Available online at http://arjournal.org

APPLIED RESEARCH JOURNAL

RESEARCH ARTICLE

ISSN: 2423-4796

Applied Research Journal Vol.1, Issue, 3, pp.164-168, May, 2015

CARBON SEQUESTRATION IN SOILS UNDER DIFFERENT LAND USE SYSTEMS AND ITS IMPACT ON CLIMATE CHANGE

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ARTICLE INFO

Article History:

Received: 12, April, 2015
Final Accepted: 13, May, 2015
Published Online: 15, May, 2015

Key words:

CO_2 emission, global warming, land management, soil degradation, soil organic carbon.

ABSTRACT

The study was carried out to assess soil organic carbon storage (SOC) under different land use systems within the same locality and interpret the results with reference to CO_2 emissions and soil degradation processes. The soils were taken from a depth of 0-20 from a cocoa plantation (cocoa under deep litter, cocoa under shallow litter and cocoa under weed), oil palm plantation, uprooted oil palm plantation and an arable land under cultivation (cassava + plantain). The SOC stored (Mg ha^{-1}) was determined by multiplying the fraction of the percent SOC (divided by hundred) to the bulk density and the volume of the soil. The CO_2 equivalent was determined by multiplying SOC stored by a factor, 3.67 (Molar ratio of 44/12). The land use systems that sequestered more organic carbon and less CO_2 emission was ranked as: uprooted oil palm plantation followed by maize> oil palm plantation> cocoa under deep litter> cocoa under shallow litter> arable land> cocoa under weed. The CO_2 emission ranged between 17.4 to 65.9 % depending on the type of land use. The study showed that, the magnitude of carbon sequestration is more under oil palm plantation than cocoa plantation. The CO_2 emission was significantly greater under cocoa plantation than oil palm plantation and even more where the cocoa plantation was not well managed (i.e. under shallow litter fall and weeds). It was observed that plantation agriculture increases the SOC storage than arable agriculture. The study indicated that, the conversion of land into different uses resulted in variable magnitudes of the carbon sequestered. Appropriate land management practices that reduce carbon emissions are therefore required to reduce global warming.

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1. INTRODUCTION

Carbon sequestration by terrestrial ecosystem is the net removal of carbon dioxide (CO_2) gas from the atmosphere or the avoidance of its emissions from terrestrial ecosystems into the atmosphere [1]. The removal process include: CO_2 uptake from the atmosphere by green plants through photosynthesis and the carbon stored as plant biomass (in the trunks, branches, leaves and roots of the plants) and organic matter in the soil [1]. Soil carbon sequestration involves adding the maximum possible organic carbon to the soil [2].

The carbon dioxide gas is a major cause of the atmospheric greenhouse effect and hence can influence the global climate. However, many other gases such as methane (CH_4), water vapour (H_2O), ozone (O_3) and nitrous oxide (N_2O) influence the global climate. Carbon sequestration studies have gained momentum in the recent decade and the amount of carbon stored in a system is a good measure of its sustainability. The

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current importance on this subject is due to the fact that carbon lost from these systems contributes significantly to atmospheric change, particularly CO_2 concentration. The process of soil carbon sequestration forms part of the global carbon balance.

Most of the factors affecting carbon sequestration are affected by land management practices. The distortion in the global carbon balance through human activities is due to the burning of fossil fuel and cement production (67%) and agriculture and land use change (33%) [3]. Actions to sequester carbon in the soils will generally increase the organic matter content of soils. Soil organic carbon, as reported by Bationo et al.[4], is simultaneously a source and sinks for nutrients and plays a vital role in soil fertility maintenance. Thus management practices that increase organic carbon could concurrently increase the fertility status of the soil.

Cocoa plantation, oil palm plantation and arable land cultivation represent an important component of the agricultural sector of Ghana. But the conversion of natural vegetation to these farming systems has the potential of altering their carbon storage capacity. Such a conversion increase the rate of change of SOC to CO_2, thereby reducing the input of biomass carbon and accentuating losses by erosion [2, 5 -7]

The hypothesis of the study was that, land use systems sequester SOC and emits CO_2 differently. The focus of the study was to assess soil organic carbon storage under different land use systems within the same locality and interpret the results with reference to CO_2 emissions and soil degradation processes. Also, to use the changes in the soil carbon storage as a guide to future land management for agriculture.

2. MATERIALS AND METHODS

2.1. Experimental site and soil sampling

The study was carried out in 2010 at the Plantation Section of the Faculty of Agriculture, KNUST, Ghana. The soil belongs to the Asuansi series [8], classified as Orthi-Ferric Acrisol [9]. Geographically, the experimental site is located between latitudes 6^o 40' North and longitude 1^0 33' West. Three bulk soil samples were taken from the 0-20 cm depth from a cocoa plantation (under deep litter, shallow litter and weed), an uprooted oil palm plantation followed by maize, an oil palm plantation and an arable land under cultivation of cassava and plantain.

