Journal of Applied Biological Sciences 2 (3): 09-13, 2008
ISSN: 1307-1130, www.nobel.gen.tr

Changes in Soil Properties Following Conversion of Humid Tropical Rainforest of Nigeria Into Cocoa Agroforests

Oke David OLANREWAJU
Department of Forestry and Wood Technology *Federal University of Technology, Akure, Nigeria*

Corresponding Author
e-mail:davoke2003@yahoo.com

Received: December 12, 2007
Accepted: April 08, 2008

Abstract

This study examined and compared some physical, chemical and microbiological properties of soil under a natural rainforest ecosystem and in young (10-12 yrs) and old (>50yrs) cocoa agroforests. Soil samples were collected to a depth of 30 cm from plots demarcated within each type of ecosystem and soil properties were determined using standard laboratory procedures. No significant differences were noted in the soil textural properties but soil chemical properties such as organic C, total N extractable P and exchangeable Ca and Mg showed significant decline as a result of the conversion to cocoa agroforests. Surface soil organic C was reduced by 12% and 31% under old and young cocoa agroforests respectively in Idanre, while a reduction of 24% and 36% were observed in Omo. Lower microbial population was also observed in the cocoa plots compared to the natural forest.

Keyword: Forest conversion, tropical rainforest, cocoa agroforest, soil nutrients, soil microbes

INTRODUCTION

The rich tropical rainforest in many parts of the humid tropics are disappearing at an alarming rate. In most areas of the world, tropical deforestation has been attributed to timber extraction and agricultural expansion [1,2]. Nigeria has the world's highest deforestation rate of primary forests [3]. The country is reported to have lost 55.7% of her primary forest to logging, subsistence agriculture, collection of fuelwood and other agents between 2000 and 2005.

Deforestation and conversion to arable land use have drastic impacts on soil properties. The principal impact of deforestation on chemical and nutritional properties is related to a decrease in organic matter content of the soil and to disruption in nutrient cycling mechanisms owing to removal of deep rooted trees [4]. The magnitude of these adverse effects depends on the method of deforestation and on soil and crop management practices. Scientists in Nigeria have expressed serious concerns about the negative impacts of the on-going conversion of natural forest cover into different agricultural land uses on soil resources and stability of the environment [5].

One of the major reasons for forest conversion, especially in Ondo State, Nigeria is cocoa cultivation. Cocoa is a major cash crop in Ondo State, which has expanded the State economy and provided employment for thousands of its inhabitants. The State Government is continually making efforts to improve cocoa output by rehabilitating old cocoa farms and expanding the area under cocoa cultivation. Expansion of cocoa farms is, however, being done at the cost of the rich tropical rainforest which provides the fertile land for cocoa cultivation.

Like in most parts of West African sub-region, cocoa cultivation in Nigeria has been dependent on cultivation of partly cleared forestland using the soil fertility built up in the forest soil and the shade provided by the remnant trees which has been termed 'forest rent' [6]. This practice results in a complex mixture of cocoa and other tree species with a canopy structure closely resembling that of the original tropical forest – agroforests.

There are reports that cocoa agroforests are less harmful to the environment than other forms of land management [7, 8, 9]. The structure of cocoa agroforests is similar to that of natural forests and therefore like natural forests they may contribute to physical and chemical conservation of soil and to plant and animal species conservation.

However, there are reports of a gradual shift in cocoa production towards a management system of lower conservation value than the traditional multistrata cocoa agroforests that harboured diverse population of plant species [10,11]. Apart from the effects of this trend on biodiversity conservation, soil conservation may also be adversely affected.

This study seeks to evaluate the tropical soil conditions under the changing cocoa agroforests in, Nigeria.

METHODOLOGY

Study site

Due to the effect of human activities in most of these areas, the natural forest has been degraded and the original forest is now restricted to forest reserves. This study was carried out in Ogun State and Ondo State, Nigeria and the study sites were located within the proximity of two selected forest reserves in each of the two states – Omo Forest Reserve in Ijebu-east local government area (LGA) of Ogun State and Idanre Forest Reserve in Idanre LGA of Ondo State.

Omo forest reserve is located between latitudes 6^0 35' and 7^0 05'N and Longitudes 4^0 19' and 4^0 10'E at an elevation of 123m a.s.l The terrain is generally characterized by undulating

lands with scattered inselbergs and gentle slopes. The total annual rainfall is between 887 and 2180 mm. The mean annual temperature is 26.5°C. The soils are pale greyish brown and are predominantly ferruginous and locally are of Iwo and Egbeda series which are coarse to fine textured but well drained.

