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Research article

Soil Carbon Sequestration and Climate Change Mitigation: A Review

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Abstract
Climatic variability affect soil ecosystem in so many ways such as increase in rainfall and temperature which determine the rate of soil microbial decomposition of organic materials and influence various activities in soil ecosystem which affect the amount of soil organic carbon (SOC) because SOC is vital for soil quality enhancements such as microbial diversity, population and soil fertility. Soil ecosystem serve as a sink and source of carbon depend on the management strategies employed in the area. This paper consist of systematic collections, review and synthesizing the relevant data on the subject matter. The data collected was evaluated and presented in systematic and logical way. The findings revealed that sustainable soil management such as zero tillage, use of organic manure, mulching and planting cover crops would manage and minimizing the release of soil C to the atmosphere. Sustainable soil management practices served as mitigation measures which include zero tillage, use of organic manure, mulching and planting cover crops served as mitigation measures to climate related risk. Soil management reduce climatic effect through SOC sequestration by reducing emission of CO_2 and other GHGs. However, soil degradation through practices such as deforestation, excessive use of pesticides and fertilizers, mono-cropping, erosion and maximum tillage need to be avoided, therefore, Conversion to a restorative land use and adoption of sustainable management practices were recommended since they create positive C and nutrient budgets, restore soil quality and enhance SOC pool.

Keyword: Soil Carbon, Green House Gas, SOC, Climate change, Mitigation

INTRODUCTION

The global climatic variability is due to the consequences of the increase in global mean temperature and atmospheric carbondioxide, Intergovernmental Panel for Climate Change (IPCC, 2007). Soil management practices through agricultural activities such as zero tillage, reduced use of inorganic fertilize, and use of organic manure have potential to mitigate the greenhouse emission from the soil. Soil organic carbon (SOC) stocks are affected by the balance between total amount withdrawn from atmosphere as net carbon (C) input to the soil and total amount of C released to the atmosphere in the form of CO_2 (Rojas *et al*., 2013). The top layer of the soil retained the largest carbon pool (1500 Pg C) in the terrestrial ecosystem which is about trice C in the amount of C in vegetation and twice the amount of C in in the atmosphere (Lal, 2004a; Batjes, 1996).

Soil organic carbon and carbon sequestration builds soil fertility improves soil quality, agricultural productivity protect soil from compaction and nurture soil biodiversity, however, it has major roles in mitigating C emissions and tackling the effects of climate change (Kumar and Babalad, 2018). The global soil carbon pool is 2500 gigaton (Gt) which is comprised of soil inorganic C (950 Gt) and soil organic carbon (1550 Gt), therefore the top one meter depth of soil contains 30 tons ha^{-1} in arid climate and 800 tons ha^{-1} in cold region (Lal, 2015). Lal (2008) reported that, conversion of some land use (like Plantation and forestry) to cultivation land use led to the depletion of the SOC pool by as much as 60% in the soil of temperate region and 75% in cultivated soil of the tropics. The diminution of SOC is exacerbated when the soil degradation is higher and when the output of C is higher than C input (Lal, 2008). Soil represent the largest C reservoir in the terrestrial environment, with about 11% of SOC held in forest soil globally (Negi *et al*., 2013).

The Earth's topsoil contain more than three times the amount of carbon in the atmosphere which is approximately 2,500 gigatons (Gt) and also four times of carbon stored in plant and animal.

However, some unsustainable soil management practice such as maximum tillage, deforestation, erosion and ploughing have damaged the topsoil, causing it to emit huge amounts of C into the atmosphere which contribute to climate change. It is worth noting that a recent study such as Kumar *et al*. (2017); Negi *et al.* (2013) found that the world's cultivated soils have lost more than half of their original carbon stocks. Fortunately, practices such as composting, carefully planned grazing, increasing plant diversity and keeping soils covered with vegetation can not only help to remove carbon dioxide from the atmosphere and put it back in the soil, but also promote soil quality.

