Journal of Environmental Sciences and Resource Management *Volume 4, March 2012*

www.cenresin.org
ISSN 2277-0097

ORGANIC CARBON AND TOTAL NITROGEN STATUS OF SOILS UNDER RUBBER PLANTATION OF VARIOUS AGES, SOUTH-SOUTHERN NIGERIA

[1]Njar, G.N.; [2]Iwara, A. I.; [2]Ekukinam U. E.; [3]Deekor, T. N. and [2]Amiolemen, S. O.
[1]Department Geography and Environmental Studies, University of Calabar, Nigeria
[2]Deparment of Geography, University of Ibadan, Nigeria
[3]Department of Geography and Environmental Science, University of Port Harcourt, Nigeria
E-mail: iwaradream2008@yahoo.com

ABSTRACT

In the tropics, the continuous destruction of the forest mostly for food crop cultivation accompanied with high rainfall in the region has resulted in the rapid loss of soil nutrient, thereby making most soil infertile. The need to restore and conserve soil fertility for agricultural productivity has led to the planting of forest trees/plantation with the sole aim of improving the nutrient balance of soil by reducing unproductive nutrient losses from erosion and leaching. The study examined the trend of organic matter and total nitrogen in rubber plantation plots of 7, 16, 39 and 41 years. The grid system of sampling was employed to collect soil samples from five quadrats of 10m x 10m in each of the plantation plots. Result showed that pH of the soils decreased with the age of plantation, while the content of organic matter (OM) and total nitrogen (TN) increased with the age of trees probably as a result of the increase in vegetation cover and tree size. This is so, as mature rubber trees have a large biomass which not only affords the ground adequate cover, but also acts as a huge reservoir of nutrients, thereby preventing them from being leached away from the plantation. The study revealed that rubber trees had no adverse effect on the depletion of OM and TN status in the soil. However, for sustainable rubber production, mature rubber trees in plantation plots should be properly managed through routine treatment, as well as selectively replaced with new ones.

Keywords: Rubber Plantation, Organic Matter, Total Nitrogen, Age of Plantation, Tree Size, Vegetation Cover, Biomass

INTRODUCTION

Rubber tree (*Hevea brasiliensis* Muel. Argo.) is one of the major forest trees grown in the rainforest belt of Nigeria. Rubber plantation like any other forest tree has a lot of ecological and edaphic effects on the soil and the atmosphere. Forest trees are known (Ogunkule and Awotoye 2011; Attoe and Amalu 2005; Shukla 2009) to bring about changes in edaphic, micro-climatic, flora, fauna and other components of the eco-system through bio-recycling of mineral elements, environmental modifications (including thermal and moisture regime) and changes in flora and fauna composition among others. Trees can improve the nutrient balance of soil by reducing unproductive nutrient losses from erosion and leaching and by increasing nutrient inputs through nitrogen fixation and increase biological activities by providing biomass and suitable microclimate (Ogunkunle and Awotoye, 2011). Indeed, forest tree plantations on arable lands have been shown to be an effective way to enhance carbon sequestration (Zhang et al. 2007; Johnsen et al. 2001; Zilberman and Sunding 2001). Forest soils are one of the major sequesters of carbon on earth due to their high organic matter status (Dixon et al. 1994). Carbon sequestration is thus the removal of CO_2 from atmosphere (source) into green plants (sink) where it can be stored indefinitely (Lal 2005). However, nitrogen (N) and organic carbon (OC) are the most complex and crucial of the macro elements essential for plant's life, and they play crucial roles in nutrient cycling, water, root growth, plant productivity, and environmental quality (Yang et al. 2004; Sainju 2002). The proportions of OC and N in the soil are good indicators of soil quality and productivity due to their favourable effects on plants. Organic carbon influences many soil characteristics including colour, nutrient holding capacity (cation and anion exchange capacity), nutrient turnover and stability, which in turn influence water relations and aeration (Reddy et al. 2005; Meena et al. 2007).

Soils with high clay content, the contribution to cation exchange from the organic fraction is generally small compared to that from clay colloids. However, in sandier soils, the relative contribution of the organic fraction is higher because there are less clay colloids, even though the amount of organic carbon present may be similar or less to that in clays. By providing a food source for micro-organisms, organic matter can help improve soil stability by binding soil particles together into aggregates or 'peds' (Pluske et al. 2005). Nitrogen (N) is the macronutrient often limiting the growth of plants on soil (Michopoulos et al. 2008). Soil total nitrogen (TN) has long been identified as a factor that is important to soil fertility in both managed and natural ecosystems (Kucharik et al. 2001). The concentration and availability of N in the soil directly influences plant productivity. Numerous field studies have shown that crop management practices can either enhanced or diminish quantities of soil OC and soil TN together (Bauer and Black 1981; Potter et al. 1998; Knops and Tilman 2000). Nevertheless, previous studies by many authors (Aweto 2001 and Cheng et al. 2007) reveal that with increase in age of plantation plots, soil nutrients are depleted, thus, plantation age becomes a factor in determining soil nutrient balance and fertility status.

