Available online at www.notulaebiologicae.ro

Print ISSN 2067-3205; Electronic 2067-3264

Not Sci Biol, 2011, 3(2):123-128

Soil Fertility Status under Different Tree Cropping System in a Southwestern Zone of Nigeria

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Abstract

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. Premised on this, this study assessed the effects of sole cropping of teak and intercropping of cocoa and kola on the soil fertility status. The study was carried out using stratified-randomed sampling technique for the study plots in all the sampling sites. Three sampling sites consisting of four (4)-400 m^2 sampling plots each were established in which vegetation and some soil parameters were assessed. Results analysis 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 effects was due to the high rate of nutrient uptake of the teak, 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%). A very strong correlation existed between organic matter content and some vegetation parameters.

Keywords: edaphic, basal area, volume of wood, organic matter, bulk density, litters

Introduction

Trees are known to bring about changes in edaphic, micro-climatic, floral, faunal and other components of the eco-system through bio-recycling of mineral elements, environmental modifications (including thermal and moisture regime) and changes in floral and faunal composition etc (Shukla, 2009). 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 (Schroth and Sinclair, 2003).

Fisher (1995) outlined five ways that a tree can ameliorate soil conditions at a given site. These include N-fixation, surface soil nutrient enrichment through litterfall and root turnover, increase in soil organic matter (SOM) through additional litter and root inputs, changes in above-and belowground microclimate (moisture and temperature extremes, aeration, etc.), and through the increase in organism activity within the rhizosphere of perennial roots.

Okigbo (1983) found tree cropping plantations to be ecologically sound production enterprise in the humid tropics while Singh *et al.* (1990) stated that tree farming systems are usually sustainable, profitable and environmentally sound. The important components of the agro-forestry that yield certain environmental benefits such as reduction of pressure on forest, efficient recycling of nutrients, reduction in nutrient leaching and soil erosion (Sunita and Uma, 1993). About 20-25% of the total living biomass of the tree is in roots and there is a constant addition of organic matter to the soil through dead and decaying roots. Sunita and Uma (1993) reported that trees showed preferential enrichment of the soil in term of Ca, Mg, Na, P and N.

The potential role of trees in reducing run-off and erosion is well appreciated and removal of vegetation cover results in an increase in bulk density. There has been reports of reclamation of wastelands by growing trees over them, Sisagh *et al.* (1990) reported that alkali soils can be improved by growing *Prosopis juliflora* trees while Onim *et al.* (1990) also noted that improvement of the existing cropping systems through incorporation of tree legumes could assist in alleviating low soil fertility. Triadiati *et al*. (2011) and there have been reports of reclamation of wastelands by growing trees over them; leguminous trees like *Gliricidia sepium* and *Leucaena leucocephala* have been noted by Schroth and Sinclair (2003) to increase the availability of nitrogen through biological nitrogen fixation. Kamanga *et al*. (2000) opined in his research on tree-based cropping systems in Malawi that tree legume-based cropping systems improves soil fertility over the traditional cropping systems and this is explained in the deep capture system of trees (Ramun, 2000).

Boley *et al*. (2009) avert that established plantations like rubber and citrus can modify microsite conditions regardless of the tree species origin and this was collaborated

Received 11 January 2011; accepted 12 April 2011

by Tanaka *et al*. (2009) in his study of soil characteristics under cash crop farming in Malaysia that soil properties in rubber farms were similar to those in the secondary forest. The objective of this study was to assess the soil fertility status under different tree cropping systems.

Materials and methods

The study area

The study was conducted between 2003 and 2005 in a part of Osun State, Southwestern region of Nigeria. The study area consists of three sites designated as A, B and C; site A is an established teak plantation (*Tectonia grandis*) of 30 years in Ila Local Government and it is under selective harvesting; site B is a 35 year-old cocoa plantation (*Theobroma cacao*) intercropped with kola trees (*Cola nitida*) without specific gapping in Boripe Local Government while site C is a relatively intact matured forest serving as the control located at Ifedayo Local Government. The area lies between the longitude 04° 00' E and latitude 05° 55' N. The climate of the study area is humid sub-equitorial type that is characterized by distinct dry and rainy season (Aweto, 1995).

