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Evaluation of the Capacity of Agroforestry of Cocoa Trees in Atmospheric Carbon Dioxide Reduction

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ABSTRACT: The emission of greenhouse gases into the earth's atmosphere has been credited as the major cause of climate change which is being experienced all over the world. Climate change mitigation is one of the strategies that have been suggested as a way of stabilising the concentration of greenhouse gases in the atmosphere. This study assessed the capacity of agroforestry of cocoa trees in reducing atmospheric carbon dioxide. The carbon content in the cocoa plant variables made up of bean, litter, leaf and podhusk were determined in the laboratory through standard procedure. The laboratory results were subjected to descriptive and inferential statistical techniques. The study showed the magnitude order of carbon storage in cocoa agroforestry as cocoa bean (2.86 kg) > pod husk (2.73 kg) >cocoa litter (2.65kg) >cocoa leaves (2.62 kg) > soil (1.14 kg).).The ability of cocoa and forest soils to retain nitrogen, leaf and litterfall to stock more carbon proved that cocoa agroforestry has a higher potential of mitigating climate change in the tropical region. The study recommended the adoption of agroforestry systems which are capable of sequestering carbon as a means of addressing the challenge of climate change.

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Environmental changes particularly those relating to climate change have been linked to the build-up of greenhouse gases in the earth's atmosphere. The adverse impact of climate change affects different facets of life globally. Some of the impacts are on human health, the earth's ecosystems and socio-economic development. Changes in climate have been linked to the transmission of important water-borne diseases by altering their geographic range, thus bringing them to regions whose populations have weak immunity and a weak public health infrastructure (WHO, 2007; Franchini and Mannucci, 2015; Hong *et al*., 2019). Global climate change is anticipated to alter freshwater temperatures, water chemistry and circulation (Ficke *et al*., 2005).In some cases, the production of food is affected leading to high rate of food importation, illegal migration, industrial liquidation, high cost of production among others. Akinyemi (2016) attributed the series of conflicts and clashes which are now being reported in the savannah region of Nigeria to climate change. Biodiversity loss as a result of man-environment interaction through mechanized agriculture, increase in population, urbanization and industrialization especially in developing countries of Africa are also some of the impacts. Due to these activities, the carbon pool in the physical environment has increased and consequently atmospheric carbon dioxide. Over the last three decades of the 20th century, the Gross Domestic Product (GDP), per capita income and population growth have been the main drivers of increases in greenhouse gas emission (Aye and Edoja, 2017). The Intergovernmental Panel on Climate Change (IPCC) in 2007 reported that human activities are the major cause of the increase in global temperature. Several studies have emphasized that the impact of destruction of ecosystem and biodiversity loss has a great impact on climate change (Pearson *et al*., 2017; Sintayehu, 2018; Nunez *et al*., 2019). To reverse this adverse trend, the appropriate strategy to apply would be that of biodiversity approach. Different approaches such as mitigation and adaptation have been suggested in combating the challenges of climate change. However, to strategically manage climate change through biodiversity approach, agroforestry system and principles require global attention because it is the easiest and most suitable system of reducing the atmospheric carbon. Some measures which have been used to sequester carbon include the conversion of marginal lands to native system, the practice of