The importance of OC and TN to the fertility of tropical soils is well recognized (Greenland and Nye 1959; Greenland and Nye 1960; Aweto 1981; Uhl et al. 1981; Greenland 1997; Lal 2005; Yasi et al. 2010). The contributory effects of forest trees on soil nutrient cycling has also been reckoned in the past by scholars; as studies abound on comparing the pool of soil organic carbon between mature plantations and native forest or immature plantations (Ogundele et al. 2011; Araujo et al. 2005; Duah-Yentumi et al. 1998; Wang and Li 2003; Yang et al. 2005). In addition, varying studies have been carried out to assess the nutritional status of soils under rubber plantation of different ages (Yasin et al. 2010; Dharmakeerthi et al. 2005; Attoe and Amalu 2005; Zhang et al. 2007), but the trend of increase in OC and TN as essential soil nutrients in the soil at varying ages of rubber plantation has been little investigated. The knowledge on OC and TN trends in soils of rubber plantation enables sound management practices to be carried out to increase its productivity as an economic base as well as help to improve soil nutrient for sustainable rubber production. This study therefore examines the trend of OC and TN in rubber plantation soils of different ages.

REVIEW OF RELATED LITERATURE ON FOREST TREES/PLANTATION

In the tropics, plantation agriculture featuring the production of forest trees in monocultures and large commercial estates has gained widespread acceptance and has consequently become an important feature of the agricultural economy of tropical Africa (Aweto and Enarube 2010). The plantation system of agriculture is assuming increasing popularity, particularly in tropical countries such as Malaysia, Indonesia, Cote d'Ivoire, Nigeria and many other parts of the world. Plantation forestry is therefore becoming a necessity in view of the fact that there is an increased demand for wood products and environmental conservation (soil fertility management). The development of a forest plantation like any other form of land use, leads to changes in ecosystem characteristics and element fluxes (Samndi et al. 2006; Oyebande et al. 2010). However, several studies have been carried out to understand the importance of forest trees (plantation) on soil conservation. For example, Yasin et al. (2010) studied changes of soil properties on various ages of rubber trees in Dhamasraya, West Sumatra, Indonesia. The result indicated that the age of rubber tree strongly affected the physical and chemical properties of soil. Organic carbon and total nitrogen contents decreased from 3.02%, 2.66%, 1.96%, in the forest plot, crab grass plot and 1 yr plantation plot, and then increased to 2.33% and 2.49% in the 10 yrs and 15 yrs plantation plots respectively. Similar pattern was also found for selected chemical properties of soil. Soil pH, available phosphorous, exchangeable base cations, cation exchange capacity and base saturation decreased from the 1^{st} to 10th years old plantation plots and then increased close the natural condition (reflected by forest soil) at 20 years old rubber tree.

Aweto and Ishola (1993) studied the impact of Cashew (*Anacardium occidentale*) on forest Soil. The impact of a 20-year-old cashew plantation on a forest soil was evaluated by comparing the properties of soil under cashew with that under an adjoining logged rain forest. The levels of organic carbon, nitrogen, exchangeable calcium and magnesium, and available phosphorus were similar under logged forest and cashew, suggesting that organic matter and nutrient cycles in a cashew plantation are similar to those in a logged rain forest and that cashew has no significant adverse effect on soil organic matter and nutrient status. Geetha and Balagopalan (2009) studied soil fertility variations within a rotation period in teak plantations in Kerala. Result showed that organic carbon in teak plantations varied from 0.9 to 2.3%. The mean values of nitrogen varied from 0.21 to 0.27%. In all, organic carbon and nitrogen were significantly lower than that in the natural forest. Soils of both teak plantations and natural forest were poor in exchangeable phosphorus. The fertility index values were observed to first decrease and then increase with age of plantations. Zhang et al. (2007) examined chemical degradation of a ferralsol (Oxisol) under intensive rubber (*Hevea brasiliensis*) farming in tropical China. Result implied that rubber cultivation resulted in significant decline of soil organic C and microbial biomass C. Available P was extremely low for all soils, resulting from the naturally low P content and the high sorption capacity of highly weathered ferralsol. Furthermore, soil pH decreased by about 0.5 units, accompanied by an increase of exchangeable Al by more than one-fold. In order to maintain tropical soil quality, farming practices such as liming and organic amendment were recommended to be best management practices of rubber farm.