Idanre is located on latitude 7°16'N, longitude 5°12'E. Topographically, Idanre is composed of undulating lands and hills. The climate is of the tropical monsoon type with two distinct seasons – the rainy (April to October) and dry (November to March) seasons. The mean annual rainfall is 1500mm and the mean annual temperature is 26°C. Humidity is high during the rainy season and low during the Harmattan period of the dry season. The soils derived from Basement complex rocks are mostly well drained with medium texture.

Experimental design

Because of the length of time involved in this study, it was not possible to monitor soil properties over a full rotation of the cocoa plantations. The methodology adopted was to compare soil properties under plantations with those under a nearby undisturbed natural vegetation. For this comparison to be valid site uniformity must be ensured under the two vegetation covers. Omo Forest Reserve was selected as representing natural vegetation in Ogun State while Idanre Forest Reserve was selected in Ondo State. Three young cocoa farms (10-12 years) and three old cocoa farms (>50 years) located very close to each of the forest reserves were also selected. The Forest Reserves and cocoa plantations in each location were on the same soil type and other conditions were judged to be uniform. There was no history of fertilizer application in the cocoa farms. Sample plots of 25 cm by 25 cm were demarcated within each of the selected cocoa farms. Three sample plots of 25m by 25m were also demarcated along transect lines cut through each of the Forest Reserves. The first plot was located 10m away from the main unsealed road and subsequent plots at a minimum distance of 75 m apart along the transect.

Soil cores (0-15 and 15-30 cm depth) were collected using a 3.5 cm diameter auger from five points within each of the demarcated plots. The auger points were located by randomly selecting five of the twelve points of intersection of grid lines drawn 5 m apart on each plot. Soil samples from the same soil depth on the same plot were bulked and a composite taken to the laboratory for analysis.

Soil pH was measured with an electronic pH meter in a 1:2.5 soil/water suspension. Soil organic carbon was determined by Walkley Black wet oxidation method. Total nitrogen was determined using semi microKjeldahl method [12]. Available phosphorus in soil was determined by extracting samples with 0.5M $NaHCO_3$ and determining P colorimetrically using molybdate [13]. Soil samples were leached with ammonium acetate solution to obtain extracts used in the determination of exchangeable cations. Ca and Mg in the leachate were determined by Ethylene Diamine Tetraacetic Acid (EDTA) titration.

Plate dilution method was used for the determination of microbial population (bacterial and fungi) in the soil. Ten gram of soil was shaken with 90 ml of distilled water. From this suspension, the serial solution was prepared. 0.5 ml of the serially diluted solution was plated on agar by pour plate technique [14]. Two main types of agar were used in this experiment; this is because the organisms to be cultured were limited to bacteria and fungi. Potato Dextrose Agar (PDA) was used for the culturing of fungi while Nutrient Agar (NA) was used for bacteria. The plates were allowed to gel and fungi count were obtained from the mixed culture after 7days of incubation while bacteria count were obtained after 24hrs of incubation. The colonies were counted using a Gallenkamp colony counter and expressed as colony forming units (cfu)

Statistical analysis of data

Soil properties were compared using the analysis of variance (ANOVA) procedure for randomized complete block design.. Values of microbial population were transformed into log (x+1) where, x = cfu g^{-1} of dried soil. Mean separation was done using the Fisher's Least Significant Difference (LSD) (p = 0.05).

RESULTS

Texture

The results of soil textural analysis of natural forest and cocoa agroforests in Idanre (Table 1) indicate that soils under the various vegetation types were generally sandy loam in texture. Slight variations were however observed in the proportions of sand, silt and clay under the various vegetations but statistical analysis showed that these differences were not significant. The textural analysis of soils from Omo presented in Table 2 shows that the soils were mainly sandy clay loam. There was no evidence of textural change as a result of the conversion of the forest into cocoa agroforest. This finding agrees with the previous works [15] that soil texture, being a comparatively stable property is unlikely to undergo any changes as a result of vegetation change

Table 1. Texture of soils under the cocoa agroforests and natural rainforest in Idanre, Idanre LGA, Ondo State, Nigeria

