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Eucalyptus Agroforestry in Tea Plantation on the Mambilla Plateau: Influence on Carbon Sequestration and Soil Organic Carbon

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ABSTRACT

Tea-Eucalyptus intercropping is common on the Mambilla plateau in order to maximize land use and increase financial income. Carbon sequestration potential of Eucalyptus and effect on soil organic carbon was evaluated. Non destructive method was used in calculating the amount of carbon sequestered in eucalyptus trees while wet chemistry was used in the determination of soil physicochemical properties. Result showed that an average of 19.48 kg CO_2 was sequestered in each tree while soil macro and micronutrients were enhanced in soil cropped with tea-eucalyptus intercrop compared with adjacent tea plantation without eucalyptus trees. Intercropping tea with eucalyptus could be a means of atmospheric CO_2 removal and consequently being a potential choice for carbon trading.

Keywords: Tea, Eucalyptus agroforestry, carbon sequestration, Mambilla Plateau.

INTRODUCTION

Since industrial revolution, there has been a dramatic increase in the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases. The atmospheric concentration of CO_2 has risen from 285 ppmv in 1750 to 379 ppmv in 2005 and is increasing at a rate of 1.4 ppmv per year (Forster *et al.* 2007). Similarly, the atmospheric concentration of nitrous oxide (N_2O) has increased from about 270 ppmv in 1750 to 319 ppmv in 2005 and is increasing at the rate of 0.84 ppmv per year (Forster *et al.* 2007), this enrichment of green house gases in the atmosphere is anthropogenically driven with fossil fuel usage and land-use change being the principal agents for CO_2 emissions, while agriculture is the principal source of CH_4 and N_2O.Carbon sequestration is a natural method for the removal of carbon from the atmosphere by storing it in the biosphere (Chavan and Rasal, 2010). A carbon sink absorbs CO_2 from the atmosphere and stores it as carbon. Trees serve as ~~a~~ sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass. As the rate of photosynthesis increases, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissues above and below ground (IPCC 2003). Eucalyptus spp are a group of trees native to Australia, with small number of species also indigenous to Indonesia, the Philippines and New Guinea (Stanturf *et a.l,* 2013) Eucalyptus dominates most of the natural forests in their habitat, growing in range of diverse climates and soil types (Pohjonen, 1989). Eucalyptus was introduced to the Mambilla plateau in the late 1950s. The tree species outperform other tree species in terms of production and farmers income generation. This can be attributed to a number of biological and physiological characteristics including fecundity, rapid growth rates (Leicach *et al.* 2012)and tolerance for a wide range of soil and climate niches (Zegeye , 2010) . It is also tolerant to severe periodic moisture stress and low soil fertility (Davidson, 1989). Eucalyptus is the main source of fuel wood, timber and wood works on the Mambilla plateau. Due to its adaptability in the semi temperate climate, it is the most popular economic tree species on the plateau. Timber from Eucalyptus is virtually used for most furniture works on the plateau. Consequently, most farmers who abandoned *Coffee arabica* cultivation due to fall in price several years back, went into mass cultivation of eucalyptus which now serves as major source of income for its growers. Eucalyptus being a hardwood and good for charcoal coppices readily and rejuvenates almost immediately after tree felling. In addition to wood products, Eucalyptus plantations are also used for honey production on the Mambilla plateau. Collectively, the multipurpose nature of eucalyptus contribute to its efficacy as a major tree species grown by smallholder farmers on deteriorated soils with low fertility status. Currently, timbers from Eucalyptus on Mambilla plateau are transported to various parts of Nigeria for various categories of wood works by timber merchants. The economic value ascribed to Eucalyptus has made many tea farmers adopt a farming system where tea is intercropped with Eucalyptus for the purpose of maximizing land

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utilization and enhanced financial income. Information on carbon sequestration as influenced by intercropping tea with Eucalyptus in Nigeria is limiting. In view of this, the study evaluated the impact of agroforestation of tea plantation with Eucalyptus on carbon sequestration and soil fertility.

MATERIALS AND METHODS

Study location

Mambilla Plateau is a plateau in Taraba State of Nigeria. The plateau has an average elevation of 1,600 meters above sea level making it the highest altitude in Nigeria. Some of the villages on the plateau are situated on hills higher than 1,700meters above sea level. Among the villages is Nguroje which is more than 1,800 meters above sea level. There are other locations on the plateau that are approximately 2,000 meters above sea level. The plateau covers an area of over 9,389 square kilometers (Leva, 2007). Mambilla Plateau receives an average annual rainfall of over 2,800mm. In 2018, it received a total rainfall of 3,157.73 millimeters from 111 rainy days of the year (CRIN, 2018). The climate of the plateau is semi temperate in nature. Outdoor temperature taken by 7.00 am hardly exceeds 19^{o}C. It can be as low as 13^{o}C during winter. At noon, temperature ranges between 14 and 30^{o}C depending on the period of the year. The increase in day time temperature on the plateau in recent time is due to climate change. The study was carried out at the Cocoa Research Institute of Nigeria, Mambilla substation located in Kusuku village (N 6.8777; E 11.1322) Taraba State, Nigeria. The experiment was carried out in an existing tea-eucalyptus intercropped plot and monocropped tea plantation adjacent to the intercropped plot. Ten core soil samples (0-20cm depth) were taken from both plantations separately with soil auger. The samples from each plot were thoroughly mixed together to obtain two separate composite samples. Tea leaves were also obtained from the two experimental sites. Soil and plant samples were processed according to standard procedures.