Ogunkunle and Awotoye (2011) examined soil fertility status under different tree cropping system in a southwestern zone of Nigeria. They contended that tree cropping has been known to bring about changes in edaphic component among other components of the ecosystem through their interactions with the soil and soil faunas. Results showed that the synergistic interaction of leaves decomposition of cocoa and kola improved the organic matter content of the soil under the cocoa/kola site. Considerable improvement in soil fertility was enjoyed in the cocoa/kola site due to the large girth sizes and basal area of trees present in the cocoa/kola site, while soil under the sole cropping of teak was impoverished. The degradation effect was due to the high rate of nutrient uptake of the teak. Hence, organic matter content was high in the forest site (9.12%) and cocoa/kola site (7.34) while the least was in the teak site (3.04%). From the review, it is evident that forest trees exert significant impact on the buildup of nutrient in the soil, depending mostly on the tree species as well as management practice adopted. Soil nutrient on the one hand increases with age of plantation, and on the other decrease showing inverse relationship. However, irrespective of the trend in nutrient accretion in plantation farms, what matters most is indeed, the type of site management technique adopted by the farmer and land manager to ensure the continuous nutrient fluxes as well as improve the nutrient balance of soil by reducing unproductive nutrient losses from erosion and leaching.

MATERIALS AND METHODS

Study Area

The study was carried out in PAMOL (Nigeria) Limited Rubber Estate in Calabar Cross River State between the 7th and 9th of February, 2010. Pamol (Nigeria) Limited, is located in Odukpani L.G.A of Cross River State, Nigeria. It lies between latitudes 05^{0} 00′ and 05^{0} 12′ north and longitudes 08^{0} 15′ and 08^{0} 28′ east (Ekukinam, 2010) (Fig. 1). The area has annual rainfall values of 2000 – 3000mm. The mean annual rainfall is 21^{0} and 30 ^{0}C, while relative humidity ranges from 75 – 80%. The soils are derived from parent materials namely sandstone and shale, the soil is loamy sand has weak medium crumb structure, moist friable (wet) non-sticky plastic consistence, many fine to medium fibrous woody roots and many interstitial pores (Attoe and Amalu 2005). It is vulnerable to active sheet erosion with the removal of vegetation cover. Predominant vegetation in the area is the tropical rainforest subdivided into the dry land rainforest and the fresh water swamp (moist) rainforest. Trees found in the area include *Elaesis guinensis ,Funtumia elastica, Pentaclethra macrophylla, Hevea brasillensis, Anthocleista vogelii,* among others (Ekukinam, 2010).

Fig 1: Odukpani L.G.A. showing Study Area

Soil Sampling

Soils were sampled under rubber plantations of 7, 16, 39 and 41 years. The plantation plots are located within the same environment less than 10m apart; as such, they have similar soil parent materials, topography and climate. In each of the rubber plantation plot, five plots of 10m x 10m were established using the grid system of sampling. In each plot, 5 surface (0-10 cm) soil samples were randomly collected with a soil auger and then composited. The soils were put in polythene bags with labels; they were thereafter air-dried and taken to the laboratory for analysis of soil physical and chemical properties. Particle size composition was determined using the hydrometer method (Bouyoucos 1926); organic carbon by the Walkley-Black method (1934) after which values obtained were multiplied by 1.724 (Aweto 1981) to convert to organic matter; total nitrogen by the Kjeldahl method (Bremner and Mulvaney 1982); available phosphorus was determined by the method of Bray and Kurtz (1945). The soils were leached with 1M neutral ammonium acetate to obtain leachates used to determine exchangeable bases and soil cation exchange capacity, while pH values were determined using a glass electrode testronic digital pH meter with a soil: water ratio of 1:2. In addition, the obtained soil data were analyzed using One-Way ANOVA to determine if significant changes in soil properties existed among the rubber plots of different ages.

