015). A 2-year rotation period of wheat-maize in Zimbabwe with the NT operation increased aggregates with a size of larger than 2 mm and decreased aggregates with a size of smaller than 0.053 mm at depths of 0-5 cm and 5-20 cm and also increased SOC in aggregates with a size of larger than 0.25 mm at a depth of 0-5 cm (Zhang et al., 2016). In other words, the addition of residues to the soil increases SOC in soil volume and creates large aggregates (Ou et al., 2016).

Effect of crop residues

The management of crop residues plays an important role in the development and stability of soil structure. It has been proven that the addition of organic material to the soil not only causes aggregate formation but also reduces the fracture of the aggregate by reducing erosion and protecting from the effects of raindrops; so it can improve the structure (Indoria et al., 2017). Reversing and crushing the soil by repeating the plowing of plant residues, through accelerating the organic matter decomposition of the residues on the soil surface, can protect the soil from erosion, prevent runoff, and increase the rate of water penetration. As a result, the amount of evaporation from the soil surface and soil conditioning decreases (Nweke and Nabude, 2015). But, soil porosity stability increases the water holding capacity and concentration and amount of organic material in the upper layers and can increase the yield of the product in the long run. In NT operations, the high amount of crop residues added annually to the soil increases the process of forming stable aggregates and increasing soil organic matter in order to increase soil resistance and also resistance to pore changes. The high biological activity in CA also improves the state of soil organic matter through various microorganisms, which leads to the establishment of a sustainable soil system by increasing aggregate size and facilitating the growth of the plant's root to explore the soil specification. Denef et al. (2002) found that adding wheat (*Triticum aestivum* L.) residue in the laboratory to three soils differing in weathering status and clay mineralogy increased both unstable and stable macroaggregate formation in all three soils in the short run (42 days).

Effect of crop rotation

Crop rotation is required not only to provide a "diet" for soil microorganisms but also to explore soil layers in order to find nutrients that have been leached into deeper layers through leaching. Crops can recycle these nutrients in rotation. Also, rotation can disturb the life cycle of pest species, biological stabilization of nitrogen, and pollution control (Bhan & Behera, 2014). Plants can affect aggregates with their root systems indirectly because roots play an important role in controlling pathogens in large aggregates (Indoria et al., 2017). Soils under wheat cultivation have larger grain aggregates than maize cultivation (Lichter et al., 2008) because wheat's root system has a horizontal growth, plant density for wheat is higher than maize, so its root system is denser on the surface, and this dense network can affect the formation and stability of aggregates. Also, microbial biomass of soil and various bacteria can affect the formation of aggregates; these factors are also affected by crop rotation. In the 15-year period of NT operations and the preservation of crop residues, the distribution of dry aggregate particles has increased in comparison with CT (Govaerts, 2009).

Aggregate particle size and aggregate stability in conservation tillage under different types of soil and agro-environmental conditions increased versus CT (Li et al., 2007). Increasing the amount of aggregate particles and its stability in conservation tillage may be due to the presence of organic matter (root parts), which acts as a connecting agent for soil particles (Bronick & Lal, 2005). In Kasper et al. (2009)'s study on loam-sand soil, the least amount of aggregate stability (18.2% and 18.9%, respectively) was obtained by the CT systems, but RT operations showed the highest aggregate stability (36.7%). Brtoval & Badalikoca (2011) found that both minimum tillage and deep soil loosening showed a positive effect on the studied crop yields (above all maize and winter wheat).

b. Soil organic carbon (SOC)

Plant growth and its yield are affected by the stability of the soil structure, reducing the total porosity, distribution of pore size, and the amount of organic matter (Balan et al., 2010). Aggregate stability and soil structure are among the soil indicators directly related to soil organic matter (Bronick & Lal, 2005). Factors such as local climate, soil texture, humidity, and mineralogical profile of the area contribute to the relationship between aggregate and SOC (Stevenson et al., 2005). As defined, the objective of agricultural management is to reduce erosion and increase the amount of SOC (Nath and Lal, 2017). Reducing tillage improves the stability of aggregates, distributes the particle size optimally, contributes to better degradation of carbon and nitrogen, and decreases bulk density (Aziz et al., 2009; Kasper et al., 2009). Aggregate's changes influence directly and indirectly soil organic matter, bulk density, and soil porosity (Lobe et al., 2001).

There was a difference in organic matter content between plowed soils and virgin soil (Jiang et al., 2011). One of the causes of organic matter loss in plowed soils is the breaking of aggregates. Therefore, the degradation of soil organic matter increases and its amount decreases. Jin et al. (2011) found that the tillage operation significantly reduced the amount of fine aggregates (more than 2 mm); the aggregate stability in the CT method compared to NT showed a reduction of 35 percent. The highest SOC values were observed for aggregates of 1-0.25 mm (35.7 mg/kg and 30.4 mg/kg for NT and CT), respectively; while the lowest SOC values were obtained in fine aggregates (<0.025 mm) (19.5 mg/kg and 15.7 mg/kg for NT and CT, respectively). CT operations often degrade aggregates by directly or indirectly applying stress through reducing the organic carbon content of the soil. However, NT methods and conservation tillage with less soil manipulation and organic soil enhancement improve the stability of aggregates. Zhang et al. (2008), found that soil stability was higher in the cultivated land than in the dry land. Also, the amount of organic matter in soil was higher in the cultivated land than in the barren area. They also found a significant correlation between organic matter and aggregates. Mean weight diameter and geometric mean diameter were higher in the cultivated soils than in the barren area.