Plants absorb CO_2 from the atmosphere through photosynthesis during this process, plants use solar radiation and water to turn carbon into roots, stems, leaves and seeds (Kumar *et al*., 2017). The plants releases some CO_2 into the atmosphere and secrete some carbon through their roots to feed some soil microbes such as bacteria, nematodes, protozoa and fungi (Werner *et al*., 2009). The dead organisms (plant and animals) decomposed by soil microbes through breaking down the dead organisms' carbon compounds (biomass decomposition) and release some carbon into the atmosphere. Soil microbes also have significant role in mineralizing of organic matter, biogenic element circulation which make nutrient element available to plant, biodegradation of impurities and maintaining soil stability and structure (Furtak and Maria 2017). Protecting soil microbes via sustainable soil management practices would enhanced the soil's potential to mitigate soil carbon emission.

The amount of soils carbon varies from one location to another, one soil type to another and it generally depends on land use type, such as the cultivation, rangeland and afforestation, and soil management practices, such as the use of crop biomass, deforestation and zero tillage. These soil management practices also determine the amount and time within which soil carbon retain in the soil. Because nearly half of the arable land in the world has been converted to rangelands, pastures and croplands. The world's soil lost about 50 – 70% of their initial carbon content which is nearly 25% global anthropogenic greenhouse gas emission. Global climate change may significantly affect the potential of soil organic carbon (SOC) storage and soil capacity to mitigate the greenhouse gas emission. High organic matter decomposition and fluctuation of Net Primary Productivity (NPP) are related to the increase in the concentration of CO_2 and increase in temperature. Increase in soil temperature induces the SOC emission to the atmosphere (Lal, 1999). High activities of soil microbes (microbial respiration, decomposition and enzymatic activities) in soil with high temperature (Mohammed, 2017). The objectives of the paper is to critically collect, analysed and synthesis the basic concept of soil carbon sequestration and its role played in mitigation climate change impact in the environment.

Soil Process and Climate Change

Soils have been a major source of C and other GHGs, the magnitude of CO_2-C emission from soil to atmosphere since industrial revolution is estimated at 78 ± 12 Pg (Lal, 1999). Most soil under agricultural land use contain lower SOC pool than their counterpart under undisturbed environment because of the lower amount of biomass and detritus materials returned, leaching losses of the dissolved organic carbon from surface to subsurface soil beyond the root zone, high decomposition rate attributed to change in soil temperature and moisture regime and severe losses by accelerated wind and water erosion (Singh *et al*., 2011). Most crops land soils have lost 25 – 75% of their original SOC pool, however, the loss of SOC pool is more from soils of the tropics than temperate climate (Bell *et al*., 2007).

The magnitude of SOC pool and rate of organic materials decomposition depend on the rainfall, temperature and soil microbial diversity and population. However, the projected global warming may decrease the global C pool due to possible heat stress which may affect the activity of soil microbes (Bell, 1999). Soil health is considered as the capacity of a soil to function, within land use and ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health. These were established through the interactions of soil's physical, chemical and biological properties, therefore sustainable soil health is very important strategy for mitigating climate change (Allen *et al*., 2011; Baethgen, 2010). Good soil health can moderate climate disruption through: sequestering CO_2 and oxidation of methane (CH_4) and reducing emission of CO_2 and other GHGs. The rate of soil C sequestration differs widely among soils, management practices and eco-regions. The SOC concentration also improves adaptation to climate change by increasing soil health and buffering capacity. Increase of the SOC concentration beyond the critical range enhance the soil quality (Singh *et al.,* 2011).