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conservation-till farming, reduction in the frequency of summer fallow in crop rotation, and the incorporation of organic amendments such as manure (USDA, 1998; Lal 2004). Globally, forest contains more than half of all terrestrial carbon, and account for about 80% of carbon exchange between terrestrial ecosystems and the atmosphere (Gbadegesin, 2011). According to Montagnini and Nair (2004), agroforestry ecosystem stores significant amounts of carbon. The largest amount of carbon present on the land is not in the living plants, but in soil organic matter (Fred and Harold, 2009). The initial attention of agroforestry research was on the interactions between trees, crops, soil and climatic factors on a small area of the landscape which is now changing due to processes on a larger scale (Schroth and Sinclair, 2003). It has been reported that perennial crops have the capacity to store carbon in their biomass thus reducing atmospheric carbon (Nash *et al*., 2016). In mitigating the challenge of climate change, nitrogen fixing and nutrient-rich litter shaded trees have profound capacity and efficiency by reducing the carbon from the atmosphere compared to arable system of farming. The possibility of nutrient and water cycling in perennial tree crops, especially carbon dynamics in the soil-plant-atmosphere system lies on the biodiversity of the area. Trees of different species perform diverse functions. Farmers in the tropical areas are aware that trees perform different functions. Over the years, they have protected, planted, selected and even domesticated some of these trees. Also, afforestation has the potential to result in carbon accretion through the build-up of plant biomass and soil organic carbon (Richter *et al*., 1999). One third of the global soil carbon is found in the tropics, while deforestation and land use change in the tropics have a significant impact on the global carbon cycle through increased rates of carbon emissions (Silver *et al*., 2000; Lemma *et al*., 2006; Gbadegesin, 2011). SOC content characterized the amount of organic matter in soil and it is the building block for all forms of life. Prominent among the perennial tree crops used in agroforestry especially in tropical region confirmed to have stood the test of time in terms of economic values and biodiversity conservation over the decades by many tropical nations is cocoa (*Theobroma cacao*). Apart from the economic value for the producing countries, its environmental benefit in terms of carbon sink via atmospheric carbon sequestration is highly recognized and appreciated. Increasing shade cover, enhanced border plantings or associated woodlots can increase carbon stocks, diversify farmer income, provide better habitat for biodiversity, and improve long-term agricultural sustainability. Therefore using cocoa agroforestry seems to present a promising platform for carbon sequestration and emission reduction in Nigeria and the tropical region at large. This study therefore seeks to assess the capacity of agroforestry of cocoa trees in reducing atmospheric carbon dioxide.

MATERIALS AND METHODS

Study Area: The study was carried out in Ondo State, Nigeria. The area is located between latitude 5^{o} 45'and 7^{o} 52'N and longitude 4^{o} 20' and 6^{o} 05'E and has an area of 15,820 km^2 (Figure 1).

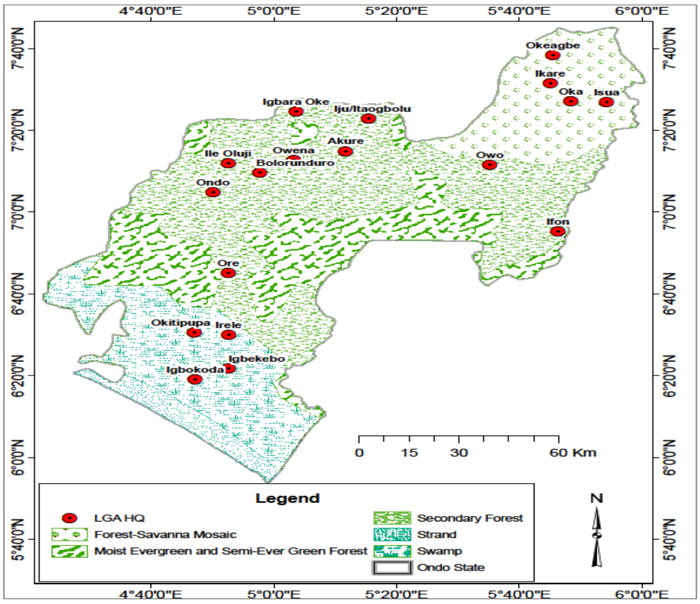

Fig 1: Vegetation Distribution in Ondo State Nigeria
Source: Adapted from Nigerian Geological Survey (2006)

