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Review

IMPACTS OF SOIL CARBON SEQUESTRATION ON CLIMATE CHANGE MITIGATION AND AGRICULTURE

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ABSTRACT

The recent trend of increase in the concentration of greenhouse gases (GHGs) in the atmosphere has led to the rising earth's temperature and consequently a change in the global climate resulting into the existence of adverse environmental conditions. Hence the need to take measures in reducing GHGs, more especially carbon dioxide (CO_2) from the atmosphere has become necessary. Removal of atmospheric CO_2 by terrestrial ecosystems via carbon sequestration and converting the sequestered carbon into the soil organic carbon (SOC) has provided a great opportunity for shifting GHG emission to mitigate the climate change. Soil is an ideal reservoir for storage of organic carbon since SOC has been depleted due to land misuse and inappropriate management over a long period of time. To optimize the efficiency of carbon sequestration in agriculture, recommended management systems, such as conservation tillage, crop rotation, cover cropping, nutrient management etc., play a critical role. Soil carbon sequestration is a multiple purpose strategy. It restores degraded soils, enhances the land productivity, improves the diversity, protects the environment and reduces the enrichment of atmospheric CO_2, hence shifts emission of GHGs and mitigates climate change.

Keywords: Soil, carbon sequestration, climate change, impact, agriculture, mitigation.

INTRODUCTION

Anthropogenic emissions have been established to be responsible for drastic increase in atmospheric concentration of CO_2 and other greenhouse gases (GHGs). Sources of all GHGs are fossil fuel combustion, industrial gaseous discharges, deforestation through biomass burning and soil cultivation, nitrogenous fertilizer application, drainage of peatlands and extractive farming practices. The principal sources of anthropogenic emissions are fossil fuel combustion, activities of large industries, change in land use, drainage of peatlands and soil cultivation (IPCC, 2007). Principal sinks of CO_2 include uptake by the atmosphere, ocean, vegetation and land-based sinks (Normile, 2009; IPCC, 2007). Concentration of CO_2 in the atmosphere has increased drastically from 280 ppm in the pre-industrial era (~1750) to 385 ppm in 2009 (Normile, 2009), and is presently increasing at the rate of about 2 ppm/yr (0.50 %/yr). Atmospheric concentration of other greenhouse gases (GHGs) particularly methane (CH_4) and nitrous oxide (N_2O) also had their share of increases during the same period (Table 1). Because of the increase in concentration of GHGs, mean earth's temperature has increased by 0.6 ± 0.2 °C, and is projected to increase by 2 to 4 °C towards the end of the 21st century under the business as usual scenario (IPCC, 2007).

Table 1: Change in the concentration of greenhouse gases (GHGs) since pre-industrial era of about 1750

Gas	Present Concentration (2009)	Present Increase Since in the Year 1750	Present Rate of Increase (% per Year)
Carbon dioxide	385 ppm	105 ppm	0.50
Methane	1789 ppb	1089 ppb	0.34
Nitrous oxide	321 ppb	51 ppb	0.25

Source: Lal (2009)

With projected climate change, there are likely risks of increase in frequency and intensity of extreme events (e.g., drought), decrease in rainfall effectiveness, increase in incidence of pests and pathogens, reduction in net primary productivity (NPP), and decrease in crop yield and agronomic production. Net primary productivity (NPP) is the amount of carbon incorporated into new organic matter produced by a plant of ecosystem in a specified time interval. Anthropogenic factor and the World's population which was 6.7 billion in 2009 and projected to increase to 9.2 billion by 2050 are the major driving forces responsible for the inter-related issues of global concern that include, climate change, food insecurity, environmental degradation including desertification and energy crisis (Lal, 2009).

Climate change affects agricultural activities through adverse changes in temperature and precipitation which alter the growing season duration, affect intensity and frequency of drought and other extreme events, aggravate incidence of pests and pathogens, and increase magnitude of biotic and abiotic stresses (Koning and Mol, 2009). Since climate change is a consequence of anthropogenic emissions of GHGs, in mitigating climate change suitable technologies that will promote radical atmospheric carbon reductions, arrest further carbon build up and at the same time enhance global food security must be adopted. According to Lal (2004 and 2008), soils have the potential to sequester carbon from the atmosphere with proper management. Based on global estimates of historic carbon stocks and projections of rising emissions, soil's usefulness as a carbon sink and drawdown solution appear essential. Since over one third of arable land is in agriculture globally (World Bank, 2015) finding ways to increase soil carbon in agricultural systems will be a major component of using soils as a sink. A number of agricultural management strategies appear to sequester soil carbon by increasing carbon inputs to the soil and enhancing various soil processes that protect carbon from microbial turnover (Kane, 2015).