Ecological techniques

Sampling procedures

In each of the sampling sites, four sampling plots of 400 m^2 were demarcated by the use of measuring tape in each study sites and a total of sixteen sampling plots of dimension 400 m^2 were used for the study.

Soil study

Three soil samples were randomly collected at a depth of 0-15 cm using a soil auger in each of the sampling plot and a total of 48 soil sample were used for the analysis. The soil samples were air-dried and gently crushed in a ceramic mortar and sieved through a 2 mm sieve for chemical analysis. The following determinations were carried out on the soil samples:

- bulk density was determined by the core method (Blake, 1965);
- soil moisture content (SMC) according to Shingsby and Cook (1986);
- soil pH determined potentiometrically in 0.1 M calcium chloride using soil a soil solution ratio of 1:2 (Peech, 1965);
- soil organic content by the chromic acid digestion method (Walkley and Black, 1934);
- nitrate-nitrogen by the Kjeldahl method (Black, 1965);
- available phosphorus using Bray No.1 method (Bray and Kurtz, 1945).

Vegetation study

All woody plants of girth breast height of 7 cm and height of 1.5 cm were enumerated according to Adesina (1989). Plant samples were identified/or confirmed in the Herbarium of the Department of Botany, Obafemi Awolowo University, Ile-Ife. The following vegetation parameters were considered:

- tree density;
- tree height;
- tree girth;
- basal area;
- volume of wood.

Statistical analysis

One-Way Analysis of Variance was used to determine variability among the study sites and Duncan Multiple Range Tests was adopted for validation of the ANOVA (SPSS 14.0, 2005). Pearson correlation was used to determine relationship between organic matter content and the other edaphic properties and also between organic matter content and vegetation parameters.

Results

Vegetation study

Tectona grandis was the only woody tree in site a; two woody species were found in site B, i.e. cocoa and kola trees while ten woody species were encountered in site C (Tab. 1). The dominant woody species in the sites in term of density are:

-site A:-*Tectona grandis;*

-site B:-*Theobroma cacao* and *Cola nitida;*

-site C:-*Dalium guineensis*, *Treculia Africana* and *Vocanga africana* (Tab. 1).

Site A has the highest total tree density of 5,475 ha^{-1}. The trend of the tree density showed site A>site C>site B. Total tree basal area was highest in site C followed by site A and site B. *Celtis zenkeris* (21% of total basal area) and *Dalium guineensis* (24% of total basal area) accounted for the large value of basal area in site C. *Tectona grandis* (4.55 m^2 ha^{-1}) in site A, *Theobroma cacao* (1.32 m^2 ha^{-1}) in site B (Tab. 1). Site C had the highest total volume of wood; 5 times that of site A, 30 times that of site B. *Dalium guineensis* and *Celtis zenkeris* (67.71 m^3 ha^{-1} and 74.88 m^3 ha^{-1} respectively) contributed largely to the total volume of wood in site C.

Site C had the highest site mean girth of 0.68 m; the girth sizes of *Triplichiton scleroxylon, Celtis zenkeris* and *Albizia adiantifolia* largely accounted for the high site girth size (Tab. 2). The teak site (site A) had mean girth size of 0.48 m while the cocoa/kola had 0.29 m.