Three communities were selected for study. These are Alade; Idanre, Ijegunma; Owo, Oniparaga; Odigbo which are the areas noted for cocoa production over several decades. The climate of the area is the lowland tropical rainforest which is characterised by distinct wet and dry seasons (Adefolalu, 1997). The rain falls between the months of March and October and is characterised by double maxima rainfall in June/July while the dry season is between November and March. The area has a mean annual rainfall of about 2000 mm and a mean monthly temperature of 27°C (Oyakale *et al*., 2009). The vegetation of the area is classified under rainforest agro-ecological zone. The soil is made up of very deep and well-drained; loam sandy surface, sandy clay and clay loamy subsoil. The area is composed of basement complex rocks. Being an agrarian environment, an average area of the vegetation is under secondary forest. Secondary forest coincides with the cocoa producing areas, especially, the central part. The Forest-Savannah Mosaic predominantly covers Akoko and the Northern parts of Owo L.G.A. of the State. Moist Evergreen and Semi Evergreen Forest is spatially found across the state due to its conversion into perennial crop production as secondary forest. This is evident in Odigbo, Idanre, the Southern parts of Ose, North-eastern part of Ese-Odo, Western part of Ile-Oluji, Central part of Ifedore and the Northern part of Akure. Ilaje, Ese-Odo and Okitipupa are covered by Swamp area while the adjoining coastline area of Ilaje is made up of Strand.

Sample Collection and Analysis: Indigenous and hybrid cocoa farms of average age of 55 years were selected for study in the area. A 25 m by 25 m quadrat was demarcated on each of the farms in Idanre, Owo and Odigbo. Soil samples were collected from twelve (12) points using the random method of sampling. The samples were collected from two different depths 0-15cm and 15-30cm. These depths are described as topsoil and subsoil respectively. Sampling was carried out in these depths because the feeding roots of cocoa are usually found in this zone (Hartemink, 2005; Aikpokpodion, 2010). The soil samples were mixed thoroughly and taken to the laboratory for analysis. Plant variables made up of podhusk, bean, leaf and litter were sampled from each location. Fresh leaves, litter and podhusk were air-dried and pulverized while cocoa beans were fermented for five (5) days and sun-dried followed by grinding to powder before chemical analysis according to Aikpokpodion (2010). Organic carbon was determined using the chromic acid digestion method (Walkley and Black, 1934) while organic matter was obtained by multiplying organic carbon value by 1.724 according to Roger (2008). Total nitrogen was determined by the Kjedahl Method (Jackson, 1970). Average carbon stock in cocoa variables was presented in tabular form while multiple regression analysis was used to quantify the influence of cocoa variables on organic carbon storage.

RESULTS AND DISCUSSION

The natural soil-plant-atmospheric nutrient dynamism is directly and significantly influenced by the major land use. Agroforestry system plays an important role in carbon sequestration. According to Houghton *et al*., (1993), reforestation is one of the strategies that can be employed to reduce the emission of carbon into the atmosphere. This is contrary to the proposed cattle colonies that predisposed the forested area to pasture of low carbon storage capability. Cocoa is the most important agroforestry crop in tropical regions due to its economic and ecological values. Apart from the monetary benefits, it is environment friendly in terms of reducing the atmospheric carbon and nitrogen fixation via the associated shaded trees. It remains the second largest source of internal revenue generation and largest agricultural output for the Nigerian government. In cocoa agroforestry, the carbon storage capacity in cocoa plantations can be compared with the adjacent forest soil by examining the cocoa pod (husk and bean), leaf, litterfall and soil (Table 1).

Table 1: Carbon Stock in Cocoa Agroforestry per kg

Location	Forest Soil	Cocoa Soil	Leaf	Litterfall	Podhusk	Bean
1	2.68	1.82	5.05	5.06	5.30	5.60
2	1.78	3.77	5.39	5.26	5.28	5.58
3	2.23	2.24	5.16	5.29	5.29	5.59
4	2.68	1.86	4.86	4.96	5.31	5.49
5	1.21	1.74	5.15	5.15	5.30	5.62
6	1.95	1.83	5.00	5.21	5.31	5.49
Mean	**2.09**	**2.21**	**5.10**	**5.16**	**5.30**	**5.56**
Sandy-clay		9.47%	21.86%	22.12%	22.72%	23.83%

Source: Authors Fieldwork (2016)

