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Influence of Conservation Tillage on Carbon Sequestration Mechanism Related to Aggregation

M. N. Amin[1*], S. C. Shil[1], R. C. Ghosh[2] and M. Shamsuzzoha[2]

[1]Department of Environmental Science, [2]Department of Emergency Management,
Patuakhali Science and Technology University, Dumki, Patuakhali-8602
[*]Corresponding author: namines@pstu.ac.bd

Abstract

This study focuses on the influence of conservation tillage on carbon sequestration mechanism related to aggregation. Conservation tillage reduces the process of rapid microaggregates formation and mineralization into the microaggregates essentially a positive influence of soil aggregation on the build up of organic matter. The Carbon mineralization is four or five times higher in crushed free micro aggregates than in crushed macroaggregates. As a result conservation agriculture ensures higher carbon sequestration in soil rather than the conventional agriculture. However, the carbon sequestration for different tillage has significant variations at 1-10 cm depth but the variations in non significant for higher depth. The carbon sink potential for conservation agriculture is much higher but it differs due to climate, soil type, nutrient use soil cover and the methodology used.

Key words: Carbon sequestration, Conservation tillage, Microaggregates, Soil aggregation

Introduction

Conservation agriculture is a concept of resource efficient agricultural crop production based on an integrated management of soil, water and biological resources combined with judicious use of external inputs. In general, conservation agriculture (CA) is based on three principles which are considered as the means of enhancing biological processes in the agriculture. These include the minimum or no mechanical soil disturbance, permanent soil cover with dead mulch of crop residues or growing crops and diversified crop rotations (Giller *et al*., 2009). Carbon sequestration is the process of sequestering the carbon into the soil reservoir (Hutchinson *et al.*, 2007). As a result, the influence of conservation tillage on carbon sequestration has been of great interest as agriculture has converted the soil from sink to a net source of CO_2 (Lal, 2008). Moreover, carbon sink capacity of the world agriculture and degraded soil is 50-60% of world historic carbon loss of 40-70 GT (Lal, 2004a).

Cropping has lead to a decrease in soil organic carbon with changes of carbon to the atmosphere during the last two century. Soil organic carbon is a dynamic pool determined by the processes of C input and losses. Promotion of this process mostly depends on the combination of input and output relationships (Zibilske, 2002). Reduced tillage or no tillage brought on by conservation agriculture affects several aspects of the soil including soil quality and organic carbon storage. Clay content, cropping history, soil fertility and crop diversity influence the changes of physical and chemical properties of soil (Zibilske, 2002).

Lot of literature discusses the carbon sequestration potential of conservation agriculture especially in particular environmental situations which enhance the process of climate change mitigation and adaptations through reducing no tillage/ reduce tillage. So considering these factors this paper analyses the influence of conservation tillage on carbon sequestration in terms of climate change mitigation.

This study mainly focuses on the no tillage/reduces tillage principles of the conservation agriculture to find out how this management practice affects the carbon sequestration potential of the soil. Therefore, this study emphasized on whether the conservation agriculture has the most potential to create carbon offsets in agriculture through reduced tillage in comparison with conventional tillage. The objectives of this study were to know how the conservation tillage does affects the carbon sequestration mechanism of soil aggregation and what are the differences of carbon sequestration between conventional tillage and conservation tillage system.

Methodology

This study was conducted fully based on literature review. A detailed literature review has been performed to find out the answers of the research questions. This review focused on the conservation tillage effect on mechanism of carbon sequestration related to soil aggregation and the differences of carbon sequestration between conservation and conventional tillage systems. The literature was collected from different national and international scientific journals, reports and different websites.

Carbon sequestration mechanism of conservation tillage

The structural ability of the soil is an important aspect of Carbon (C) dynamics to stabilize soil organic carbon. In fact, stabilization of soil organic carbon (SOC) occurs via sorption to minerals and organic soil surface, occlusion within aggregates and by the depositions in pores and other locations inaccessible to decomposers (Six *et al*., 2000). Furthermore, one of the potential means of enhancing carbon sequestration is to increase the activities of fungi through the means of favourable physicochemical environment to fungi which is enhanced by no tillage (Six *et al*., 2002).

Soil aggregation and carbon sequestration

Six *et al*. (2002) suggests that, a positive influence of aggregation on the build up of soil organic matter. He also addressed that, inclusion of soil organic matter within soil aggregates reduces the decomposition rate. Therefore, increase in aggregate formation/stability means increase in organic carbon. It has been found in conservation tillage whereas conventional tillage has been found to get C rich macro aggregates and gain more of C depleted micro aggregates (Six *et al.*, 2002). Golchin *et al.* (1994) reported significant differences in the chemical structure between the free and within aggregates light fraction. The light fraction is the material that floats on the top of dense salt solution. The light fraction is considered to be materials rich in plant nutrients, relatively large in size compared to other organic matter components and insoluble in water.