Soil analysis

Sub-samples meant for major cations analysis were leached with 1N ammonium acetate. The leachate was analyzed for exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) determination (Schollenberger and Simeon 1945). Soils were analyzed for particle size by the Boyocous hydrometer method. Soil pH was measured with glass electrodes in 1:1 soil-water suspension. The organic carbon was determined according to Walkley and Black (1934). Total Nitrogen was determined by the Macro Kjedahlmethod (Bremner,1996).Available Phosphorus was determined using Mehlich 3 method (Mehlich, 1984). Mehlich 3 extracting solution was preferred to Bray 1 solution (Bray and Kurtz, 1949) owing to the inability of Bray 1 solution to extract available phosphorus from the soil samples at detectable level.

Carbon sequestration determination

The non destructive method of carbon sequestration (Saral *et al*, 2017)was used to quantify carbon sequestered in the tea-eucalyptus plantation.

The biomass of tree was estimated on the basis of Diameter at breast height (DBH) and tree height. DBH was determined by measuring tree Girth at Breast Height (GBH), approximately 1.3 meter above the ground. The GBH of trees having diameter greater than 10cm were measured directly using measuring tape.

Above ground Biomass (AGB) of Tree

The above ground biomass of tree includes the whole shoot, branches, leaves, flowers and fruits. It was calculated using the formula:

AGB (kg) = Volume of tree (m^3) x wood density kg/m^3. $V = \pi r^2 H$

Where V = volume of the cylindrical shaped tree in m3

R = radius of the tree in meters

H = Height of tree in meter

Radius of tree was calculated from GBH of the tree while the value of wood density was obtained from Global density database. The standard average density is 0.6gm/cm

Below ground Biomass (BGB)

The below ground biomass includes all biomass of live roots excluding fine roots. The BGB has been calculated by multiplying AGB X 0.26 factors as the root:shoot ratio,

BGB (kg/tree) = AGB (kg/tree) X 0.26

Total biomass was calculated by the summation of Above Ground Biomass (AGB) and Below ground biomass (BGB) i.e TB = AGB (kg/tree) + BGB (kg/tree)

Carbon stored in each tree was calculated by multiplying the total biomass by 50%

Determination of the weight of CO_2 sequestered in the tree

The weight of CO_2 is C + 2 X O = 43.99915

Hence, the ratio of CO_2 to C was calculated as 43.99915/12.001118 = 3.6663

Hence, in order to determine the weight of CO_2 sequestered in the tree, the weight of carbon in the tree was multiplied by 3.6663

RESULT AND DISCUSSION

Carbon sequestration in Eucalyptus trees

Calculated above ground biomass was 8.44 kg per tree, while the below ground biomass was 2.194 kg per tree on the average. Result of carbon sequestration in eucalyptus trees within tea-eucalyptus intercrop plot in Mambilla substation showed that on the average, 19.48 kg of CO_2 was sequestered in each eucalyptus tree. Saral *et al*. (2017) reported CO_2 sequestration of 35.681, 8.70, 52.58, 25.67 and 23.90 kg per tree for Sausage tree, Neem tree, Cork tree, Silver tree fern and Yellow flame tree respectively. On the overall, approximately 10 tonnes of CO_2 was sequestered in all the available eucalyptus trees within the tea-eucalyptus intercrop. The outcome of the study implies that, eucalyptus tree has economic potential to be used in carbon trading which involves the use of forest in cleaning up the environmental hazards. Estimation of carbon content in forest woody biomass is important with regard to Greenhouse effect mitigation. Wooden perennials during their growth absorb CO_2 from the air during photosynthesis in such a manner to sequestrate carbon in biomass thereby, decreasing the concentration of the greenhouse gas in the air. For this reason, forest trees are regarded as Carbon pools or Carbon sinks.

Table 1: Chemical properties of soils under eucalyptus and outside eucalyptus

Parameters	Soil outside Eucalyptus	Soil under Eucalyptus
pH	4.82	5.00
P (ppm)	9.55	9.96
Na ($cmolkg^{-1}$)	0.31	0.28
K($cmolkg^{-1}$)	0.32	0.34
Ca ($cmolkg^{-1}$)	1.31	1.47
Mg ($cmolkg^{-1}$)	1.28	1.39
Al+H	0.27	0.13
N (%)	0.27	0.48
Org C (%)	4.42	5.13
Cu ($mgkg^{-1}$)	0.90	1.45
Zn ($mgkg^{-1}$)	2.89	3.73
Mn ($mgkg^{-1}$)	13.50	15.65
Fe ($mgkg^{-1}$)	13.95	13.53

Note: values are means of three replicates.