2.2 Experimental design and statistical analysis

The experiment was arranged in Randomised Complete Block Design (RCBD) and the Genstat 9^{th} edition statistical software was used in analysing the data. Soil organic carbon stored under each land use system was replicated 3 times.

2.3. Physical and chemical analysis of soil

The soils sampled were air-dried and then passed through a 2 mm sieve. The soil particles that passed through the 2 mm sieve were used for the physical and chemical analysis. The particle size distribution of the soil was determined using the hydrometer method [10] after digesting the organic matter with hydrogen peroxide and dispersing the soil in sodium hexametaphosphate (calgon).

Soil organic carbon (SOC) was determined by the modified Walkley and Black dichromate digestion method as described by Nelson and Sommers [11].

The pH of the samples was determined in water using a soil: water ratio of 1:2.5 by a standard pH meter in the laboratory. The soil bulk density was determined using the metal core sampler method [12].

2.4. Calculation of the organic carbon sequestered (stored)

The SOC stored was calculated using the Donovan [13] formula.

$$CT = CF \ x \ D \ x \ V \quad (1)$$

Where:

CT is the total carbon stored per area in Mg ha^{-1},
CF is the fraction SOC (percentage carbon divided by hundred),
D is the soil bulk density and
V is the volume of the soil in cubic meters (which is = Depth of soil x area of soil)

2.5. Conversion of soil organic carbon to CO_2

The final results were multiplied by a factor of 3.67 (i.e. the molecular mass of CO_2/ atomic mass of C) to convert the total carbon stored to carbon dioxide.

3. RESULTS AND DISCUSSIONS

3.1. Physico-chemical properties of the soils

The soil pH and textural class of the soils are presented in Table 1. The texture of the soils ranged from sand to loamy sand. Landon's [14] guidelines were used to interpret the results. The pH of the soils were moderately acidic indicating acid conditions in the soils. The soil bulk density was highest in the uprooted oil palm plantation and lowest in the cocoa plantations. The soil bulk densities was within the range for maximum crop production for sand and loamy soils.

Table 1 The texture and pH of the soil under the different land use systems

Samples	pH	Bulk density kg m^{-3}	Sand (%)	Silt (%)	Clay (%)	Texture Class
Uprooted oil palm fallowed by maize	5.21	1659	79.10	10.43	10.47	Loamy Sand
Cocoa under deep litter	5.44	1605	88.20	7.90	3.90	Sand
Oil palm plantation	5.30	1557	84.97	7.40	7.80	Loamy sand
Arable land (plantain + cassava)	5.32	1557	89.93	4.83	5.23	Sand
Cocoa under weed	5.44	1499	92.20	1.90	5.90	Sand
Cocoa under shallow litter	5.44	1557	84.30	5.90	9.80	Loamy Sand

3.2. Soil carbon storage and emissions under different land use systems

The carbon stored in the soils and its equivalent CO_2 are presented in Table 2. The soil under the uprooted oil palm plantation stored the highest ($p < 0.01$) organic carbon and the lowest was recorded in the cocoa under weed although no significant difference was recorded between the cocoa under shallow litter, cocoa under weed and the arable land. The equivalent CO_2 gas stored followed the same trend. The soil organic carbon content is an important component of any land use system as it indicates the productivity level of the system. A soil with high organic carbon content is perceived to be of high quality [15]. Any land use practice that reduces soil quality could lead to a reduction in the SOC pool and an increase of CO_2 emission into the atmosphere. The decline in soil quality of the other land use systems in comparison to the uprooted oil palm plantation followed by maize could as reported lead to loss in the ability of the soils to retain water which could lead to low plant productivity. This concords with the findings of Magdoff and Weil [16] who reported that, reduction in soil quality could reduce the productivity of plants. The most sustainable and less degradable land use system in terms of the carbon sequestered in the study was ranked as: uprooted oil palm plantation > oil palm plantation > cocoa under deep litter > cocoa under shallow litter > arable land > cocoa under weed.

Higher carbon sequestered in the cocoa plantation under deep litter than cocoa under shallow litter and under weed could be attributed to the low organic inputs to the soil under the latter systems. Also, weed infestation tended to constrain carbon sequestration in the soil. In cocoa plantation where litter fall was thick, soil carbon sequestration was high. This is due to continuous decomposition of the accumulated litter under the system. The thick litter also reduced the amount of CO_2 gas emitted into the atmosphere. The implication is that, crop residue application as surface mulch could play an important role in the maintenance of soil organic carbon levels and productivity. According to Roose and Bathes [17] surface mulching increases recycling of nutrients and minerals, fertilizer use efficiency, improves soil chemical and physical properties and, decreases soil erosion.

In spite of the higher carbon sequestered under cocoa plantation with deep litter than shallow litter and weeds, the amount sequestered was less than that under the uprooted oil palm followed by maize and oil palm plantation. The lower decomposition rate of the cocoa litter than the in situ accumulated oil palm fibrous roots may account for this observation.