c. *Bulk density (Bd)*

Tillage is one of the most important operations in determining bulk density, porosity, hydraulic conductivity, water penetration, and moisture content whose measurements depend on soil state. The effects of soil tillage and residue management on soil density mainly depend on the soil surface (plowing layer). The short-term effects of tillage on Bd are not clear and there is no significant difference in Bd between NT and CT systems. It takes more than 15 years to achieve the desired effects of tillage. Li et al. (2007) showed that the control of the tillage in the NT system was effective in reducing the probable free space, and NT could reduce total porosity or increase Bd during long-term experiments. Systems that have more crop residues on the surface can reduce the amount of Bd and increase the total porosity compared to the systems with less crop residues (Brtoval & Badalikoca, 2011). As already mentioned, the effect of tillage decreases over time. CT systems increase Bd depending on the amount and intensity of soil manipulation during various soil operations in the long run. This reduces the amount of water and nutrients (Qin et al., 2007). In the CT method, irrigation and rainwater increase Bd commensurate with the amount and frequency of irrigation (Osunbitan et al., 2005). Golchin and Askari (2004) reported that Bd in soils plowed with a chisel was 4-25 percent higher than soils with no-tillage. Some researchers have reported that soil bd was higher in conservation tillage than in CT In contrast, other researchers have not shown significant differences (Rusu, 2009) or found lower Bd values in conservation tillage along with the maintenance of organic residues compared to CT (Aziz et al., 2009). Some have also stated that the CT tillage has higher NT than Bd (Rahimzadeh & Navid, 2010), but some have shown that Bd has the lowest values under NT conditions (Olaoye, 2002; Sekwakwa & Dikiny, 2012). Adding crop residues in conservation tillage plays an important role in reducing bulk density because organic residues are more degradable than minerals, and the resulting products can make more aggregates (Shaver, 2010).

Mousavi Boogar et al. (2012), who studied wheat, showed that soil tillage methods had a significant effect on Bd and soil porosity. At soil depth of 0-5 cm, the lowest Bd was related to CT treatment. By increasing the depth to 15-30 cm, Bd was increased; however, this increase was significantly lower in CT.

d. Electrical conductivity and capacity to maintain water

Conservation tillage plays an important role in improving soil moisture, especially during rainfall, due to the effect of mulch and crop residues on the soil surface (Ghosh et al., 2015). This reduces the evaporation rate and increases water penetration by decreasing surface runoff in uncultivated soils compared to soils with tillage operation (Dardanelli et al., 2004). In conservation tillage, more water is available in comparison with conventional tillage, especially in dry and semiarid weather conditions (Slawinski, 2015). The inconsistent results on the effect of increasing the hydraulic conductivity and capacity to maintain water may be due to the amount of soil disruption, the type of soil structure, the amount of water, the different periods of tillage, the amount of residues, the weather, the problem of measuring the hydraulic conductivity in the presence of residuals in NT operations, and the amount of mulch and local features (such as soil texture and ground gradient). Shaxson & Barber (2003) concluded that increasing conservation tillage with higher porosity led to an increase in water penetration and the reduction of surface runoff. Therefore, the moisture content of the plant increased. Although in many studies a higher hydraulic conductivity in NT was observed compared to CT, water retention capacity was increased with increasing soil organic matter content (Indoria et al., 2017). Studies have also shown that different methods of tillage do not change the hydraulic conductivity, but in some studies, its effect was negative (Celik, 2011). In some studies, an increased fungal activity and organic matter stored in the soil due to the preservation of crop residues have increased hydraulic conductivity (Indoria et al., 2017). One of the ways to reduce soil erosion is increasing soil permeability by using appropriate tillage patterns. In a study on an 11-year rotation, Jin et al. (2011) reported that soil moisture storage at a depth of 0-30 cm for wheat in no-tillage conditions was improved by 19.3 percent compared to traditional operations. If conservative measures, such as minimum tillage, crop rotation, and conservation of crop residues, act as a hybrid system, they can reduce soil degradation and crusting, thereby increasing the penetration and water retention capacity in the soil. Despite the inconsistent results of the effects of tillage and the management of crop residues on the hydraulic conductivity of the soil, penetrance in NT with plant residuals, compared to CT and NT without any residue, is high. The reason is the effect of residue covering on water penetration. So, NT prolonged operation increases the penetration of water and decreases runoff (Lenka & Lal, 2013).

CONCLUSION

Soil stability is one of the most important factors in choosing a soil tillage system. According to the previous results, it can be concluded that different tillage methods have significantly different effects on the stability of soil structure. Improper soil tillage results in the degradation of soil physical properties. Conservation tillage can bring agronomy to ecological agriculture and sustainable development. Considering the benefits of conservation tillage systems such as reducing evaporation, soil conservation, increasing organic materials, improving soil structure, adjusting temperature, it is recommended to use this method as a good alternative to conventional tillage. In general, conservation agriculture improves the stability of aggregates compared to conventional tillage. Studies have shown the beneficial effects of conservative agriculture on the physical, chemical and hydrological properties of soil. The combination of no-tillage operations with the preservation of plant residuals increases the organic carbon content of the soil. Tillage operations and management of crop residues have an important effect on the size distribution of aggregates. Achieving increased performance, permanent production, and reducing environmental hazards require operational management that increases soil quality in combination with crop rotation.

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