Climatic variability will likely affects the oil ecosystem in so many ways such as increase in rainfall and temperature form determine the rate of soil microbial decomposition of organic materials which influence the various activities in soil ecosystem and affect the amount of SOC. This is because SOC influences some important soil quality indicators such as microbial diversity and population and soil fertility. This is adduced by Mohammed (2017) who discovered that high mean values of microbial biomass carbon where temperatures are found to be high, which implies that microbial biomass carbon influenced markedly by soil temperature changes. This is further explained by Brady and Weil (2000) that soil microbial activities virtually ceases below 5ºC and increase more than double for every 10ºC rise in temperature up to an optimum of about 35ºC to 40ºC. Lal (2004) also shows that surface soil (top soil, 5 – 20 cm deep) led to the release 9 – 12% more C than normal because at first meter, soil stores about 1420 Gg of C, while the above to below ground vegetation and dead organic matter store about 460 Pg of C. However at sub surface (100 cm deep) led to release as much as 37% more C than normal when they experience 4ºC temperature increase.

Soil as a Source and Sink of Carbon

The CO_2 is by far largest source of radioactive force in the atmosphere, responsible for >50% of the greenhouse warming that has occurred for decade. Most of this, is from fossil fuel use, but a substantial portion is from the net release of CO_2 from soil when forests and grasslands are first dried for agriculture. Soil C sink capacity of the world's agricultural and degraded soils is 50 – 66% of the historic carbon loss of 42 – 78 Gt of C. The rate of soil organic C sequestration with adoption of recommended technologies depends on soil texture, structure, rainfall, temperature, and soil management (Lal, 2004b). Soil serve as source and sink for C and therefore regarded as double-edged when it comes to C fluxes. The anthropogenic impacts on soil can make it into a net source of C and at the same time a net sink. Considering soil as a source of C, the soil emit C in to the atmosphere in form of carbon dioxide (CO_2) where they trap thermal radiation that increase the C effect and contributes to global warming. The CO_2, CH_4 and nitrous oxide (N_2O) emitted by soils in which their emission are increasingly anthropogenically driven, largely from livestock facilities and soil agricultural practices (IPCC, 2007).

The net carbon storage in soils results from changes in C inputs, changes in decomposition rates, or both. The rate at which these materials decomposes largely determines whether soil C will accumulate. If more organic carbon enters the soil pool than can be readily oxidized by microbes and other soil organisms, soil C stores will increase and the soil will become a net sink of CO_2. If biomass that enters the soil is readily decomposed, then there will be no net change in C store. If decomposers oxidize soil organic matter faster than it is replaced by new biomass, then C stores will declined (Lal, 2004c).

Soils Potential To Mitigate Carbon Emission

The principal sink of SOC consist of uptake by the ocean (2.2 Pg C/year), atmosphere (3.3 Pg C/year), vegetation (1.5 Pg C/year) and soil (2.6 Pg C/year), this indicates that, soil is the largest C sink among the terrestrial ecosystem (Fig. 1). The concentration of C in the atmosphere has increased from 280 ppm in pre-industrial era to 385 ppm in 2009 (Lal, 2004c) and is currently increasing at the rate of 2 ppm/year World Meteorological Organization (WMO, 2008).

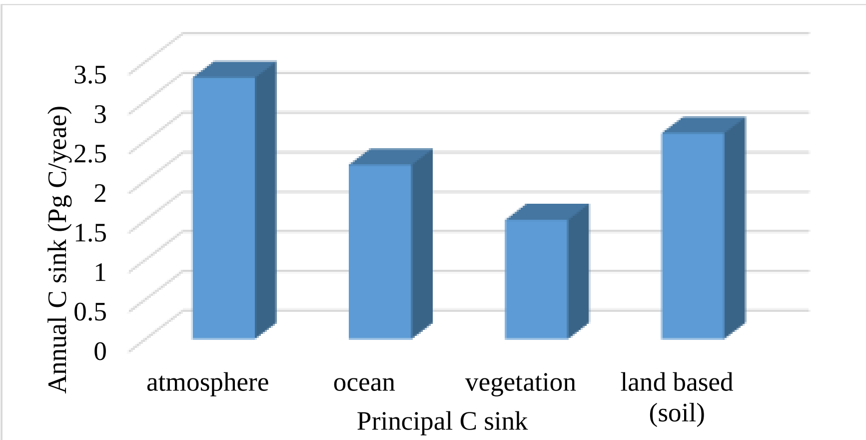

Figure 1. Principals C sink and their rate. Adopted and modified from Lal (2004a)