RESULT AND DISCUSSION

Physical Properties of Soils

The particle size composition of soil in the rubber plantation is shown in fig 1 – 3. The soils are principally sandy with sand constituting more than 85% of the inorganic mineral fragment in the soil (fig 1). There is no significant variation in the proportion of sand across the plantations. The sandy nature of soil in the plantation indicates that the soils are prone to excessive leaching and loss of nutrient due to their loose texture. Also, the soils cannot provide sufficient mechanical supports for the trees (Attoe and Amalu 2005); this is probably responsible for the tilting of trees in the plantation. The amount of silt in the soil is relatively higher in the 16 years old rubber plot, but low in the 7 years old rubber plot (fig 2). This implies that silt content in the rubber plantation reduces with the age of trees; despite the downward trend in the proportion of silt, there is however no significant variation in the concentration of silt across the rubber plots. There is a steady increase in clay content between the 7, 16 and 41 years old rubber plots, but a decrease in the 39 years old plot (fig 3). The content of clay in the soil does not vary among the plantations. The particle size composition of soils in the plantations is texturally similar, being loamy-sand and having been derived from the same parent material (granite) under the same climate and topography. In addition, the sandy nature of soils (poor physical conditions) in the rubber plantation plots is attributed to the high rainfall which results in weathering of parent materials (Attoe and Amalu 2005).

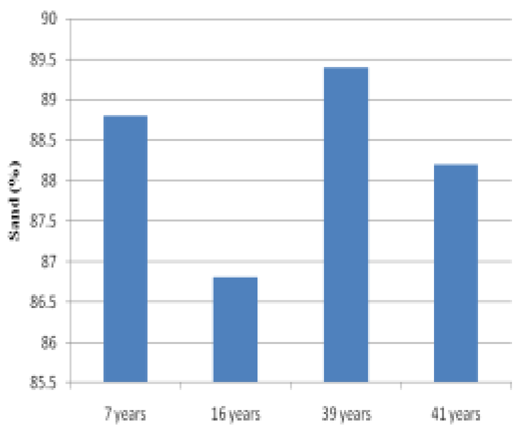

Fig 1. Sand content in the plantation plots

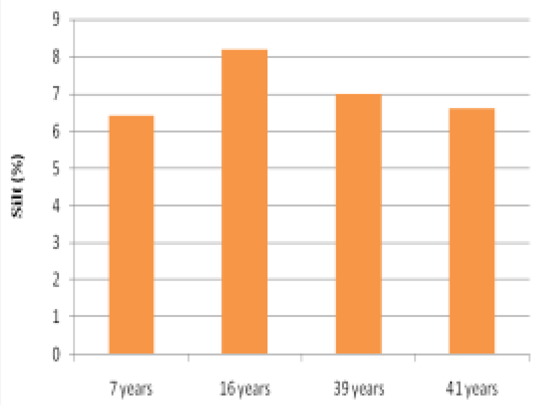

Fig 2. Silt content in the plantation plots

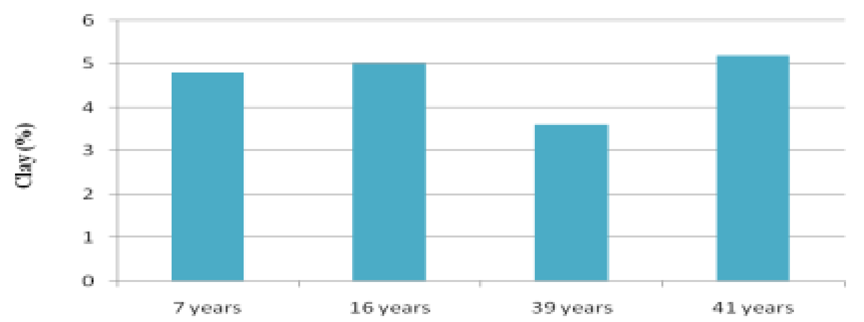

Fig 3. Clay content in the plantation plots

Chemical properties of soils

The chemical properties of soils across the plantation are depicted in table 1. The soils of the area are acidic with a pH range of 4.06 to 4.44. The acidic nature of soil may be attributed to the high rainfall, which is sufficient to leach basic cations especially calcium from the surface horizons of the soils (Paudel and Sah 2003; Foth 2006). Nevertheless, the pH value of the soil in the rubber plots falls within the critical range of 4.3 to 4.6 recommended by Chan et al. (1975) as desirable limits for the optimal growth and performance of rubber in tropical soils. Rubber trees according to Attoe and Amalu (2005) have been reported to thrive in acidic soils. The content of pH however varied significantly among soils of the rubber plantation plots ($p<0.05$) (table 1). In addition, the content of cation exchange capacity (CEC) in the rubber plantation plots increased steadily in the 7 and 16 years old rubber trees with mean values of 3.78 and 4.96cmol/kg^{-1} respectively. It thereafter decreased and increased considerably. The proportion of CEC did not vary among the rubber plantation soils ($p>0.05$).