	Natural forest	**Young cocoa**	**Old cocoa**
	0-15 cm		
Sand (%)	75.1	76.1	74.1
Silt (%)	6.6	6.9	5.1
Clay (%)	18.3	19.0	20.8
	15-30 cm		
Sand (%)	75.0	77.8	74.1
Silt (%)	6.5	4.2	5.1
Clay (%)	18.5	18.0	20.8

Table 2. Texture of soils under the cocoa agroforests and natural rainforest in Omo, Ijebu east LGA, Ogun State, Nigeria

	Natural forest	**Young cocoa**	**Old cocoa**
	0-15 cm		
Sand (%)	73.1	70.5	70.5
Silt (%)	4. 4	3.9	3.9
Clay (%)	21.5	25.6	25.6
	15-30 cm		
Sand (%)	73.7	70.1	68.6
Silt (%)	4. 1	3.3	3.9
Clay (%)	22.2	26.6	27.5

General chemical properties

The mean values of chemical analyses of the topsoil under the different vegetation covers in Idanre are as shown in Table 3 while that of Omo is presented in Table 4. Much of the organic carbon and nutrient reserves were contained in the upper 0-15 cm of the soil profile. All soils were generally acid but in all cases, lower pH values were observed in Omo than in Idanre. Although the pH values were slightly higher in the natural forests the differences were not statistically significant.

Table 3. Soil chemical properties under cocoa agroforests and natural rainforest in Idanre Idanre LGA, Ondo State, Nigeria

	Natural forest	Young cocoa	Old cocoa
	0-15 cm		
pH-H_2O	5.8[a]	5.5[a]	5.6[a]
Organic C (%)	1.48[a]	1.02[c]	1.29[b]
Total N (%)	0.31[a]	0.22[b]	0.20[b]
Available P (mg kg^{-1})	1.30[a]	1.10[b]	1.08[b]
Exchangeable cations (cmol kg-1)			
Ca	3.30[a]	3.20[a]	2.70[b]
Mg	2.50[a]	2.56[a]	2.13[b]
	15-30 cm		
pH-H_2O	5.9[a]	5.6[a]	5.6[a]
Organic C (%)	0.85[a]	0.66[a]	0.64[b]
Total N (%)	0.29[a]	0.20[b]	0.19[b]
Phosphorus (mg kg^{-1})	1.30[a]	1.10[b]	1.10[b]
Exchangeable cations (cmol kg-1)			
Ca	2.50[b]	2.70[a]	2.66[a]
Mg	2.30[c]	2.40[b]	2.50[a]

Means on the same row followed by the same superscripts are not significantly different (P=0.05)

Table 4. Soil chemical properties under cocoa agroforests and natural rainforest in Omo, Ijebu east LGA, Ogun State, Nigeria

	Natural forest	Young cocoa	Old cocoa
	0-15 cm		
pH-H_2O	4.8[a]	4.6[b]	4.8[a]
Organic C (%)	1.90[a]	1.22[c]	1.44[b]
Total N (%)	0.28[a]	0.18[b]	0.18[b]
Available P (mg kg^{-1})	2.16[a]	1.06[b]	1.11[b]
Exchangeable cations (cmol kg-1)			
Ca	2.90[b]	3.30[a]	3.10[ab]
Mg	2.17[b]	2.03[b]	2.47[a]
	15-30 cm		
pH-H_2O	4.7[a]	4.8[a]	4.8[a]
Organic C (%)	1.75[a]	1.36[b]	1.28[b]
Total N (%)	0.26[a]	0.17[b]	0.17[b]
3.36x10^4	1.80[a]	1.07[b]	0.72[b]
Phosphorus (mg kg^{-1})			
Exchangeable cations (cmol kg-1)			
Ca	2.60[b]	3.10[a]	3.26[a]
Mg	2.50[a]	2.70[a]	2.40[a]

Means on the same row followed by the same superscripts are not significantly different (P=0.05)

Organic carbon, total N and extractable P were significantly reduced at both 0-15 and 15-30 cm depths under young cocoa and old cocoa plots at Idanre and Omo when compared to corresponding levels under natural rainforest. Organic carbon was also significantly lower under the young cocoa plots than in the old cocoa plots. The differences in total N and available P between young and old cocoa plots were however not significant at any soil depth in both locations.