Due to the increase in some greenhouse gas (GHG), the mean Earth's temperature has already increase by 0.6 ± 0.2ºC and is projected to increase by 2 – 4ºC toward the end of the 21st Century under business as usual Intergovernmental Panel on Climate Change (IPCC, 2007). The primary way to mitigate C in the soil is to add organic soil amendment such as compost or animal manure (Lal, 2004a). Climate smart soil management practices which is defined by Food and Agricultural Organization (FAO, 2010) as the sustainable soil management practices that increases productivity, resilience (to climate change), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals. These practices are summarized below:

a. Adoption of no till or minimum tillage system, this prevent mechanical disturbances of the soil and prevent exposing the tiny particles and carbon that can be removed by induced erosion.
b. Leaving crops biomass on the soil without burning because the biomass decomposes by soil microbes and turn to the soil as organic matter, however the burning affect the diversity and population of soil organisms so that their role in soil will be reduced.
c. Addition of biochar to the soil which is microbial resistant carbon substance produced by heating organic materials in the absence of oxygen. This enhances the SOC storage and retention in soil.
d. Addition of soil organic amendment such as organic manure, biosolids, compost, green yard manure and organic mulching. The organic amendment is a complex of carbon compound, and include everything in the soil that is of biological origin it include plant and animals remains in various forms of decomposition, cells and tissues of soil organisms and substance from plant roots and soil microbes (Franzluebbers *et al*., 2001).
e. Adoption of crop rotation with cover crops in rotation cycle.
f. Grow bio-energy crops which are grown specifically for their fuel value to make biofuel like switch grasses in marginal land. This will reduced more pressure on the vegetation for bio-fuel which reduced the atmospheric C via photosynthesis.
g. Management practices that can store, maintain and enhance ecological balance such as organic farming or gardening
h. Use of leguminous crop/plant which enhance biological nitrogen fixation such as groundnut, cowpea and alfalfa.

These soil management practices have the potential to store an additional 1.85 gt of C annually which is equivalent to the amount of C the global transportation sectors emits annually and was reported that, with these soil management, soil can mitigate C emission for up to 40 years before it become incapacitated to mitigate the C (Lal, 2004a).

Soil C Sequestration for Climate Change Mitigation

The maximum sink capacity of a specific pool potential SOC sequestration to which atmospheric CO_2 can transferred for safe storage and retention over long time is considered as potential SOC sequestration. Thus, soil C sequestration implies increasing the concentration of SOC through land-use conversion and adoption of Recommended Management Practices (RMPs) in agricultural ecosystems and restoration of degraded and drastically disturbed soils (Fowles, 2007). Morris (2006) explained that improving soil quality and agronomic productivity, agricultural intensification and adoption of RMPs can reduce the net rate of CO_2 emissions through SOC sequestration. Estimation of the total potential carbon sequestration in the world soils vary widely from a low of 0.4 – 0.6 Gt C/year to a high of 0.6 – 1.2 Gt C/year (Lal, 2004c).. The potential C sequestration by soil is finite in capacity and time (Lal, 2004c). The SOC emissions can be drastically reduced by increasing production from existing land so that any additional deforestation can be avoided (Fargione *et al*., 2008). SOC sequestration have both mitigation and adaptation implications. The mitigation impacts of innovative agricultural systems accrue from the net reduction in GHG emissions. The adaptation impacts of accepting improved soils and crop management systems are based on the reduction of the adverse effects of projected climate change. Sustainable soil management is an important measures for mitigation and management of climate risk. Soil management reduce climatic effect through: SOC sequestration and reducing emission of CO_2 and other GHGs. The techniques are to transform agricultural marginal soil to restorative land use and adoption of RMPs on good soil to create a positive C budget like $C_{input} > C_{output}$ (Baethgen, 2010). The amount of SOC sequestered improved mitigation to climate change by increasing soil quality and buffering capacity. Improvement of SOC concentration beyond the critical range, increases soil quality (Lal, 2004a).