Analysis of variance carried out showed significant variations in the vegetation parameters across the sites

Tab. 1. Biomass characteristics of the woody species in the study sites

Sites	Density (ha^{-1})	Height (m)	Girth (m)	Basal Area (m^2ha^1)	Volume of Wood (m^3ha^{-1})
Site A-Teak					
1. *Tectona grandis*	5475	8.82±0.58	0.48±0.003	4.55	47.65
Site B-Cocoa/Kola					
1. *Theobroma cacao*	2750	4.67±1.27	0.34±0.18	1.32	7.57
2. *Cola nitida*	875	6.20±1.32	0.24±0.07	0.18	1.10
Total	3625			1.49	8.66
Site C-Matured Forest					
1. *Albizia adiantifolia*	100	25.0±8.04	1.19±0.31	0.48	13.41
2. *Albizia zygia*	250	16.3±8.25	0.78±0.53	0.68	17.52
3. *Alchornea laxiflora*	50	5.5±0.71	0.24±0.08	0.01	0.06
4. *Anthiaris africana*	250	20.5±8.48	0.87±0.38	0.72	17.30
5. *Celtis zenkeris*	250	27.5±12.07	1.48±0.84	2.09	74.88
6. *Dalium guineensis*	700	18.9±8.48	0.89±0.55	2.41	67.71
7. *Ficus exaspirata*	225	13.4±3.43	0.50±0.88	0.19	2.68
8. *Khaya ivorensis*	175	8.7±2.14	0.33±0.07	0.06	0.57
9. *Lecanoidiscus cupanoides*	200	12.1±2.23	0.47±0.10	0.14	1.82
10. *Milicia excelsa*	250	10.8±4.11	0.42±0.17	0.22	2.84
11. *Sterculia setigera*	200	9.1±2.47	0.32±0.10	0.07	0.48
12. *Sterculia tragacantha*	250	19.2±6.94	0.94±0.20	0.82	19.53
13. *Terminalia superba*	100	9.8±2.06	0.33±0.07	0.04	0.36
14. *Treculia africana*	825	10.0±3.10	0.39±0.15	0.34	4.47
15. *Triplochiton scleroxylon*	175	26.4±8.36	1.26±0.47	0.99	30.63
16. *Vocanga africana*	450	12.3±3.87	0.50±0.21	0.67	5.81
Total	4450			9.95	260.10

Note: ± = standard deviation

Tab. 2. Mean values of vegetation parameters in the study sites

Treatments	Tree height (m)	Tree girth (m)	Basal Area ($m^2\ ha^{-1}$)	Volume of Wood ($m^3\ ha^{-1}$)
Site A-Teak	8.82_c	0.48_c	0.021_c	0.215_c
Site B-Cocoa/Kola	5.44_b	0.29_b	0.586_b	2.089_b
Site C-Forest	15.3_a	0.68_a	2.405_a	63.902_a

Values in the same column with different subscripts are significantly different according to Duncan Multiple Range Test at 5% probability level

studied (Tab. 2). As expected, site C, (forest site) showed highest values of tree height, girth, basal area and volume of wood.

Soil study

The mean values of all soil properties measured in the forest site (Site C) were higher than those in the other sites (Teak and Cocoa/kola sites) Tab. 3. Bulk density was lowest in site C while it was highest in the teak site showing soil compaction. There was no significance in pH values between teak and cocoa/kola site using DMRT at $p<0.05$. It is also evident from Tab. 3 that the nutrient elements under teak (site A) are most affected; these elements are available phosphorus, moisture content and organic matter.

The correlation coefficients between organic matter content and vegetation matrices showed positive correlations in all the sites except tree density in teak site which is negative correlations (Tab. 4). Soil elements interrelationship in the study sites showed organic matter content exhibits strong positive correlation with moisture content, available phosphorus, pH and nitrate-nitrogen in all the three sites while the strongest correlation exists between organic matter content and moisture content ($r=+0.99$) (Tab. 4).

Tab. 3. Soil properties of the study sites

Treatments	Bulk density ($g/c\ m^3$)	Moisture Content (%)	pH ($CaCl_2$)	Organic matter (%)	Available phosphorus (ppm)	Nitrate-nitrogen (ppm)
Site A-teak	1.62_c	3.57_d	5.44_b	3.04_c	34.38_c	46.12_d
Site B-Cocoa/kola	1.24_b	6.55_b	5.57_b	7.34_b	61.8_b	74.93_b
Site C-Forest	1.08_a	8.08_a	5.86_a	9.12a	87.46_a	95.45a