Variations in exchangeable Ca and Mg were inconsistent in both locations. While exchangeable Ca and Mg were significantly lower at 0-15 cm depth in old cocoa plots than in both natural forest and young cocoa plots, the reverse was the case at 15-30 cm where lowest values were observed under the natural forest. In Omo, values of exchangeable Ca were consistently lower under the natural forest.

Microbial population

The populations of bacteria in soils were generally higher than that of fungi in all the sites and at both depths. Total bacterial population in Idanre (Table 5) was significantly lower in young cocoa plots than in old cocoa and natural forest (Table 6). Although slight differences were observed in fungal population, these were statistically not significant. Higher values of microbial populations were also observed at 0-15 cm depth in Omo (Table 7) but these were not significantly different from those of young cocoa and old cocoa plots (Table 8).

Table 5. Soil microbial population under cocoa agroforests and natural rainforest in Idanre, Idanre LGA, Ondo State, Nigeria

	Natural forest	Young cocoa	Old cocoa
	0-15 cm		
Bacteria	1.81x10^5	4.93x10^4	1.34x10^5
Fungi	1.30x10^3	0.63x10^3	1.76x10^3
	15-30 cm		
Bacteria	2.52x10^5	2.80x10^4	1.31x10^5
Fungi	1.30x10^3	1.30x10^3	1.60x10^3

Table 6. Statistical comparison of soil microbial population under cocoa agroforests and natural rainforest in Idanre, Idanre LGA, Ondo State, Nigeria (Log cfu+1)

	Natural forest	Young cocoa	Old cocoa
	0-15 cm		
Bacteria	6.26[a]	5.70[b]	6.13[a]
Fungi	4.11[a]	3.80[a]	4.25[a]
	15-30 cm		
Bacteria	6.40[a]	5.45[b]	6.12[a]
Fungi	4.11[a]	4.20[a]	4.11[a]

Means on the same row followed by the same superscripts are not significantly different (P=0.05)

Table 7. Soil microbial population under cocoa agroforests and natural rainforest in Omo, Ijebu-east LGA, Ondo State, Nigeria

	Natural forest	Young cocoa	Old cocoa
	0-15 cm		
Bacteria	4.20x10^4	3.03x10^4	3.86x10^4
Fungi	2.40x10^3	2.16x10^3	1.86x10^3
	15-30 cm		
Bacteria	3.80x10^4	2.63x10^4	3.36x10^4
Fungi	2.03x10^3	1.36x10^3	1.20x10^3

Table 8. Statistical comparison of soil microbial population under cocoa agroforests and natural rainforest in Omo, Ijebu east LGA, Ogun State, Nigeria (Log cfu+1)

	Natural forest	Young cocoa	Old cocoa
	0-15 cm		
Bacteria	5.48[a]	5.59[a]	5.62[a]
Fungi	4.27[a]	4.38[a]	4.33[a]
	15-30 cm		
Bacteria	5.58[a]	5.53[a]	5.42[a]
Fungi	4.08[a]	4.31[a]	4.13[a]

Means on the same row followed by the same superscripts are not significantly different (P=0.05)

DISCUSSION

Soil pH did not show marked differences with type of vegetation cover except for slight reduction in pH under the cocoa agroforests.

Maintenance of organic C is the key to sustainable crop production [16,17]. Soil organic C was significantly reduced under the cocoa agroforests at both sites. In Idanre, a reduction of 12% (at 0-10 cm depth) was recorded under old cocoa while that of young cocoa was 31 %. Also in Omo, topsoil organic C was reduced by 24% and 36% under old and young cocoa respectively. These values are similar to what was reported by Ekanade [18] and Ogunkunle and Eghaghara [19]. Ekanade [18] in a study carried out near Ibadan, Nigeria reported a reduction of 34.5% in soil organic C under cocoa plantation compared to natural forest. Also, in southern Nigeria, Ogunkunle and Eghaghara [19] found soil organic C under a 10-year-old cocoa to be 25.6% lower than under a secondary forest.

There was an improvement in the soil organic C content under old cocoa farms compared with young cocoa. This may be attributed to the carbon recycling by both the cocoa trees and other forest and fruit trees that usually dot the cocoa agroforests. It may be an indication of a gradual recovery process after an initial soil disturbance during cocoa establishment.

Acknowledgements

The assistance of Mrs H.B. Dafiewhare during laboratory analyses is gratefully acknowledged. The author is also grateful to the cocoa farmers in Idanre and Omo for the permission to carry out this study on their farms.