The increase in CEC in the 16 years old rubber plot is probably because at this time, the number of leguminous plants had increased which decomposed to add nutrient in the soil. Information in table 1 also shows that the content of organic matter (OM) in the soils increased with the age of plantation, invariably age of trees. The content of OM was low in the 16 years old rubber plot with mean value of 0.25%, but, increased steadily from the 39 to the 41 years old rubber plots with mean values ranging from 1.99 to 3.24%, probably due to the increased rate of nutrients returned to the soil through the fall and subsequent decomposition of litter. The low OM content in the 7 and 16 years old rubber plots is attributed to the insufficient cover which is unable to reduce the direct impact of raindrops as well as suppress runoff which results in the loss of nutrient (table 1). However, the content of OM varied significantly among soils of the rubber plots ($p<0.05$). The trend of total nitrogen (TN) in the soil also shows a rapid increase occurred between the 39 and 41 years old plots when there were increases in cover, tree size and the number of legumes (Aweto 1981). Indeed, the content of OM and TN increased with the ages of trees probably as a result of the increase in vegetation cover and tree size. The increase in vegetation cover and tree size implies that raindrop intensity is reduced, loss of soil nutrient through runoff is minimized and more litter is produced which in situ decomposes to form nutrient. The accumulation of OM and TN in the soils is not unique to this study alone, as the soil under tree canopies in the forest is acknowledged to enhance organic matter and nutrient levels compared to soil outside their influence (Greenland and Nye 1960; Aweto and Dikinya 2003). Despite the increase in TN with the age of trees, the content of TN did not vary among soils of the rubber plots ($p>0.05$) (table 1). In addition, the increase in OC and TN in the old plantation plots is because, mature rubber trees have large biomass which not only affords the ground adequate cover, but also acts as a huge reservoir of nutrients, thereby preventing them from being leached away from the plantation. Also, due to the dense cover of the mature rubber trees, nutrient loss from the soil under the tree through leaching is minimal (Iwara 2008).

According to Aweto (1989), litter fall and decomposition is the main means of recycling nutrients back to the soil in the tropical ecosystem; as nutrient cycling in a mature tree is "closed" so as the loss of nutrients from the soil is minimal over time. Although, the acidic nature of soil in the rubber plots of varying ages showed an inverse relationship with age, but the proportion of OM and TN revealed a direct relationship, as its content increased with the age of plantation (trees). However, the increasing trend of OM and TN in soils of rubber trees of varying ages observed in this study does not corroborate the findings of earlier and similar studies like those of Aweto (2001); Cheng et al. (2007) and Zhang et al. (2007) who reported decrease in soil nutrient particularly OM and TN with the increasing ages of forest trees, but corroborated those of Geetha and Balagopalan (2009); Yasin et al. (2010) when they reported a steady increase in the proportion of OM and TN in rubber and teak plantation soils with increasing age of plantation. This therefore means that nutrients accretion are directed influenced by the age of plantation or rubber trees/plantation.

Table 1: Chemical properties of Soils[a]

Soil properties	7 years	16 years	39 years	41 years	F-values
pH	4.44±0.12	4.06±0.02	4.24±0.02	4.08±0.04	6.821 *
OC (%)	1.14±0.26	1.04±0.19	1.16±0.07	1.88±0.22	3.835*
OM (%)	1.97±0.44	1.79±0.33	1.99±0.13	3.24±0.38	3.838 *
TN (%)	0.28±0.06	0.25±0.05	0.28±0.02	0.45±0.07	3.062 ns
CEC (cmol/kg^{-1})	3.78±0.74	4.96±0.22	4.36±0.18	4.64±0.18	1.536 ns
Av. P (mg/kg^{-1})	36.16±5.72	21.90±6.31	15.38±4.37	13.52±2.51	4.303*
Exch. Ca (cmol/kg^{-1})	0.88±0.10	0.38±0.05	0.67±0.05	0.32±0.09	11.70**
Exch. Mg (cmol/kg^{-1})	0.24±0.03	0.16±0.01	0.18±0.01	0.14±0.01	6.584*
Exch. Na (cmol/kg^{-1})	0.56±0.09	0.72±0.02	0.69±0.06	0.64±0.03	1.485 ns
Exch. K (cmol/kg^{-1})	0.06±0.01	0.07±0.00	0.10±0.01	0.09±0.01	4.519*

[a] values are means ± standard errors.
* Difference between means is significant at 5% alpha level.
** Difference between means is significant at 1% alpha level.
ns: Difference between means was not significant at 5% alpha level.