The idea for the light fraction was that a more intense disrupt of soil exerts a greater amount of light fraction which might be entrapped within aggregates and tested by increasing the agitation time of a sample. The aggregated light fraction had higher C concentration then the free one. Furthermore, it resembles that no till aggregate contained more alkyl C (i.e. long chain of C compounds such as fatty acid, lipid cutin acid, protein and peptide) and less O-alkyl C (e.g. Carbohydrates and polysaccharides) (Golchin *et al.*, 1994). This data suggested that there is a preservation of long chain alkyl C and selective decomposition for easily decomposable carbohydrates in this intra aggregate which forms due to the physical protection into the macro aggregates at the earlier stage of life cycle. Six *et al*. (2002) stated that cultivation leads to faster mineralization of soil organic carbon and preferential loss of alkyl C due to the disruption of aggregates. Hence the conservation tillage enhances the protection of soil organic matter (SOM) through the aggregates better than the disrupted soil of conventional tillage.

Six el al. (2000) developed a conceptual model that explains the differences in C- sequestration between no-tillage and conventional tillage. The fresh plant residues induce the formation of macro aggregates entering the soil as it is a C source for microbial activity and the production of microbial derived binding agent. If the residue input is same for both no tillage and conventional tillage then the micro aggregate formation for both systems would be similar. They also addressed that the proportion of crop- newer C (Crop derived C) relative to older C (native grassland) is similar in non tillage and conventional tillage macroaggregates which conforming the similar rate of macroaggregates formation in both systems.

The ratio of course particulate organic matter vs. fine organic matter is higher in conservation tillage than in the conventional tillage system resembling the decomposition rate of organic matter which is lower in conservation tillage. The formation process of fine intra aggregated particulate matter is slow in conservation tillage system which enhance the process of sequestering the carbon into the soil. The model suggests that, the increase in macro aggregate turnover induced by tillage, reflects less accumulation of crop- derived C in free micro aggregates, which represents the differences of carbon sequestration potential between conventional and conservation tillage. In the conceptual model it has been proved that, conventional tillage shortcuts the life cycles of macro aggregates as well as reduces the formation of more stable micro aggregates inside the macro aggregates (Six *et al.,* 2000).

Moreover, tillage diminishes the formation of new micro aggregates and the sequestration of carbon within the soil as a whole (Six *et al.,* 2000). The differences of carbon sequestration between no tillage and conventional tillage systems depend on different C decomposition rates. On an average the mean residence time is 1.5 times larger under no tillage than under conventional tillage (Six *el al.,* 2002). Conventional tillage is harmful to soil structure by continuously revealing new soil to wet-dry and freeze-melt cycle at the surface. Increased aggregation under reduced tillage is not the only function to make the physical disturbance due to plowing. Fauna and microbial biomass is exclusively higher under reduce tillage or non tillage. Eventually, this results in the formation of more binding agent like extracellular polysaccharides. In addition, the development of hyphal networks, catching the particles and favouring the aggregate stability in non tillage system (Six *el al.*, 2002).

Biota and soil carbon dynamics

Soil structure is complex network inhabit by millions of organisms each conducting specific function relative to soil aggregation, SOC distribution and protection. Micro aggregates develop in the high microbial active area and production of humic substances is a prominent feature of that particular zone. Micro aggregates provide habitat for the microbes as well as soil biota are responsible for stabilization and turnover of SOC in aggregates (Blanco-Canqui and Lal, 2004). Interactions of SOC with aggregates are attributed by the soil biota like fungi, bacteria, earth worms etc. These organisms control the decomposition along with the transformation and sequestration of carbon into the soil. However, the scale at which the soil organism act depends on the species group. For example, earthworms and termites are associated to form and stabilize macro aggregates whereas the fungi and bacteria commonly form micro aggregates. In particular earthworms form macro aggregates which are richer SOC, therefore it impacts the micro aggregates by mixing the soil with SOC and enhance the SOC accumulation in cast (Blanco-Canqui and Lal, 2004). On the other hand, fungal hyphe stabilizes the macroaggregates by forming a mat type mesh of network of hyphe inside the aggregates and also bind the organic particles into the aggregates (Blanco-Canqui and Lal, 2004). However, tillage hinder both the earth worm and the fungal hype, as a result the carbon sequestration potential is reduced through reducing stable aggregation formed by this two. It is generally well known that microbial biomass and earth worm abundance is higher under no tillage system than under conventional tillage (Six *et al.,* 2002). Furthermore, No tillage (NT) also favours the fungal over bacterial population and the preferential stabilization of this community can lead to more efficient C and N cycling.