Agriculture is highly vulnerable to climate change and needs to adapt to changing climate conditions. Under the projected temperature rise, climate change may reduce crop yields by 10 to 20 percent and will also impact agriculture through effects of pests and disease. The agriculture sector has a pivotal role to play in mitigating greenhouse gas (GHG) emissions. Agriculture and land-use change currently account for about one-third of total emissions. Agriculture is the primary driver of deforestation in many developing countries. The net increase in agricultural land during the 1980s and 1990s was more than 100 million hectares (ha) across the tropics. About 55 percent of the new agricultural land in the tropics came at the expense of intact forests, while another 28 percent came from the conversion of degraded forests. Projected increases in demand for food and bio-energy by 2050 may further increase pressure on forests in the tropics with profound implications for an increase in GHG emissions. Even if emissions in all other sectors were eliminated by 2050, growth in agricultural emissions would perpetuate climate change under the conventional agricultural practices. The triple imperatives of increasing productivity, reducing emissions, and enhancing resilience to climate change call for alternative approaches to practicing agriculture. Climate smart agriculture (CSA) seeks to increase productivity in an environmentally and socially sustainable way, strengthen farmers' resilience to climate change, and reduce agriculture's contribution to climate change by reducing GHG emissions and increasing soil carbon storage (World Bank, 2012).

The objective of this review paper is centered on discussing the contributions of agricultural management strategies to soil carbon sequestration (SCS) and the attendant impacts on agricultural productivity and climate change mitigation.

MATERIALS AND METHOD

This review was conducted on the basis of articles search from university library and also from electronic database such as pubmed and google scholar.

REVIEW AND DISCUSSION

Carbon sequestration

Carbon sequestration refers to both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations.

Before human-caused CO_2 emissions began, the natural processes that make up the global carbon cycle maintained a near balance between the uptake of CO_2 and its release back to the atmosphere. However, existing CO_2 uptake mechanisms (sometimes called CO_2 or carbon sinks) are insufficient to offset the accelerating pace of emissions related to human activities. Annual carbon emissions from burning fossil fuels in the United States are about 1.6 gigatons (billion metric tons), whereas annual uptake amounts are only about 0.5 gigatons, resulting in a net release of about 1.1 gigatons per year (Fact Sheet, 2008).

The idea of carbon sequestration is to stop carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage or to remove carbon from the atmosphere by various means and stores it. One set of options involves capturing carbon from fossil fuel combustion before it reaches the atmosphere. For example, CO_2 could be separated from power plant flue gases, from effluents of industrial processes (e.g., in oil refineries and iron, steel, and cement production plants), or during production of decarbonized fuels (such as hydrogen produced from hydrocarbons such as natural gas or coal). The captured CO_2 could be concentrated into a liquid or gas stream that could be transported and injected into the ocean or deep underground geological formations such as oil and gas reservoirs, deep saline reservoirs, and deep coal seams and beds. Atmospheric carbon can also be captured and sequestered by enhancing the ability of terrestrial (vegetation, soils, and sediments) or ocean ecosystems to absorb it naturally and store it in a stable form (USDE, 1999).

Soil and soil organic matter

Soil has been described as a living membrane between bedrock and the atmosphere (CNIE 1998), it is a diverse ecosystem containing microorganisms and many types of invertebrates and vertebrates as residents. It is a large reservoir of carbon, with about 60% organic carbon in the form of soil organic matter (SOM), and the remaining inorganic carbon in the form of inorganic compounds (e.g., limestone, or $CaCO_3$). It is estimated that SOM stores about twice as much carbon as the atmosphere, and about three times more than forests and other vegetation (Waste 2 Resources, 2013).