Values in the same column with different subscripts are significantly different according to Duncan Multiple Range test at 5% probability level

Tab. 4. Correlation coefficient between organic matter content and other assessed parameters

Treatments	Tree girth	Tree density	Basal area	Moisture content	Available phosphorus	Nitrate-nitrogen
OM (Teak)	+0.75	-0.10	+0.79	+0.72	+0.69	+0.78
OM (Cocoa/kola)	+0.79	+0.83	+0.71	+0.92	+0.96*	+0.98*
OM (Forest)	+0.79	+0.86	+0.99*	+0.99*	+0.96*	+0.85

*significant at 5% probability level
OM-Organic matter content

Discussion

Soil fertility under matured forest and cocoa/kola farm

Soils under matured forest and cocoa/kola farm in the study area rated high in soil nutrients and this is due to the fact that they enjoys minimized anthropic disturbance and the soils are under more or less permanent shelter from rain-wash and sun heat. All these factors are known to be important in ensuring and sustaining high soil fertility in forest and forest-simulation and this was corroborated by Ratnayake *et al*. (2011) in his work on the effect of cultivation on organic carbon content in soils.

Shukla (2009) noted that nutrients accumulated in leaves return to the ecosystem through litter fall and this is the most important component of the forest ecosystem; it is a major pathway of nutrient and energy transfer. Also, Bowen *et al*. (1988) puts that plant residues or litter has multi-beneficial effects which include maintenance of good soil physical conditions as well as soil organic matter, provision of nutrients and stimulation of biological activity as well as moderately acidity in soil. Nutrient uptake, their retention and release are the three components of nutrient dynamics in forest ecosystem (Shukla, 2009). The nutrient cycling in forest ecosystem comprises of cyclic circulation of nutrients between forest soils and plants through the process of nutrient uptake, retention and restitution. All these contributed to the good soil status in the matured forest and cocoa/kola sites as evident in their organic matter content values (9.12% and 7.34% respectively).

The intercropping of cocoa/kola produces a better soil quality than the teak site. The cocoa/kola site is better with respect to all the edaphic properties (bulk density, organic matter content, available phosphorus and nitrate-nitrogen). Ekanade (1990) opined that mixing of litter components produces synergistic interactions that are beneficial to soil. The improved soil fertility under cocoa/kola could probably be attributed to the high level of organic matter content maintained under the trees through the accumulation of litters. Bernhard-Reversat and Loumeto (2002) affirmed that the most relevant parameter for soil organic matter binding-up could be the amount of standing litter on the soil which integrates litterfall and decomposition and also essential in the soil aggregate stability (Mbah *et al*., 2007; Emadi *et al*., 2008). There is a known fact that when there is accumulation of soil organic matter; being a storehouse and source of important plant nutrients, there is usually a "build up" of nutrients in the topsoil (Young, 2000) as found in the values of soil parameters. It also explained the positive correlations between organic matter content and the other edaphic elements assessed (Tab. 4).

The role of organic matter content in the build up of soil nutrients appears crucial in all vegetation ecosystems and the higher level of organic matter with subsequent high levels of other soil nutrients under cocoa/kola (Tab. 4) is related to the nature of organic matter found under it. It seems that organic matter materials, especially leaves emanating from kola so decomposed faster than that emanating from cocoa because cocoa leaves are lignified making cocoa leaves decompose very slowly (Ekanade, 1990). So the synergistic relationship in which the rapid decomposition of kola leaves brings about higher rate of decomposition of cocoa leaves as well and thereby helps in the restoration of fertility to soils through the process of mimicking the natural systems that have constant inputs of organic carbon via litter deposition of varying quality. This is evident in the positive correlation between organic matter content and tree height, girth and basal area of trees in the study (Tab. 4) which conformed to the discovery of Sharma *et al*. (2009) in his study of the relationship between vegetation and soil parameters in Himalaya region.