Composition of plant residue and aggregates

Blanco-Canqui and Lal (2004) stated that, soils under no tillage have higher C and N concentrations than the soil under conventional tillage. According to Wright and Hons 2004 no tillage improve sequestration of both SOC and organic N in macroaggregates compared to conventional tillage as no tillage has lower C: N ratio. In fact, rapidly decomposing residues enhance the formation of aggregates although its action is transient. On the other hand, slowly decomposing residues have a gradual impact on aggregation and their long term effect on organic carbon sequestration is higher than rapidly decomposing residues.

Conservation tillage and climate change mitigation

The mechanism discussed above clarifies the idea of carbon sequestration potential of conservation tillage against conventional tillage. Next to this conservation tillage has the potential to increase the carbon sequestration in the soil. The following discussion may solicit the detail of it.

Conventional tillage and erosion deplete SOC pools in agricultural soils. In opposition, conservation tillage by reducing soil disturbance, decreasing the fallow period, adding cover crop in the rotation cycle can store carbon. The benefit of no till on SOC sequestration may be soil/site specific and improvement of the carbon sequestration may be inconsistent in fine textured and poorly drained soil. Fine textured soil means less aggregated soil, and in poorly drained soil anaerobic decomposition is high (Lal, 2004b). Moreover, it is estimated that adoption of conservation tillage has the potential to sequester about 23 Tg Cyr^{-1} in the European union which is about 43 Tg Cyr^{-1}in the wider Europe including the former soviet union (smith *et al.,* 1998). Additionally, to enhance SOC pool up to 3.2 Tg Cyr^{-1}may also be saved in agricultural fossil fuel emission. Smith *et al.* (1998) also remarked that 100% conversion of no till agriculture could mitigate all fossil fuel emission from agriculture in Europe.

Lal (2004b) addressed the rate of SOC sequestration on agricultural cropland ranges from 0.02 to 0.76 Mg $Cha^{-1}Yr^{-1}$ for using improved system of crop management and it is 0.1 to 1.3 Mg $cha^{-1}Yr^{-1}$ by converting from conventional till to no till, but 0.25 to 0.5 Mg $Cha^{-1}Yr^{-1}$ for rice land management. In addition, it is assessed that a range of options for C mitigation in European agricultural soils is 56 Tg Cyr^{-1} . It is also reviewed that the potential of world cropland soils to sequester C at the rate of 0.4-0.6 Pg CYr^{-1} (Smith *et al.*, 1998; Lal, 2008). The estimation of the realistic potential for C mitigation in UK on agriculture is 10.4 Tg Cyr^{-1}, which is about 6.6% of 1990 U.K. CO_2-C emissions (Lal, 2004b). As Carbon sequestration affected by soil management and with a change from conventional tillage to no tillage it could be 300 to 600 kg $Cha^{-1}Yr^{-1}$, in the US Great plains where as 100 t0 500kg $Cha^{-1}Yr^{-1}$ in the Canadian prairie region (West and Marland, 2002). Moreover, based on the crop inputs, NT emitted less C from agricultural practices than the conventional tillage do, and it is 137 and 168 Kg $Cha^{-1}Yr^{-1}$ respectively. Therefore, changing from conventional tillage to conservation tillage enhance the C sequestration and decrease the CO_2 emission where the enhanced carbon sequestration will continue for a specific period of time but the reduction of net CO_2 will fluxes to the atmosphere caused by the reduced fuel use continue as long as the practice persist (West and Marland, 2002).

It is found that for years under this non tillage mechanisms enhance the stock of SOC in both temperate and tropical region. In fact, the carbon sequestration of C in the 0-10 cm layer of tropical soil is two times higher than temperate soil which is 0.43 versus 0.16 Mg Cha^{-1} (Six *et al.,* 2002). However, the data considered here for the tropics is 20 to 22 years old experiment and also the surface layer is considered where the plowing depth in usually 15-25 cm. In addition Six *et al.* (2002) also stated the same SOC storage potential depth for both tropical and temperate region within 0 to 30 cm depth which is 325 ± 113 Kg $Cha^{-1}Yr^{-1}$.