Soil sample obtained under tea- eucalyptus intercrop had higher concentration of exchangeable K, Ca, Mg, Zn, Mn, total N, organic carbon, available P and pH compared with soil samples under mono-cropped tea plantation (Table 1). The higher organic carbon in soil under tea-eucalyptus intercrop compared with soil under mono-cropped tea plantation was due to leaf litter fall from the eucalyptus trees. The effect of leaf litter on soil chemical properties obtained in this work is in agreement with the report of Sarkar *et al.*, (2010) in which leaf litter increased soil pH, organic matter, total N, available P, exchangeable K, Ca and Mg. Leaf litters are rich in organic matter after decomposition and mineralization which increases the total organic matter content of the soil. Decomposition of leaf litter is an integral and significant part of biochemical nutrient cycling. Decomposition refers to both the physical and chemical breakdown of litter and the mineralization of nutrients (Boulton and Boon, 1991). Through decomposition of plant materials, nutrients locked up within leaf litter are converted into bio-available form for plant uptake. This was evident in the result of chemical analysis of tea leaves obtained from both experimental sites. Result of the analysis (Data not shown) showed that, tea leaves obtained under tea-eucalyptus intercrop were higher in N, P, K, Ca, Mg, Zn, and Mn compared with tea leaves obtained from the mono-cropped tea plantation. Litter plays a fundamental role in the turnover and in the transfer of energy between plants and soil. Higher organic matter occasioned by eucalyptus leaf litter fall in sample obtained from eucalyptus-tea plantation might also have been responsible for higher nitrogen content of soil under eucalyptus-tea intercrop compared with mono-cropped tea. This can occur through the activities of humus in soil organic matter. Organic matter decomposition produces humus which is a valuable reservoir of nitrogen. Humus contains 10% nitrogen. Aside being a source of soil nitrogen, chemical properties of humus also contributes to the retainability of nitrogen in soil via enhanced anion exchange capacity. Loss of soil nitrogen via leaching and runoff is high on the

Mambilla plateau due to high annual rainfall (2,800-3,400 mm) and land steepness. Owing to the fact that nitrate is negatively charged (anion), it is not attracted to the negatively charged edge of clay in the soil. Rather, the spongy soil humus with high anion exchange capacity provides means of attraction for nitrate thereby reducing its proneness to leaching and runoff. In agroforestry, there are both ecological and economical interactions between the different components (Nair, 1989). In contrast to temperate ecosystem, where soils are more fertile and a greater part of the nutrients is supplied by the weathering of parent materials, conditions of high temperatures and rainfall in the tropics accelerate soil processes, including loss of nutrients, so that the greater stock of nutrients is found stored in the biomass and made available through decomposition (Ricklefs, 1996; Primavesi, 2001). The high temperature and humidity of tropical climates are conducive to the decomposition of organic matter, so that there is not only the release of nutrients but also the formation of negatively charged particles, which help to retain cations such as Ca, Mg and K and maintain them in constant interface with the soil solution where they can be taken by plants. In tropical soils, the cover of organic matter helps in creating a conducive environment for microflora and fauna that carry out nutrient cycling. Consequently, many of the studies on the effects of trees on tropical soil concentrate on the importance of organic matter from litterfall. Litter production can be a very important contribution in systems where perennial crops are grown under shade of trees. Souza *et al.*, (2004) observed that litter production in a coffee plantation shaded with diverse tree species was similar to that of native forests in the same region. Jaramillo-Botero *et a.l*, (2006) reported that the quantity of accumulated litter and level of K in the soil was positively influenced by the number of trees present in a distance of 0-3 meters from the coffee bushes. Since K is highly mobile in soil, its enrichment may be partly due to throughfall and stem flow, as observed by Pinho *et al.*, (2002) in coffee agroforestry systems. Also in coffee systems, Jesus *et al* (2006) found higher pH and base saturation in areas intercropped with rubber *(Hevea brasiliensis*) than in monocultures. The studies suggest that roots of trees occupy deeper soil layers that may not be accessible to other crops or that they are more efficient in extracting nutrients, due to their greater size and possibly through association with mycorrhizal. As such, comparison with other agricultural systems in tropical conditions implies that, agroforestry can accumulate greater amounts of carbon and help maintain soil fertility through a more efficient cycling of nutrients and a reduction of losses through leaching and erosion (Pinho *et al.*, 2012)

CONCLUSION

Eucalyptus trees planted in tea plantation have the potential to sequester carbon in their biomass by the absorption of CO_2 from the atmosphere thereby reducing the greenhouse effect of the gas in the atmosphere. Intercropping tea with Eucalyptus increased soil organic carbon which is a good index for soil health. Concentrations of soil macronutrients and micronutrients were enhanced in soil as a result of Tea-Eucalyptus intercropping. Massive cultivation of eucalyptus on the Mambilla plateau could be a source of carbon trading in the nearest future. Hence, increased Eucalyptus planting on the plateau should be encouraged for environmental benefits in addition to the benefits accrued to its existence on the plateau.

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Fig 1: Agroforestry system at kusuku village on the Mambilla Plateau with Tea plant (*Camellia sinensis*) as principal cash crop intercropped with Eucalyptus.

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