The large girth sizes and vegetation cover via basal area in the matured forest and the cocoa/kola site led to the increase in nutrient and organic matter content of those sites as against the teak site. Great girth sizes and basal areas increases litter production which has a protective capacity on soil against accelerated organic matter destruction and nutrient losses through leaching and erosion (Aweto, 1995). The observed high significant contrast in the soil properties between the teak site and the cocoa/kola site is evidently resultant of the differences in the vegetation parameters (girth size, basal area, volume of wood) which culminated to the differences in the nutrient returns of the vegetation units (Shukla, 2009).

Soils fertility under teak plantation

The deteriorated status of the soils under the teak site as evident in the low organic matter content (3.04%), available phosphorus (34.38 ppm) and nitrate-nitrogen (46.12 ppm) could be related to the frequent fire that is occasionally used to clear the teak plantation. When fire is applied in the dry season which is the period of higher litter accumulation, the subsequent decomposition and mineralization of the litter at later time is not possible since the litter has been burnt and this reduce organic matter input. The degradation effects of the soil properties under the exotic trees can also be related to the total rate of uptake of nutrients from the soil, hardwoods like teak and sal, are reported by Shukla (2009) to return through litter fall only 8 to 10% of the total potassium and phosphorus absorbed by them and deplete the soil considerably, hence the low fertility status of soils under teak. Boley *et al*. (2009) also affirmed that there is significantly lower concentration of organic matter under teak in his research in Costa Rica. Bulk density was highest in teak (1.62 g/cm^3) and this could be a result of the frequent trampling of soil by loggers after burning (Penuel and Drew, 2004).

In a homogenous plant community, the stage of development of the plant communities affects both the nutrient uptake and nutrient return of the vegetation which could cause differentiation of soil properties under various plant communities as encountered under the teak. Ekanade (1991) stated that nutrient immobilization in the tissue of those rapidly growing exotic communities is not matched by the rate of nutrient returns to the soil through the fall and mineralization. Nutrient dynamics is very important for the understanding of ecosystem functioning and ecological status and in teak sole cropping system, more uptake and less returns to the soil leads to deterioration of soil as shown in the result of the soil parameters under teak.

Conclusions

The vegetation-soil relationship in this study has shown the importance of vegetation cover to soil fertility. High basal area and girth size accounted for the high fertility status of the soil under the matured forest and the cocoa/kola sites. Sole cropping of trees especially exotic types is not encouraged because of the rate of nutrient uptake with fewer returns to the soil (Pandey and Brown, 2000).

It is highly recommended that sole teak establishment should not be used in land management because of its degradation effect on soil fertility.

References

Adesina FA (1989). Plant Species Characteristics and Vegetation Dynamics in the Tropics. International Journal of Environmental Studies 33:67-68.

Aweto AO (1995). Organic carbon diminution and estimates of carbon dioxide release from plantation soil. Environmentalist 15:10-15.

Bernhard-Reversat F, Loumeto JJ (2002). The litter system in African forest-tree plantation. In: Reddy MV (Ed.). Management of tropical plantation, forest and their soil litter system. Science Publishing Inc, New Hampshire, USA.

Black CA (1965). Method of soil analysis II. American Society of Agronomy, Madison, WI, p. 573-590.

Blake GR (1965). Bulk Density, p. 374-377 In: Methods of Soil Analysis, Part 1.Physical and Mineralogical Properties including Statistics of Measurement and sampling. No. 9, Agron. Am. Soc. Agron., Inc.,Publisher Madison, Wisconsin, USA.

Boley JD, Drew AP, Andrus RE (2009). Effects of active pasture, teak and mixed native plantations on soil chemistry in Costa Rica. Forest Ecology and Management 257:2254-2261.

Bowen WT, Quitena JQ, Pereira J, Bouldin DR, Reid WS, Lathwell DJ (1988). Screening green manures as nitrogen sources to successing non-legume crops. Plant Soil 111:75-89.

Bray RH, Kurtz LT (1945). Determination of total organic and available forms of phosphorus in soils. Soil Science 59:39-46.