REFERENCES

[1] Benhin, J. K. A. and Barbier, E. B. 2004. Structural adjustment programme, deforestation and biodiversity loss in Ghana. Environmental and Resource Economics 27: 337-366.

[2] Donald P.F. 2004. Biodiversity impacts of some agricultural production systems. Conservation Biology. 18:17-37.

[3] Butler R.A. 2005. Nigeria has worst deforestation rate, FAO revises figures. www.mongabay.com

[4] Lal, R. 1986. Conversion of tropical rainforest: Agronomic potential and 4cological consequences. Advances in Agronomy 39: 173–264.

[5] Ikhouria I.A., Ero I.I. and Ikhuoria A.E. 2006. Satellite detection and GIS analysis of lowland rainforest reserve reduction in Edo State, Nigeria. In: Salami A.T. (ed) Imperatives of Space Technology for Sustainable Forest Management in Nigeria. Proceedings of an International Stakeholders Workshop Sponsored by NARSDA, Abuja, Nigeria. Pp 72-93.

[6] Ruf F. 2001. Tree crops as deforestation and reforestation agents: the case of Cocoa in Cote d'Ivore and Sulawesi. In: Angelsen A. and Kaimowitz D (eds) Agricultural Technologies and Tropical Deforestation. CABI Publishing, Oxford.

[7] Gockowski J. Baker D., Weise S., Ndoumbe M., Tiki – Manga T., and Touaguegue. 1998. Characterisation and diagnosis of farming systems in ASB Forest Margins Benchmark of southern Cameroon. Mimeograph. Yaounde IITA Humid Ecoregional Center. 65 pp.

[8] Gockowski J. and Weise S.F. 1999. Revitalising traditional tree crop systems at the forest margins in Cameroon. American Society of Agronomy meeting – Special session of Alternatives to Slash and Burn Agriculture. Salt Lake City. (Poster, Abstract published).

[9] Kotto-Same J., Moukam A., Njomgang R., Tiki-Manga T., Tonye J.. Diaw C. Gockowski J. Hauser S., Wiese S., NwagaD., Zapfack L., Palm C., Woomer P., Gillison A., Bignell D. and Tonoh J. 2000. Alternatives to Slash and Burn. Summary Report and Synthesisof Phase II in Cameroon. ASB Coordination Office, ICRAF – Nairobi, Kenya. 72pp.

[10] Asare, R., 2006. A review on cocoa agroforestry as a means for biodiversity conservation. In: Paper presented at World Cocoa Foundation Partnership Conference, Brussels, p. 15.

[11] Oke D.O. and Odebiyi K.A. 2007. Traditional cocoa-based agroforestry and forest species conservation in Ondo State, Nigeria. Agriculture, Ecosystems and Environment, 122:305-311.

[12] Bremner J.M. 1965. Total nitrogen. In: Black C.A. (ed) Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, American Society of Agronomy, pp 1149-1178.

[13] Olsen S.R., Cole C.V., Watanabe F.S. and dean L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA circular 939, Washington.

[14] National Standard Methods, 2004. colony count by the pour plate method. Standards Unit, Evaluation and Standards Laboratory. www.evaluation-standards.org.uk. Pp:13.

[15] Kadeba O. and Aduayi E.A. (1985) Impact on soils of plantations of Pinus caribaea stands in natural tropical savannas. Forest Ecology and Management, 13:27-39

[16] Greenland, D. J. (1994). Soil science and sustainable land management. In: J. K. Syers and D. L. Rimmer (Eds.), Soil Science and Sustainable Land Management in the Tropics, CAB International, Wallingford, pp. 1–15.

[17] Greenland, D. J. (1994). Soil science and sustainable land management. In: J. K. Syers and D. L. Rimmer (Eds.), Soil Science and Sustainable Land Management in the Tropics, CAB International, Wallingford, pp. 1–15.

[18] Ekanade, O., Adesina, F. A., and Egbe, N. E. (1991). Sustaining tree crop production under intensive land use: An investigation into soil quality differentiation under varying cropping patterns in western Nigeria. J. Environ. Manage. 32, 105–113.

[19] Ogunkunle, A. O., and Eghaghara, O. O. (1992). Influence of land use on soil properties in a forest region of Southern Nigeria. Soil Use Manage. 8, 121–125.