Soils are critical to plant production and essential for carbon sequestration (soils currently contain ~75% of the terrestrial carbon). Soils in which high levels of carbon are present as soil organic matter (SOM) exhibit improved nutrient absorption, water retention, texture, and resistance to erosion, making them particularly useful for both plant productivity and sequestration. The primary way to store (sequester) carbon in the soil is to add organic soil amendments such as compost or animal manures. SOM is a complex of carbon (C) compounds, and includes everything in or on the soil that is of biological origin. It includes plant and animal remains in various states of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. Organic carbon in the form of humus, the dark, spongy organic matter in soils, is highly resistant to soil microbial decomposition. It can be stored in the soil for hundreds to thousands of years, while other SOM (e.g., partially decomposed plant residues) can be quickly released as CO_2 back into the atmosphere (Waste 2 Resources, 2013).

Storage of carbon in belowground systems is the best long-term option for carbon storage in terrestrial systems because most SOM has a longer residence time than most plant biomass. It was estimated that 25 billion tons of soils are lost through erosion each year. About one-third of the current 1.5 billion tonnes of carbon emitted to the atmosphere because of changes in tropical land use is from oxidation of soil carbon. Also estimated was that 40 to 60 billion tonnes of carbon may have been lost from soils as a result of forest clearing and cultivation since the great agricultural expansions of the 1800s (USDE, 1999). When land is converted from natural perennial vegetation and cultivated, SOM generally declines by 50% in the top 20 cm of soil and 20 to 30% in the top meter of soil. Because less organic matter is introduced to the soil and because soil aggregates are destroyed (causing the loss of physical protection mechanisms that trap soil carbon), SOM declines significantly. In addition, cultivated soil is exposed to the air which aid decomposition by soil organisms, hence SOM is oxidized and the carbon discharged into the atmosphere as CO_2. With good management to protect soils and the development of methods to improve texture of soils, it may be possible to exceed the original native SOM content of many soils (USDE, 1999).

Soil carbon sequestration

The term soil carbon sequestration implies removal of atmospheric CO_2 by plants through photosynthesis and storage of fixed carbon as soil organic matter that is not rapidly decomposed. Changes in soil organic carbon levels can have significant effects on atmospheric CO2 levels. Each 1% increase in average soil organic carbon content could reduce atmospheric CO_2 by up to 2%.

The strategy is to increase soil organic carbon (SOC) density in the soil, improve depth distribution of SOC and stabilize SOC by binding it within stable micro-aggregates so that the carbon is protected from microbial processes. It is suggested that the post-2012 regime would benefit if soil carbon storage could be recognized as an eligible carbon sink in all land use systems, in particular agricultural soils. Indeed, the IPCC (2007) noted that soil carbon sequestration is the mechanism that holds the greatest global mitigation potential.

Managing agro-ecosystems is an important strategy for SOC/terrestrial sequestration. Land use change, along with adoption of recommended management practices (RMPs), can be an important instrument of SOC sequestration (Post and Kwon, 2000). While land misuse and soil mismanagement causes depletion of SOC with addition of CO_2 and other GHGs emissions into the atmosphere, enhancing SOC pool could substantially reduce the level of CO_2 emitted into the atmosphere which in turn mitigate the effects of climate change in addition to improving food productivity. But the SOC sink or pool capacity depends on the antecedent level of soil organic matter (SOM), climate, profile characteristics and management. The sink capacity of SOM for atmospheric CO_2 can be greatly enhanced when degraded soils and ecosystems are restored, marginal agricultural soils are converted to a restorative land use or replanted to perennial vegetation, and RMPs are adopted on agricultural soils. SOC can accumulate in soils because tillage-induced soil disturbances are eliminated, erosion losses are minimized, and large quantities of root and above-ground biomass are returned to the soil. These practices conserve soil water, improve soil quality and enhance the SOC pool and energy. Biodiversity is also important to soil C dynamics (Figure 1).