Deen and Kataki (2003) experiment shows that the storage of SOC was compared for zero tillage (ZT) versus spring tillage versus fall tillage operation. The results revealed that the SOC storage on a soil depth basis was significantly higher ($P<0.05$) for zero tillage over both the spring and fall tillage operation at 0-5 cm and 0-10 cm depth. On the other hand it significantly lowers in ZT compared to spring tillage at 0-40cm depth. Moreover, spring tillage results higher storage of SOC compared to fall tillage at 0-60 cm depth. However, the other analysis on soil depth basis remains insignificant.

Likewise, comparison of zero tillage (ZT) versus mouldboard versus chisel tillage practices showed that, the zero tillage has the significant higher SOC storage on a soil depth 0 to 5 cm over mouldboard and chisel tillage operations and similarity at 0-10 cm depth. At 0-40 and 0-60 cm depth mouldboard had a significantly higher storage over Chisel tillage. Finally, they conclude that CA in terms of conservation tillage has high carbon sequestration potential but it is only true for the surface layer not for the entire soil layer in comparison with conventional Agriculture (Deen and Kataki, 2003).

West and Postma (2002) concluded form a global database of 67 experiments on the SOC levels under zero tillage vs. conventional tillage that the SOC levels is significantly different whereas it is not significantly different in reduced vs. conventional tillage. The same report also showed that a move from conventional to zero tillage (both with residue retention) can sequester on an average 48±13 gm $cm^{-2}Yr^{-1}$. Averaging out 161 experiments West and Postma (2002) also addressed the SOC difference under zero tillage and reduce tillage over ploughing and there was an increase of 2.1 t Cha^{-1}.

Lal (2004a) reported that the potential of SOC sequestration in the agricultural soil estimated at 4961 Mha and this soil have lost a significant part of their original SOC pool. However, it has the capacity of restoring carbon by changing the land management practices. CA has the potential to reduce 30-35 kg Cha^{-1} per season in terms of chemical input as it use soil coverage with crop residues. Moreover, other option for SOC sequestration is the residue used as nutrient rather than fossil fuel, and erosion control (Lal, 2004a).

Discussion

The first problem of working with this carbon sequestration due to conservation tillage is full of substantive uncertainty. Lots of controversial but fully scientific ideas by different authors increases this type of uncertainty (Deen and Kataki, 2003; Wright and Hons, 2004; Lal, 2004b; Hutchinson *et al*., 2007). Moreover, the difference of methodological approach may cause the differences in carbon sequestration calculations. However, the most of the studies shows high carbon sequestration potential for conservation tillage. The mechanisms of carbon sequestration are also depending on the climate, soil type, crop cover, nutrient use etc which may also cause the difference (Deen and Kataki, 2003; Wright and Hons, 2004; Hutchinson *et al*., 2007). In addition, most of the study discuss about soil carbon sequestration not only on the basis of low tillage but also with other factors like residue incorporation, covering etc (Wright and Hons, 2004; West and Marland, 2002). Interestingly, there are studies showing lower carbon sequestration in non tillage (Deen and Kataki, 2003). On the other hand, most of the study showing carbon sequestration in the upper surface layer (0-10 cm) for conservation tillage but below this depth the case is different. For many of the studies the general depth for conventional agriculture is 0-30 cm (Deen and Kataki, 2003). In terms of climate change mitigation, the conservation agriculture has the potential to sequester the carbon into the soil but the CO_2 emission from the agriculture is not significant for global warming (IPCC, 2007). Again some of the studies also show that Green house gas like N_2O is higher in no till system (Lal, 2004b).

The main limitation of this study is, it only consider the carbon sequestration and no till/conservation tillage which is not enough to get the conclusion for soil carbon sequestration potential induced by the conservation agriculture. It may also related with other principles (such as mulching, residue incorporations etc. of it. Nevertheless carbon sequestration by conservation agriculture may be interesting and it may enhance the process of carbon storage but the concern lies in the conversion of conservation agriculture to conventional which may have the chance of emitting the stored carbon by regular tillage.

In spite of all these limitations this paper may serve as a very good conception of carbon sequestration potential through conservation agriculture. It may contribute to further guideline for eliminating the controversy in this field.

Conclusions

Conservation agriculture has the most potential than the conventional tillage to create carbon offsets in agriculture through reduced tillage but it is only true for the surface layer up to (0-10 cm). The difference between conventional and conservation tillage in terms of carbon sequestration is very much evident by the most of the reviews. Aggregation depending on soil minerals less dependent on soil management eventually occurs in the tropics. On the other hand, aggregation is more dependent on SOM and determined by the management which is tropic soil character. Therefore, carbon sequestration potential cannot be express in detail on the world perspective exclusively on the basis of tillage management. Yet the carbon sink potential for the agricultural soil in terms of conservation tillage is much higher. Nonetheless it differs due to the soil type, climate and also for using the right methodology.

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