Furthermore, the proportion of exchangeable bases (Ca, Mg, Na and K) varied substantially across soils of the rubber plots. Exchangeable bases according to Brix (2008) are important properties of soil and sediments as they relate information on the soil's ability to sustain plant growth, retain nutrients, buffer acid deposition or sequester toxic heavy metals. The proportions of exchangeable calcium (Ca) and exchangeable magnesium (Mg) reduced drastically with increasing age of rubber plantation plots; the values of Ca and Mg ranged from 0.14 to 0.88 cmol/kg^{-1}. On the other hand, the levels of Na and K increased with increasing age of rubber plantation plots. The proportions of Na and K ranged from 0.06 to 0.72cmol/kg^{-1}. There were significant variations in the contents of Ca, Mg and K among the rubber plots ($p<0.05$), while the content of Na across soils of the plantation plots did not vary ($p>0.05$), though Na is often considered as a non-essential element for most plants (Aweto and Dikinya 2003). The high content of Ca and Mg in the early stages of cultivation (7 and 16 yrs old rubber plots) is attributed to the leaching of base cations to the deeper layer of soil. Since the soil layer at this phase is not adequately covered, rain drops hit the soil surface directly; this condition enhances intensive leaching process of base cations compared to the latter phase of the plantation (Yasin et al. 2010)

However, the generally low levels of exchangeable bases across the rubber plantation plots reflect a low fertility status of soils in the area. The proportion of available phosphorus (Av. P) in soils of the rubber plots declined substantially with increasing age, with the highest value of 36.16 mg/kg^{-1} recorded in the youngest rubber plot (7 yrs old rubber plot) while the oldest plot (41 yrs old rubber plot) had the lowest value of 13.52 mg/kg^{-1}. The proportion of Av. P varied significantly among the rubber plots ($p<0.05$). Av. P is an essential nutrient for plant growth, and is a primary fertilizer element; this element in the 7 yrs old plantation plot may have been enhanced due to the abundance of woody and herbaceous vegetation with high litter input. The increased in litter inputs and in situ decomposition increases the pH content, which also favours increase in Av. P (Iwara et al. 2010). The increase in pH value in the 7 yrs old plot has substantial effects on nutrient availability in the soil (Brady and Weil 2005; Osemwota 2010).

CONCLUSION AND RECOMMENDATION

The present study has shown clearly that the contents of organic matter and total nitrogen in rubber soils increase with the age of trees, which perhaps is affected by the increase in tree size and vegetation cover. These attributes of a mature rubber tree help to conserve essential nutrients in the soil by minimizing the loss of nutrients in both dissolved and sediment-bound form mostly during periods of heavy rainstorm. The study therefore implies that rubber has no significant adverse effect on soil organic matter and nitrogen status of the soil. However, for sustainable rubber production in line with the need to improve the nutrient balance of soil by reducing unproductive nutrient losses from erosion and leaching, mature rubber trees in plantation plots should be properly managed through routine treatment, as well as selectively replaced with new ones for continuous nutrient conservation and fluxes.

REFERENCES

Araujo, Q. R., Comerford, N.B., Ogram, A.V., Al-Agely, A., Santos, L. P. & Santos, J. G. (2005). Soil carbon and physical property changes in Brazilian coastal tableland soils with land use following deforestation. *Agroforestry System,* 63: 193-198

Attoe, E. E. & Amalu, U. C. (2005). Evaluation of phosphorus status of some soils under estate rubber (*Hevea brasiliensis Muel. Argo*.) Trees in southern Cross River State. *Global Journal of Agricultural Sciences,* 4(1):55-61.

Aweto A.O. & Enaruvbe G. O. (2010). Catenary variation of soil properties under oil palm plantation in south western Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 3 (1): 1 - 7

Aweto, A. O. (1981). Total nitrogen status of soils under bush fallow in the forest zone of south-western Nigeria. *Journal of Soil Science,* 32: 639 – 642

Aweto, A. O. (1987). Physical and nutrient status of soils under rubber (*Hevea brasiliensis*) of different ages in south-western Nigeria. *Agricultural Systems,* 23(1987) 63-72

Aweto, A. O. (1989). *Biogeography*. Ibadan: External Studies Programme Unit

Aweto, A. O. (2001). Impact of single species tree plantation on nutrient cycling in West Africa. *International Journal of Sustainable Development and World Ecology, 8:356 – 368*

Aweto, A. O. & Dikinya, O. (2003). The beneficial effects of two tree species on soil properties in a semi-arid savanna rangeland in Botswana. *Land Contamination & Reclamation,* 11 (3): 339 - 344

Aweto, A. O. & Ishola, M. A. (1994). The impact of cashew (*Anacardium Occidentale*) on forest soil. *Experimental Agriculture,* 30: 337-341