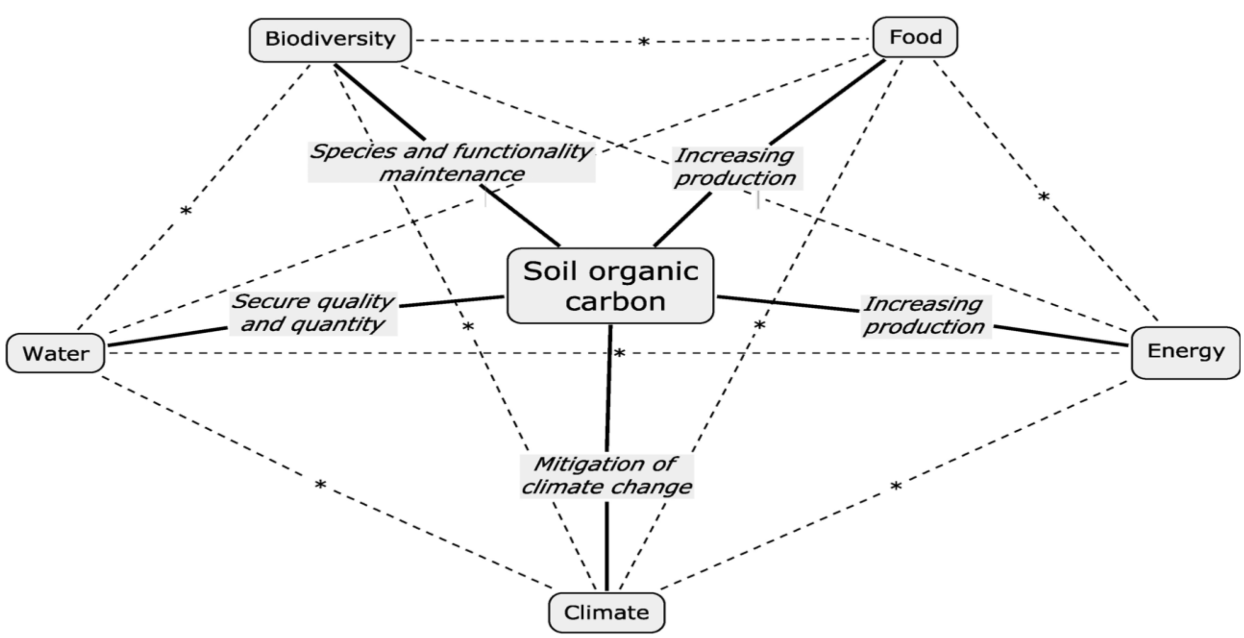

Figure1: Interactions between soil organic carbon and the five essential services. *Source: SCOPE-RAP(2014)*

Basic requirements for efficient soil carbon sequestration

The fundamental requirements for efficient soil carbon sequestration are in the improvement of soil biodiversity and soil aggregation, research has proved that good management of agro-ecosystems provides a suitable mechanism for sustaining enhanced soil biodiversity and aggregation, which consequently leads to an increase in the soil organic carbon (SOC) pool and agricultural produce harvest.

Soil biodiversity

Soil biodiversity is defined as the variability among living organisms from all sources, including terrestrial, marine ecosystems and other aquatic ecosystems and ecological complexes of which they are part; this includes diversity within species, between species and for ecosystems. It is possible to distinguish between genetic diversity, organism species diversity, ecological diversity and functional diversity. A healthy soil is teeming with life, and comprises highly diverse soil biota which comprises representatives of all groups of micro-organisms and fungi, green algae and cyanobacteria, and of all but a few exclusively marine phyla of animals (Lal, 2004).

Soil biodiversity has a positive impact on the SOC pool. All other factors being equal, ecosystems with high biodiversity sequester more carbon in soil and biota than those with reduced biodiversity. In managed ecosystems, soil biodiversity is likely to increase with conversion to conservation tillage, replacement of toxic chemicals with viable alternatives, substitution of monoculture with mixed crop rotations and complex/diverse systems, restoration of degraded soils and ecosystems, and conversion of crop or pasture land to a restorative land use. Application of chemicals in high input systems decreases population density of soil fauna and biomass. In comparison with cropland, biomass carbon is also more in pastures, fallow and forest ecosystems. Soil biodiversity has a favorable impact on soil structure. Activity of soil biota produces organic polymers, which form and stabilize aggregates. Fungal hyphae and polysaccharides of microbial origin play an important role in soil aggregation. Earthworms and termites also positively impact soil structure, and enhance aggregation (Lal 2004).

Soil Aggregation

Soil aggregation enhancement is the basic determinant for successful SOM improvement activities which in turn increases the SOC pool. One of the most important ways carbon is sequestered in soils is through the process of soil aggregation. Soil aggregates are formed when smaller soil particles adhere together into larger, more stable groups, bound together by clay particles present in the soil and glue-like substances generated by microbes decomposing organic matter, such as glomalin produced by arbuscular mychorrhizal fungi (Oades, 1984; Six *et al*., 2004; Wilson *et al*., 2009). As these aggregates form, small particles of carbon, such as partially decayed plant residues, are captured in the center of the aggregates. At the center of these aggregates, these carbon rich materials are physically protected from microbial attack. Microbes cannot penetrate the center of these stable aggregates, and conditions at the center, where oxygen and water are low, discourage microbial metabolism (Six *et al*., 1998, 2000). When aggregates remain stable and undisturbed, they can protect soil carbon for much extended periods of time. However, tillage can quickly break apart aggregates, exposing soil carbon to microbial attack (Kane, 2015).