Ekanade O (1991). Degradation of the physical elements of the rural environment resulting from tree crops cultivation in the Nigerian Cocoa belt. Singapore J Trop Geogr 12:83-94.

Ekanade O (1990). An evaluation of soil productivity in interplanted cocoa and kola environmental systems in Southwestern Nigeria. Int J Environ Stud 35:253-259.

Emadi MM, Baghernejad G, Emadi M (2008). Effect of shifting cultivation on distribution of nutrient elements and carbohydrates within water-stable aggregates in Northern Iran. Pak J Biol Sci 11:195-201.

Fisher RF (1995). Amelioration of degraded rain forest soils by plantations of native trees. Soil Science Society of America Journal 59(2):544-549.

Kamanga BCG, Kanyama-Phiri GY, Minae S (2000). Maize production under tree-based cropping systems in Southern Malawi: A Cobb-Douglas approach. Afr Crop Sci J 8(4):429-440.

Mbah CN, Anikwe MAN, Onweremadu EU, Mbagwu JSC (2007): Soil organic matter and carbohydrate content of a dystric leptosol under organic waster management and their role in structural stability of soil aggregates. Int J Soil Sci 2:268-277.

Okigbo BN (1983). Plants and agroforestry in land use systems of West Africa, p. 25-43. In: Huxley PA (Ed.). Plant research and agroforestry. International Council for Research in Agroforestry, Nairobi, Kenya,

Onim JFM, Mathuwa M, Otieno M, Filtzhugh HA (1990). Soil Fertility and Response of Maize and Beans to Green Manures of Leucaena, Sesbania and Pigeon peas. Agroforestry Systems 12:197-215.

Peech M (1965). Hydrogen ion activity, p. 914-926. In: Black CA (Ed.). Methods of Soil Analysis, vol. 2.

Pandey D, Brown C (2000). Teak: A global overview. Int J For Ind 51:1-15.

Penuel MC, Drew AP (2004). A model to assess restoration of abandoned pastures in Costa Rica based on soil hydrological features and forest structure. Restoration Ecology 12(4):516-524.

Ramun MK (2000). A general tree-environment-crop interaction equation for predictive understanding of agroforestry systems. Agric Ecosyst Environ 80:87-100.

Schroth G, Sinclair FL (2003).Trees, crops and Soil fertility concepts and research methods. CABI Publishing, Wallingfold.

Sharma CM, Ghildiyal SK, Gairola S, Suyal S (2009). Vegetation structure, composition and diversity in relation to the soil characteristics of temperate mixed broad-leaved forest along an altitudinal gradient in Garhwal Himalaya. Ind J Sci Technol 2(7):39-45.

Shingsby D, Cook C (1986). Practical ecology. London, Macmillan Press Limited.

Singh G, Arora YK, Narein P, Grewal SS (1990). Agroforestry research (In India and Other Countries). Senya Publication, India, p. 136-140.

Sunita M, Uma M (1993). Environment and Agroforestry. Indian Farmers Digest 25(3):29-30.

Ratnayake RR, Seneviratne G, Kulasooriya SA (2011). The effect of cultivation on organic carbon content in the clay mineral fraction of soils. Int J of Soil Sci 6:217-223.

Shukla PK (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.

SPSS 14.0 Software version (2005). SPSS Inc, Chicago, Il.

Tanaka S, Tachibe S, Bin-Wasli ME, Lat J, Seman L, Kendawang JJ, Iwasaki K, Sakurai K (2009). Soil characteristics under cash crop farming in upland areas of Sarawak, Malaysia. Agric Ecosyst Environ 129:293-301.

Triadiati S, Tjitrosemito B, Guhardja E, Sudarsono H, Qayim I, Leuschner C (2011). Litterfall production and leaf-litter decomposition at natural forest and cacao agroforestry in Central Sulawesi, Indonesia. Asian Journal of biological sciences 4(8):221-234.

Walkley A, Black IA (1934). An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil science 37:29-38.

Young A (2000). Agroforestry for soil conservation. CAB International, Wallington, UK, 2nd Edition.