The organic carbon quantity varies for different parts of cocoa ecosystem and period of the year. It is usually concentrated in the upper organic layer, close to the soil surface or on the soil surface. The first two components are of nutrient output (podhusk and bean) while others are input (leaf and litterfall). Cocoa bean and podhusk considered to be output were shown to have the highest carbon concentration followed by leaf and litter while soil was least ranked. The lowest concentration in the soil may be due to the fact that roots take up nutrients into different parts of the plant. In order of magnitude, cocoa bean (5.56 kg), podhusk (5.30 kg), litterfall (5.16 kg), leaf (5.10 kg) and cocoa soil (2.21 kg), that is Sc < L < Lf < P < B, respectively (Table 1). This opposes Sonwa *et al*. (2009), who stated that associated plants stored 70%, cocoa 5%, root 7% and soil 15% of carbon stock in cocoa ecosystem. The basis for the contradiction lies on the exclusion of cocoa roots and its associated plant parts such as bark, twig and branches. Lal (2004) reported that the estimated amount of carbon in the soil is more than that in the biotic and atmospheric pool. Gbadegesin, (2011) noted that the soil organic carbon pool is higher than the atmospheric pool and biotic pool. However, cocoa pod (husk and bean) is 5 times, cocoa leaf and litter 2.3 times of carbon storage in the cocoa plot and forest soil. Also, conversion of the five parts of cocoa tree parameters considered in Table 1 from percentage to kilogram amounts to 12 kg of carbon storage seasonally, which is considered low when compared to other cocoa biomass such as tree, roots, branches and bark. Perennial crops have proved to be beneficial because they sequester carbon in the soil and their tree biomass thus mitigating climate change. In mature cacao trees, aboveground biomass ranges from 20-40 kg per tree (Somarriba *et al*., 2013; Mohammed *et al*., 2015). Increased tree biomass resulted in increased carbon sequestration. According to Dexter (2010), the average tropical tree sequesters 22.6 kg of carbon per year. Carbon sequestration potential of tropical agroforestry systems produced a median sequestration value of 95 metric tons per hectare per year. Assuming a median of 95,000 kg divided by 1250 trees per hectare, one would get 76 kg per tree. In managed plantations, trees are often culled back to about 600 trees per hectare, which would result in 158 kg per tree per year (Dexter, 2018). Considering 12 kg of SOC for a cocoa tree multiplied by 600 trees per plantation exclusive of shaded trees would give a total of 7200 kg per year. Hence, multiplying this by 5,000 hectares of land proposed for cattle colony by the Federal Government of Nigeria, it totals 36000000 kg per state and 504,000,000 kg for the 14 Cocoa producing States in Nigeria annually. Carbon content in evaluated variables were determined using multiple regression equation in conjunction with determination of the dry mass and carbon content of the tree (Table 2).

Table 2: Multiple Regression Analysis Coefficients of Organic Carbon Storage

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	T	Sig.
1	(Constant)	34.714	9.226		35.195	0.018
	Leaf	3.641	0.128	0.856	28.475	0.022
	Litterfall	-2.528	0.091	-0.406	-27.743	0.023
	Podhusk	-51.567	1.642	-0.768	-31.410	0.020
	Bean	-9.857	0.168	-0.716	-58.508	0.011

Source: Authors Fieldwork (2016)

$$y = 34.714 + 3.641\ (\text{leaf}) - 2.528\ (\text{litterfall}) - 51.567\ (\text{podhusk}) - 9.857\ (\text{bean}).$$

Leaf has the least influence on Soil Organic Carbon with coefficient of 0.856 while litterfall, podhusk and bean negatively influenced organic carbon storage in cocoa ecosystem with p-values less than 0.05. This may be attributed to the fact that litterfall, cocoa bean and podhusk withdraw nutrients from one compartment to the other including carbon.

Nutrients from the aerial parts of the plant are removed into the soil in form of litterfall while a negligible amount is lost through erosion and leaching. Leaf and litterfall are carbon inputs while that of the pod is partial. Bean is however considered as an output. In the process of yield harvest, cocoa pod converges in a designated area in conjunction with the nutrients while bean totally extracts nutrients from cocoa soil-plant ecosystem thereby considered as a nutrient loss channel.