Role of Soil in Kyoto Protocol

The amount of carbon stored in soils globally is therefore large compared to gross and net annual fluxes of carbon to and from the terrestrial biosphere, and the pools of C in the atmosphere and vegetation. The Kyoto Protocol allows carbon emission to be offset by demonstrable removal of C from the atmosphere. Thus, soil management change and forestry activities that are shown to reduce atmospheric CO_2 levels can be included in Kyoto emission reduction targets. The activities include reforestation, deforestation and afforestation and also include the improved management of agricultural soils, land management, grazing, forest management and regeneration. Increasing the size of the global soil C pool by even a small proportion has the potential to sequester large amount of C and thus soils have an important role to play in mitigating climate change (Smith *et al*., 2001). The role of soil on Kyoto protocol framework indicate the possible magnitude of expected C mitigation potentials for soil and proposed the future challenges for researchers/scientist and policy makers. The soils have special role to play in Kyoto framework because it tend to have a depleted soil C relative to comparable soils under native vegetation and thus, have a large capacity for increasing soil C storage and also are actively manageable and thus can be manipulated for carbon sequestration (Smith *et al*., 2001).

Societal Benefits of Soil C Sequestration

Soil carbon sequestration is a process under the control of human management and, as such, the social dimension needs to be considered when implementing soil carbon sequestration practices. Due to the increases in competition for limited land resources, soil carbon sequestration cannot be viewed in isolation from other environmental and social needs. Sequestration of atmospheric C into the terrestrial ecosystems in general and soils in particular, is a win-win-win strategy which ensure availability of good quality water (Lal, 2015). Kerr (2009); Rodelle *et al*. (2009) reported that, payments for green water credits and charging users a fair price of the scarce water resource may be the only strategy to reverse the severe depletion of the ground water resources. Both water credits and C credits are important to adoption for the recommended management practices (RMPs), and sustaining the resource use. Sustainable crop management is important to alleviating poverty (Lipton, 2005). Furthermore, this cost-effective option of mitigating climate

A no-regrets policy option is also beneficial to soil carbon sequestration which is considered as change is also a bridge to the future until C-neutral or C negative fuel sources take effect.

The three major C market based mechanisms includes Clean development mechanism (CDM), joint implementation (JI) and emission trading scheme (ET). These C market allow credit for projects aimed at reducing anthropogenic emission of GHGs from sources and enhancing anthropogenic removal by sinks of GHGs through C sequestration. However, soil C sequestration does not fit under these three mechanisms (CDM, JI and ET) of Kyoto protocol specifically include soil carbon as an option (FAO, 2000). The CDM under Kyoto protocol allow industrialized countries with GHGs reduction commitment like USA to invest in mitigation project in developing countries (such as Nigeria and Ghana) as an alternative to what is general more costly in their own countries. Both developing and developed countries may drive benefits from CDM. Developing countries receive more capital for environmentally sound investment that contributed to sustainable development such as Reducing Emission from Deforestation and Degradation (REDD) and REDD+, while developed countries can implement their emission at lower cost (Koskela *et al*., 2000).

Potentially there are two ways in which farmers could benefit from the entering in to contract to reduce GHGs as farmers would be compensated for the C they sequester based on the quality and quantity of C sequestered and the market price. The farmers also would benefited from any gain in productivity associated with adoption of C sequestration practices such as maintaining forest cover, avoiding slash and burn, agroforestry, and some sustainable soil management (Renaldo *et al*., 2012).