Continuous cultivation of the arable land led to a decrease in the amount of organic carbon stored in the soil as compared to the uprooted oil palm plantation, oil palm plantation and cocoa under deep litter. In agricultural systems, because the economic parts of the plants are harvested, only a small percentage of the production becomes available for incorporation into soil to enhance the organic carbon pool. All the aboveground production may be harvested, leaving only the root biomass [3]. The low SOC recorded under the arable land could be attributed to the little organic inputs from its component crops (cassava and plantain).

Table 2 Soil organic carbon and its equivalent CO_2 sequestered under different land uses

Samples	**Organic carbon Mg ha^{-1}**	**CO_2 Mg ha^{-1}**
Uprooted oil palm followed by maize	40.2	147.4
Oil palm plantation	33.2	121.7
Cocoa under deep litter	26.3	96.6
Cocoa under shallow litter	17.5	64.1
Arable land (plantain + cassava)	16.2	59.5
Cocoa under weed	13.7	50.4
CV (%)	13.4	13.4
Lsd ($p< 0.05$)	6.0	21.9

Using the uprooted oil palm plantation followed by maize (the land use system emitting the least CO_2) as the basal value for comparison, the percentage increment in CO_2 emission by the other land use systems ranged from 17.6 to 66.0 % of the carbon sequestered (Table 3). These values corresponded to a ranged between 7.0 and 26.5 Mg ha^{-1}. Although the general perception is that cocoa plantation sequesters substantial amounts of soil carbon and thereby mitigate climate change [18], the study showed that the magnitude of sequestration is even more under the oil palm plantation. It is further shown that CO_2 emission is significantly greater under cocoa than oil palm and even more when the cocoa plantation is not well managed (i.e. under shallow litter and under weeds). On this score, the potential of oil palm farmers to benefit from carbon credits needs to be carefully examined.

Soil under the arable land recorded higher emissions than the oil palm plantation and the cocoa plantation under deep litter. Land use change and soil degradation processes as well as rapid decomposition of organic matter in cultivated soils were the major cause for the release of CO_2 from the system as the land use systems that added more residues recorded less emission of CO_2. The conversion of natural vegetation to other uses therefore reduces the carbon pools and increase CO_2 emissions.

Reducing such emissions, including other greenhouse gases is a necessary strategy for controlling global warming. Increased CO_2 emissions contributes to global warming. Lal [2] posited that if 8 % of the carbon being photosynthesized by the biosphere is retained within the soil and biotic pools, the global carbon budget could be balanced. The following management practices could be adopted to enhance carbon sequestration in soils of arable lands.

- No-till farming coupled with residue mulch and cover cropping
- Incorporation of crop residue into the soil rather than burning
- Integrated nutrient management (INM) which balances nutrient application with judicious use of organic manure and mineral fertilizers
- Inclusion of rotations and intercropping in the management system

Table 3 Emissions of CO_2 using the uprooted oil palm plantation as the standard

Samples from different land use	**CO_2 Emissions (Mg ha$^{-1)}$**	**CO_2 Emissions (%)**
Uprooted oil palm followed by maize	147.4*	-
Oil palm plantation	7.0	17.4
Cocoa under deep litter	13.9	34.6
Cocoa under shallow litter	22.7	56.5
Arable land (plantain + cassava)	24.0	59.7
Cocoa under weed	26.5	65.9

147.4* = The amount of CO_2 sequestered under uprooted oil palm followed by maize and was use as the basal value for comparison between the land use systems

4. CONCLUSIONS AND RECOMMENDATIONS

The study showed that the conversion of land into different land use systems results in variable magnitudes of carbon sequestered. The land use systems that sequestered more carbon and less CO_2 emission was ranked as: uprooted oil palm plantation followed by maize> oil palm plantation> cocoa under deep litter> cocoa under shallow litter> arable land> cocoa under weed. The CO_2 emission ranged between 17.4 to

65.9 % depending on the type of land use. The study also showed that, the magnitude of carbon sequestration is more under oil palm plantation than cocoa plantation. The CO_2 emission was significantly greater under cocoa plantation than oil palm plantation and even more where the cocoa plantation was not well managed (i.e. under shallow litter fall and weeds). The land use systems that added more residues recorded less emission of CO_2. Finally, it was observed that plantation agriculture increases the SOC content than arable agriculture.

Agriculture practices can lead to increased global warming if proper land management systems are not instituted. Global warming can worsen the climate change effect as a result of increased heterotrophic respiration and further decomposition of soil organic matter. To use cocoa to offset climate change, short duration cultivars that produce a lot of litter throughout the dry season are recommended. Appropriate land management practices that reduce CO_2 emissions are also recommended to reduce global warming.

The hypothesis of the study as stated in section 1.1 was accepted based on the findings.

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