Agricultural strategies for soil carbon sequestration

Several agricultural strategies have emerged as having the potential to increase soil carbon, although important details about the permanence of the carbon they sequester should be carefully considered.

No-till (No tillage)

Among the most widely studied agricultural management strategies that can increase soil carbon are no-till systems. No-till is a system that generally relies on specialized planting equipment, chemical herbicides, and genetically modified seed to reduce or eliminate the need for tillage equipment. Since soils in these systems remain undisturbed, soil aggregates remain intact, physically protecting carbon. Several studies have demonstrated that no-till can increase soil carbon rapidly, especially at the soil surface, and several more detailed studies have found that this increase in carbon is linked to increases in aggregation (Kane, 2015). However, in order to maintain gains in soil carbon, it is important to continuously manage soils with no-till. Grandy and Robertson (2006) found that tilling a previously untilled soil quickly reversed nearly all the previously recorded gains by disrupting aggregates and exposing carbon molecules to microbial attack.

Conservation Tillage

Conservation tillage utilizes tillage implements less aggressive than the classic mold board plow and requires fewer tillage passes per season such that more residues are left on the surface and disruption of soil aggregates is reduced. This approach also generally relies on chemical herbicides and genetically modified seed to reduce weed pressure. Although conservation tillage comes in many forms, several studies have demonstrated that it also can increase soil carbon by increasing soil aggregation and physically protecting carbon, but sequestration generally occurs at rates lower than no-till. The large number of studies on carbon sequestration in no-till and conservation tillage systems seems to have generated some consensus that both these approaches can increase soil carbon. Conventional tillage and erosion deplete SOC pools in agricultural soils. Thus, soils can store carbon upon conversion from plow till to no till or conservation tillage, by reducing soil disturbance. (Lal, 2004))

Cover Crops

Growing cover crops is an effective approach to improve carbon sequestration and SOC storage. In the temperate region, winter cover crops, such as rye, ryegrass, oats, pea, vetch, clover, are commonly grown in fall, survived through the mild winter and grow again in spring to cover the bare lands during the off season. The biomass production of vetch and rye winter cover crops in biculture often ranges 5.7 to 8.2 Mg ha^{-1} in the aboveground, and 372 to 880 kg ha^{-1} belowground, which result in a total carbon input to the soil that ranged from 6.8 to 22.8 Mg ha^{-1} by cover crops, cotton and sorghum in rotation. It was also reported that SOC increased by 6-8% with cover crops at 0 to 10 cm, and by 0.4% with rye in monoculture and 3% with vetch and rye in biculture at 0-30 cm. However, in the tropical or subtropical region, summer cover crops, such as sunn hemp, velvet bean, sorghum and sudan grass, are prevailing species grown during the hot and humid summer to cover the bare land conserving soil and water and those summer cover crops, especially sunn hemp can produce as much as 15 Mg ha^{-1} of aboveground biomass and 3.5 Mg ha^{-1} belowground biomass, combined contributes to 8 Mg ha^{-1} of organic C input into the soil within 3 months. Therefore, cover cropping system provides an excellent strategy to improve carbon sequestration for mitigation of climate change (Wang *et al*., 2010).

Cover crops protect soil aggregates from the impact of rain drops by reducing soil aggregate breakdown, slowing down wind speeds at ground level and decreasing the velocity of water in runoff. Cover crops can increase nutrient efficiency through reduced soil erosion (less soil organic matter and soil nutrients losses in the topsoil). Cover crops are scavengers of residual nitrogen (N), converting nitrogen to proteins (enzymes, hormones, amino acids). Nitrogen uptake depends on soil nitrogen, climate, cover crop species, seeding rate, planting and killing date. Cover crops increase mycorrhizal fungus activity promoting a symbiotic relationship with the plants' roots for water and nutrient uptake. Plants provide the polysaccharides and the mycorrhizal fungus provided the protein to form a glycoprotein called glomalin which promotes soil aggregate stability (more macro-aggregates) and improved soil structure. Mycorrhizal fungus grows better in undisturbed soils. No-till and actively growing roots promote this reaction to occur (Hoorman, 2009).