The key to increasing soil carbon sequestration, as part of wider programmes to enhance sustainability, is to maximize the number of winners and minimize the number of losers. One possibility for improving the social/cultural acceptability of soil carbon sequestration measures would be to include compensation costs for losers when costing implementation strategies. By far the best option, however, is to identify win–win measures, those that may enhance C stock and at the same time enhance the quality of environment like soil quality, fertility and water holding capacity (Lal, 2004c).

For example, soil carbon sequestration on soils would considerably help in restoration the land, by increasing carbon stocks and improve the quality of the ecosystem.

land management practices available that could be implemented to protect and enhance existing carbon sinks now, and in the future. A no-regrets climate change policy is a choice among policies that are equally beneficial, apart from the consideration of climate change. Therefore, the policy have some benefits like increasing soil carbon sequestration, increasing agricultural production as well as being robust to climate change, this is because increasing carbon storage means improving sustainable agricultural production at the same time mitigating climate change. Soil carbon sequestration can reduce the rate of enrichment of atmospheric CO_2, while enhancing biodiversity and controlling desertification. Restoration of degraded/desertified soils and ecosystems is an important ancillary benefit of soil carbon sequestration (Lal, 2015).

The soil carbon pool of many soils of sub-Saharan Africa is as low as 0.1 to 0.2%, in contrast to the critical limit of the soil carbon concentration of 1.1% for maintenance of an adequate level of soil quality (Aune and Lal,1998). The entry point for breaking the vicious cycle of degraded soils – depleted soil carbon pool – low crop yields – poverty – hunger – further degradation of soils – is through adopting land-use and management systems that restore soil carbon pools (Lal, 2004b). There is a very close link between soil carbon sequestration and global food security. Indeed, soil carbon sequestration is an important ancillary benefit of the inevitable necessity of enhancing soil quality for feeding the global population of 6 billion in 2000, which is expected to reach 7.5 billion by 2020 and 9.4 billion by 2050 (Smith and Powlson, 2003). Some co-benefits of soil C sequestration include:

a. Restoring degraded soils and desertified ecosystems

b. Mitigating climate change while improving the environment.

c. Advancing food security through improvements in soil quality

It is extremely important to realize that enhancing SOC pool and maintaining it above the threshold of1.1% in the surface layer is essential to advancing food security (Aune and Lal, 1998). For malnourished and resource-poor small landholders who are perpetually threatened by drought and crop failure, enhancing soil resilience and guaranteeing a minimum assured crop yield even during the worst seasons of below-normal rains is important to their survival, thus, soil C sequestration is essential to their survival. Rather than being driven into the futile debate of who is responsible for gaseous emissions, food-insecure population would appreciate C-positive action towards elimination of hunger and malnutrition for which soil C sequestration is an important step and in the right direction. Commoditization of soil C can also create another income stream and provide the much-needed incentives for adoption of RMPs. Land managers can benefit by trading soil C in the emerging C-offset markets and by claiming the environmental benefits of the sustainable land management practices.

CONCLUSION

Soils provide various ecosystem services essential to wellbeing such as producing biomass, cycling of nutrient elements, denaturing and transforming of pollutants, purifying and filtering of water, storing and creating habitat for a vast gene pool. Soil’s capacity to provide these services depends on its quality as moderated by the total and reactive C pools. Sustainable soil management may have multiple purposes in the ecosystem. The magnitude and severity of the depletion of soil C are exacerbated by decline in soil quality via accelerated erosion and other degradation processes. The treat of climate change can be reduced through sustainable soil management practices that improve the soil C storage capacity for longer period based, on that soil can be considered as source and sink of C. However, soil degradation through practices such as deforestation, excessive use of pesticides and fertilizers, mono-cropping, erosion and maximum tillage cause soils to emit carbon into the atmosphere, leading to climate change, reducing soil quality and it’s productive capacity. Conversion to a restorative land use and adoption of recommended management practices, such as use of organic manure and zero tillage may create positive C and nutrient budgets, restore soil quality and enhance SOC pool. The drawdown potential of soil C sequestration will help reduce atmospheric C concentration and improving the environmental quality.

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