Bauer, A. & Black, A. L. (1981). Soil carbon, nitrogen and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. *Soil Sci. Soc. Am. J.,* 45: 1166-1170

Bouyoucos, G. J. (1926). Hydrometer method for making particle size analysis of soils. *Soil Science Society of America Proceedings,* 26, 464–465

Brady, N. C. & Weil, R. R. (2005). *The Nature and properties of soils, 13th ed*. Delhi: Pearson Education

Bray, R. H. & Kurtz, L. T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Sci.,* 59: 39-48

Bremner, J. M. & Mulvaney, C. S. (1982). "Nitrogen", in A. I. Page, R. H. Miller & D. R. Keeney (Eds.). *The method of soil analysis*: Agronomy. Monogram, Madison: ASA Ltd.

Chan, H. Y., Pushparajah, E., Yew, F. K. & Eusof, Z. (1975*)* A soil suitability technical grouping system for heavea *brasiliensis. Third ASEAN Soil Conference, Kuala Lumpur, Malaysia, pp: 55 - 60*

Cheng, C., Wang, R. & Jiang, J. (2007). Variation of soil fertility and carbon sequestration by planting *Hevea brasiliensis* in Hainan Island, China. *Journal of Environmental Sciences,* 19 (3):348 - 352.

Dharmakeerthi, R. S., Silva, S. N., Yakandawala, A., & Jayasinghe, W. K. (2005). Nutritional status of rubber growing soils in the Moneragala District. *Journal of the Rubber Research Institute of Sri Lanka,* 87, 23-35

Dixon, R. K., Brown, S., Houghton, R. A., Solomon, A.M., Trexler, M. C. and Wisniewski, J. (1994). Carbon pools and fluxes of global forest ecosystems. *Science* 263, 185–190.

Duah-Yentumi, S., Ronn, R. & Christensen, S. (1998). Nutrients limiting microbial growth in a tropical forest soil of Ghana under different management. *Applied Soil Ecology,* 8: 19-24

Ekukinam, U. E. (2010) Effects of Rubber (Hevea brasiliensis) Monoculture Cultivation on Variations in Soil fertility. Unpublished M.Sc. Thesis, University of Ibadan, Nigeria.

Foth, H. D. (2006). *Fundamentals of Soil Science*. 8th Edition. New York: John Wiley & Sons

Geetha, T. & Balagopalan, M. (2009). Soil fertility variations within a rotation period in teak plantations in Kerala. *Advances in Plant Sciences,* 22 (1): 317-319

Greenland, D.J. (1997). *The sustainability of rice farming*. CAB International, Wallingford.

Greenland, D.J. & Nye, P.H. (1959). Increases in the carbon and nitrogen contents of tropical soils under natural fallows. *J. Soil Sci.* 10: 284-299

Iwara, A. I. (2008). *The concept of tree influence cycle*. Seminar Presentation (GEO 713), Dept. of Geography, University of Ibadan

Iwara, A.I., Ewa, E. E., Ogundele, F.O., Adeyemi, J.A. and Otu, C.A. (2011). Ameliorating effects of palm oil mill effluent on the physical and chemical properties of soil in ugep, cross river state, south-southern Nigeria**.** *International Journal of Applied Science and Technology,* 1 (5): 106 – 112

Johnsen, K.H., Wear, J. D., Oren, R., Teskey, R. O., Sanchez, F., Will, R.E., Butnor, J., Markewitz, D., Richter, D.D., Rials, T., Allen, H.L., Seiler, J., Ellsworth, D., Maier, C., Katul, G. & Dougherty, P.M.. (2001). Meeting global policy commitments: carbon sequestration and southern pine forests. *Journal of Forestry,* 99: 14-21.

Knops J. M. H. & Tilman, D. (2000). Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. *Ecology.* 81:88-98

Kucharik, C.J., Brye, K.R., Norman, J. M., Foley, J. A., Gower, S.T. & Bundy, L.G. (2001) Measurements and modeling of carbon and nitrogen cycling in agroecosystems of southern Wisconsin: potential for soc sequestration during the next 50 Years. *Ecosystems,* 4: 237-258

Lal, R. (2005). Forest soils and carbon sequestration. *Forest Ecology and Management,* 220, 242–258

Meena, S., Senthilvalavan, P., Malarkodi, M. & Kaleeswari, R.K. (2007). Residual effect of phosphorus from organic manures in sunflower-assessment using radio tracer technique. *Research Journal of Agriculture and Biological Sciences,* 3: 377-379

Michopoulos, P., Baloutsos, G. & Economou, A. (2008). Nitrogen cycling in a mature mountainous beech forest. *Silva Fennica.* 42: 5-17

Nye, P. H. & Greenland, D. J. (1960). *The soil under shifting cultivation*. Commonwealth Agricultural Bureau, Farnham Royal, UK.