Crop rotation

Crop rotation is the deliberate order of specific crops sown on the same field. The succeeding crop may be of a different species (e.g., maize or sorghum followed by legumes) or a variety from the previous crop, and the planned rotation may be for 2 or more years. GHG abatements of cover crops were 1.7 to 2.4 tonnes CO_2 emitted per ha per year, while those of crop rotation were 0.7 to 1.5 tonnes CO_2 emitted per ha per year. There is a tendency toward higher carbon sequestration rates in triple cropping systems, although variation is high. Differences in soils, climate, and cropping systems also affect carbon sequestration under crop rotation (ARD, 2012).

Meta-analyses of belowground crop rotation effects show increases in soil fertility factors, such as soil carbon and nitrogen and microbial biomass (West and Post 2002; McDaniel et al., 2014), but these effects cannot be separated from the influence of other land management factors, such as the application of external fertilizers and pesticides. For the belowground effects of rotational diversity in isolation, a 33% increase was observed in sand-corrected soil carbon compared to monocultures at this site, which is considerably higher than the average 3.6% gains reported by McDaniel *et al.*, (2014). As crop diversity increased, we found increases in the stability of mega-aggregates, with indications of increasing SOC and total nitrogen concentrations. Based on enzyme activity levels and SOC mineralization rates, the increases in crop diversity appear to have stimulated microbial activity in the mega-aggregates. This increase in microbial activity is likely responsible for the increase in aggregate stability through the production of soil binding agents, such as fungal hyphae, glomalin and polysaccharides (Tiemann *et al*., 2015).

Nutrient management

Judicious nutrient management is crucial to SOC sequestration. In general, the use of organic manures and compost enhances the SOC pool more than application of the same amount of nutrients as inorganic fertilizers. The fertilizer effects on SOC pool are related to the amount of biomass carbon produced/returned to the soil and its humification. Adequate supply of nitrogen and other essential nutrients in soil can enhance biomass production under elevated CO_2 concentration. Long-term manure applications increase the SOC pool and may improve aggregation and the effects may persist for a century or longer. The potential of conservation tillage to sequester SOC is greatly enhanced whereby soils are amended with organic manures. It was reported that 820 million metric tons of manure are produced each year in Europe, and only 54% is applied to arable land and the remainder to non-arable agricultural land. They observed that applying manure to cropland can enhance its SOC pool more than it does on pasture land. Lal *et al*, (2004) reported that if all manure were incorporated into arable land in the European Union, there would be a net sequestration of 6.8 Teragramme (Tg) carbon/year, which is equivalent to 0.8% of the 1990 CO_2 carbon emissions for the region.

Irrigation systems

Irrigation takes an important role in crop production in arid and semiarid regions. Compared to rain-fed crops, irrigated crops produce twice as much as plant biomass. Irrigation increases carbon input to soils through increasing plant residues and root systems. It was estimated as reported in Xiao (2015) that irrigation resulted in a SOC sequestration rate of between 50 and 150 kg C ha^{-1} yr^{-1}, SOC sequestration due to irrigation in the western U.S. ranges from 0.25 to 0.52 Mg C ha^{-1} yr^{-1}. Also reported was that irrigation significantly increases SOC stocks under different pasture and conservation tillage compared to the native sagebrush ecosystem. Carbon storage (sequestration) is expected to increase if efficient water use allows the expansion of irrigated agriculture. Xiao (2015), again reported that land-use shifts from arid native vegetation could sequester 8.0 Mg C ha^{-1}, and assuming 10% expansion of irrigated agriculture, 7.2 x 10^6 Mg C could potentially be sequestered in Pacific Northwest soils.