Table 3: Variability of Organic Carbon Storage

	Cocoa Soil	Forest Soil	Leaf	Litter
pH	5.82	5.72	6.55	6.51
Nitrogen (%)	0.64	0.60	0.42	0.28
Carbon (%)	2.21	2.09	5.10	5.16

Source: Authors Fieldwork (2016)

In cocoa agroforestry, organic carbon, organic matter and nitrogen are synergistically interrelated. As carbon dioxide is evolved and nitrogen retained, the C/N ratio narrows until it is again controlled by the lack of easily oxidizable carbon. Both cocoa and forest soil retained nitrogen (0.64 and 0.60) than leaf and litter (0.42 and 0.28) while concentration of carbon was higher in cocoa leaf and litter than the soil. Table 3 shows the storage order of carbon in cocoa farm as litter < leaf < soil respectively. As the rate of loss of carbon dioxide and nitrate stabilize, the C/N ratio returns to the level it had at the beginning (Thompson *et al*., 1993). Organic carbon represents approximately 50% of SOM, so a conversion factor of 2 is often used to estimate SOM concentration (Ann et al., 2017). The SOC content under cocoa farm in this study ranged from 1.74 to 3.77% (0.21 to 0.45 kg) and 1.21 to 2.68% (0.15 to 0.32 kg) in forest soil (Table 1). The fertility of soils under cocoa was lower when compared to the primary forests (Hartemink, 2005). Litterfall in cocoa ecosystem is made up of litter from cocoa and associated shade trees which include branches, twigs, leaves, fruits, and flowers. In many parts of the world, cocoa is produced under natural or planted shade tree. Excess of Soil Organic Carbon is recorded on cocoa farms compared to the adjacent forest soil. This may be due to the quick decomposition of the leguminous shade trees which are interplanted within the cocoa plantations. Ekanade (1990) reported that litter fall from kola decompose faster than those from cocoa which may be attributed to the fact that cocoa leaves are lignified thus they decompose slowly. High concentration of organic carbon under cocoa farm can also be linked to the impact of the litterfall from interplanting tree crops such as kola, citrus and other shade trees. Cocoa and other tree crops are usually considered as secondary forest of lesser nutrient comparable to the primary forest. According to Ofori-Frimpong *et al*. (2010), organic carbon content of soil in the secondary forest was significantly higher than in the cocoa system. Woodruff (1949) noted that cultivation of virgin soils leads to decline in organic carbon content. The increase in the content of organic carbon and total nitrogen in the secondary forest can be attributed to the increase in plant diversity and cover which provides a large amount of biomass that decomposes to form nutrient in the soil (Deekor *et al*., 2012). Cocoa plant is characterized with surface feeder roots. It has been suggested that a minimum requirement of about 2% organic carbon in the top 15cm of soil is good for cocoa growth (Ahenkorah, 1979). All examined soils under indigenous cocoa farms have their organic carbon above 2%, twig, bark and roots that also stock their own carbon as well. This may be related to other parts of the plant; also be linked to other plant parts; branches, large girth, height, pod size and weight and yield compared to the indigenous species. Hartermink (2005) noted that nutrients immobilized in the stem and branches of cocoa and the associated shade trees are also lost in the system because they are not included in the process of nutrient cycling. The IPCC (2000) and other studies (Mbow *et al*., 2014; Reppin *et al*., 2020) noted that agroforestry has the capacity to sequester carbon thus aiding climate change mitigation. The findings of this study call for the intensification of agroforestry and biological diversity as a viable and suitable option for managing the challenges of climate change.

Conclusion: Apart from the economic value of cocoa agroforestry in the tropical rainforest, its stability and capability of storing carbon in its components serving an effective strategy in mitigating global climate change cannot be underscored. Variation in the magnitude order of carbon storage in cocoa components also proved beyond reasonable doubt that the plant has the capacity to reduce atmospheric carbon dioxide. Intensification of cocoa agroforestry in southern Nigeria will go a long way in addressing Goal 13 of the SDGs which relates to climate action.

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