Ogundele, F. O., Akoteyon, I. S., Omotayo, A. & Odewumi, S.G. (2011). Assessment of soil properties under a newly established teak plantation in Abia, south-west, Nigeria. *International Journal of Academic Research,* 3(3):184 – 190

Ogunkunle, C. O. & Awotoye, O. O. (2011). Soil fertility status under different tree cropping system in a southwestern zone of Nigeria. *Not Sci Biol,* 3(2):123-128

Osemwota, O. I. (2010). Effect of abattoir effluent on the physical and chemical properties of soils. *Environ Monit Assess,* 167:399–404

Oyebande, B.A., Aiyeloja, A. A. & Ekeke B.A. (2010). Sustainable agroforestry potentials and climate change mitigation. *Adv. Environ. Biol.,* 4(1): 58-63

Paudel, S. & Sah, J. P. (2003). Physico-chemical characteristics of soil in tropical Sal (*Shorea robusta gaertn*) forest in eastern Nepal. *Himalayan J. Sci.,* 1 (2):107-110

Pluske, W., Murphy, D. and Sheppard, J. (2005). Organic carbon. Www. Soilquality.org.au.

Potter, K. N., Torbert, H.A., Jones, O. R., Matocha, J. E., Morrison, J. E. J. & Unger, P. W. (1998). Distribution and amount of soil organic carbon in long-term management systems in Texas. *Soil Tillage Res.,* 47: 309-321

Reddy, S. S., Reddy, V. C., Ananda, M.C. & Sivaraj, B. (2005). Direct effect of fertilizers and residual effect of organic manures on yield and nutrient uptake of maize (Zea mays L) in groundnut-maize cropping system. *Crop Research,* 29: 390-395

Sainju, U. M., Singh, B. P. & Whitehead, W. F. (2002). Long –term effects of tillage, cover crops and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Journal of Soil and Tillage Research*, 63: 167 - 179

Samndi, M. R., Raji, B. A. & Kparmwang, T. (2006). Long-term effect of fast-growing tree species (*Tectona grandis linns. F.*) on the distribution of pedogenic forms of iron and aluminium in some soils of southern guinea savanna of Nigeria. *Savannah Journal of Agriculture,* 1 (1): 39 - 45

Shukla, P. K. (2009). Nutrient dynamics of teak plantations and their impact on soil productivity-a case study from India. *Proceedings of the 8th World Forestry Congress, Oct. 18-23, Buenos Aires, Argentina, p. 1-11*.

Uhl, C. et al. (1981). Early plant succession after cutting and burning in the upper Rio Negro region of the Amazon Basin. *J. Ecol.,* 69, 631–649

Walkley, A. & Black, I. A. (1934). An examination of the detjareff method for determining soil organic matter and a proposed modification to the chronic acid titration method. *Soil Science,* 37: 29-38

Wang, H. H. & Li, D.H. (2003). Effect of man-made rubber-tea community improving ecological condition of soil. *Journal of Mountain Science,* 21: 318-323

Yang, J. C., Huang, J. H., Pan, Q.M., Tang, J. W. & Han, X.G. (2004). Long-term impacts of land-use change on dynamics of tropical soil carbon and nitrogen pools. *Journal of Environmental Sciences,* 16: 256- 261

Yang, J. C., Huang, J. H., Tang, J. W., Pan, Q. M. & Han, X. G. (2005). Carbon sequestration in rubber tree plantations established on former arable lands in Xishuangbanna, SW China. *Acta Phytoecologica Sinica,* 29: 296-303

Yasin, S., Junaidi, A., Wahyudi, E., Herlena, S. & Darmawan (2010). Changes of soil properties on various ages of rubber trees in Dhamasraya, West Sumatra, Indonesia. *J Trop Soils,* 15 (3):221-227

Zhang, H., Zhang, G. L., Zhao, Y. G., Zhao, W. & Zhi-Ping, Q. (2007). Chemical degradation of a ferralsol (oxisol) under intensive rubber (*Hevea brasiliensis*) farming in tropical China. *Soil & Tillage Research,* 93: 109–116

Zilberman, D. & Sunding. D. (2001). Climate change policy and the agricultural sector. pp.629-643, in: R. Lal, J.M. Kimble, R.F. Follett & B.A. Stewart (eds.) *Assessment methods for soil carbon*. Boca Raton: Lewis Publishing