Pasture management

In general, soils under pasture tend to have a higher SOC than cropped soils because they have a higher root to shoot ratio than many crops, are typically less disturbed, and have lower rates of SOC decomposition (Chan *et al*., 2010). Studies have demonstrated improving pasture management through seed sowing and fertilization application can increase SOC stocks (Chan, 1997; Chan *et al*., 2010). Other pasture management practices (e.g. grazing management and use of other pasture species) are reported to increase SOC stocks. For example, among studies that examined different levels of grazing intensity, about 30% found lower SOC contents for moderately grazed compared to heavily grazed treatments (Conant *et al*., 2001). Nyborg *et al* (1999), found that nitrogen and sulfur fertilization increased SOC stocks at a rate of 0.5-1.0 Mg C ha^{-1} yr^{-1} over 5-13 years. Generally, perennial grasses have a deeper, more extensive root system compared to annual ones. The use of perennial grasses in marginal pastures has the potential to increase SOC stocks. Young *et al*., (2009) found significant increases in SOC stocks (0.15 to 0.35 Mg C ha^{-1} yr^{-1}) at the depth from 0-20 cm over 6 years of repeated measurements when various perennial pastures were cultivated.

Organic farming systems

Many studies have demonstrated organic farming systems which rely on use of recycled organic materials (e.g. animal manures and compost) offer many benefits (Xiao, 2015) which include:

- Increased SOC storage (sequestration).
- Reduced greenhouse gas emissions.
- Lowered energy consumption.
- Maintained or increased farm profitability.

Xiao, (2015) reported that SOC was increased by 15% and 28%, in two organic systems (one legume based and one manure based) respectively, compared to adjacent conventional farming systems. Also reported by Xiao, (2015) in vegetable farming was that, organic farming systems significantly increased SOC levels over conventional systems and SOC stocks in the depth of top 15 cm increased by 0.3 and 0.5 Mg C ha^{-1} yr^{-1} for low-input crop rotation and organic systems respectively in California, while no change was observed in the conventional farming systems over the same period. An estimated average of 20% higher SOC sequestration rates for organic farming, compared to conventional farming on the global scale was observed, and 22 years of manure based and legume-based organic farming systems increased SOC at a rate of 0.7 and 0.3 Mg ha^{-1} yr^{-1} respectively, compared to a conventional farming system (Xiao, 2015). However, it was found that the new increased SOC was primarily in the biologically active fractions that may have little permanence if there are no new inputs. CO_2 emissions are about 40-60% lower in organic farming systems compared to conventional systems, mainly because organic farming systems are not allowed to use chemical fertilizers which consume a large amount of energy for their production (Xiao, 2015).

CONCLUSION

Adding organic matter to farmland is good for soil quality and crop yields, both short-term and long-term. Continuous no-till is an efficient way of doing this. Cover crops and manure also help raise carbon levels. Soil carbon sequestration is a natural, cost-effective, and environmentally- friendly process. Once sequestered, carbon remains in the soil as long as restorative land use, continuous no-till and other best management practices are followed. While mitigating climate change by off-setting fossil fuel emissions, it also improves quality of soil and water resources and enhances agronomic productivity. Carbon sequestration by agricultural land has generated international interest because of its potential impact on and benefits for agriculture and climate change.

Recommendations

Developing countries such as Nigeria should pursue agricultural development programmes vigorously through the use of the recommended management practices, with a view to addressing the impending food insecurity resulting from the rapid growing population and use of conventional systems of agriculture. This will also reduce atmospheric carbon and consequently mitigate climate change. The following aspects of management practices in agriculture are recommended.

- Large scale livestock production whose manure will be used for plant growth in recommended management practices
- Discourage use of inorganic fertilizers because these chemicals are capable of decomposing soil carbonates with the discharge of more CO_2 into the atmosphere.
- Effective utilization of existing dams for irrigation farming and construction of more dams.
- Farmers should be encouraged to practice all the recommended management systems of agriculture for improve yield and the climate benefits derivable out of these new farming strategies.
- Incentives for sequestering carbon to reduce greenhouse gas emissions (GHG) from agricultural soils, and support by Governments and Development partners, would encourage smallholders at subsistence level as well as larger commercial farmers and herders to adopt improved management practices and by so doing enhance productivity for their produce, while contributing to reversing degradation and desertification, conserving biodiversity, and mitigating and adapting to climate change.
- Bush burning should be discouraged and measures taken to prevent accidental bush burning, instead grasses grown on fallow lands may be opened to grazing for herds. While the herds remove the grasses by grazing, they also leave behind their manure which will improve the soil organic carbon.
- Leaching, another alternative to bush burning that is also capable of improving soil organic carbon should also be encouraged.

CONFLICT OF INTEREST

None declared

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