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Ecological Stoichiometry along Urban-Rural Land-use Gradients in Southeastern Nigeria

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Abstract

The inter-link in soil biogeochemical reactions made the study of soil ecological stoichiometry an important necessity. The study was carried out in Imo state, a southeastern part of Nigeria, to assess the soil carbon stock as a key element of the soil ecology. Three urban-rural gradients were delineated for the study, viz; urban soils, suburb soils and rural soils. Three pedons were dug, described and sampled at each of these areas using the guidelines of FAO (2006). Soil samples were prepared in the laboratory and analyze for its properties. Among the ecological stoichiometry, soil organic carbon was given an important priority because of its chelation with other elements. Results showed that the soil carbon stock (SCS), available phosphorous and bulk density were asymmetric in their distribution (Skewness = -1.07, 1.05, -1.47 for SCS, P and bulk density respectively) only in the suburb areas. Moisture content, hydraulic conductivity and K varied highly (CV $\geq$ 45% $\leq$ 150%) in most of the soils, base saturation, Mg, Ca, organic carbon, Nitrogen, clay and silt varied moderately (CV $\geq$ 17% $\leq$ 39%) while the bulk density, ECEC, exchangeable acidity, P, pH and sand had a low variability (CV $\geq$ 3% $\leq$ 13%). Soils in the rural areas had the greatest carbon pool (mean SCS = 1.65 Mg C ha^{-1}) followed by suburb (mean SCS = 6.59 Mg C ha^{-1}) and then urban (mean SCS = 8.63 Mg C ha^{-1}). The study of soil carbon stock at various depths in the respective land use gradients showed a greatest difference having at least 4 Mg C ha^{-1} greatest pool in the rural soils than the other two areas.

Keywords: Stoichiometry, ecology, soil carbon stock, land use, biochemical reactions

Introduction

More recently, scientists have concentrated efforts in their study of ecological stoichiometry, especially the most dynamic elements in the soil. Most researchers (example Mulvaney *et al*., 2007; Christoph *et al*., 2013) have considered carbon and nitrogen sequestration, and phosphorous distribution (Osodeke *et al*., 2006) in soils around the world which dominate the soil ecology. In our study of ecological stoichiometry, carbon, nitrogen, sulphur and phosphorous are very important because during the decay and synthesis of organic matter in the soil, transformation and mineralization of these elements which chelates as compounds are usually involved. Because of our advancing land-use, it is not clear for example how carbon sequestration may change in response to the changing land use. Sterner and Elser (2002) stated that ecological stoichiometry implied that plant communities with low biomass carbon to nutrient ratio have fast turnover rates, high nutrient cycling and low carbon sequestration while that with high biomass carbon to nutrient ratio have slow turnover rates, slow soil nutrient cycling and high carbon sequestration in organic soils.

The transformation of landscapes from non-urban to urban land use has the potential to greatly modify soil carbon (C) pools and fluxes (Pouyat *et al*., 2002). They stated that for urban ecosystems, very little data exists to assess whether urbanization leads to an increase or decrease in soil C pools. Urban areas play a significant role in the global carbon cycle as source of carbon emission due to the effects of urban sprawl against other land use types. It is expected that by 2030, an additional 1.2 million square kilometers of land will be converted to urban land use which is expected to result in a loss of carbon storage in natural vegetation of about 138 PgC (Seto *et al*., 2012). During the decomposition of organic matter, mostly made up of C, nitrogen is usually mineralized. Because of the inter-link in biochemical reactions between C, nitrogen and phosphorous, the study is thus necessary for a proper understanding of ecological stoichiometry, especially carbon, in our ecosystem. One of such stoichiometry that signifies the breakdown of carbon in the soil is given thus; $CO(NH_2)_2 + 2H_2O \rightarrow (NH_4)_2CO_3$. In this research, carbon was given an important priority and was converted to a proper SI unit for a good understanding of the concentrations sequestered. Leaf litter from trees and shrubs are mainly the organic matter components of natural soils. Organic matter is usually decomposed by soil inhabiting organisms and the nutrients and energy they contain are released for utilization by the organisms themselves or the vegetation. Soils in urban and peri-urban areas are interrupted from the cycles by various factors; leaf litter is often swept up as trash, or very little litter falls on urban soils because of the low amount of biomass produced by the plants. Assessment of sequestered carbon and other ecological stoichiometry along urban and rural gradients are important to be able to give an account of changes in carbon pool with consequent land use change since carbon has been recorded as the most important element to sequester if we can check the global climate change.

The objective of the study was therefore to use and detect the soil carbon stock as a key element of the ecology in defining soils that were highly sequestered with carbon and other ecological stoichiometry along urban-rural gradients.

Materials And Methods

Description of the Study Site

The study was conducted in three urban-rural gradients namely; urban, suburban and rural soils. Soils were delineated in this order based on ongoing activities and evidence of changing land uses. Soils in the urban areas had some parts with gullies as a limitation, the suburb soils were mainly used for arable crop production while that of the rural had thick vegetation that were made up of shrubs and trees. The whole study areas were located in Imo State, a Southeastern part of Nigeria. Imo state is located approximately between longitudes 6˚50'E and 7˚25'E and latitudes 4˚45'N and 7˚15'N. The state lies within a tropical climate characterized by rainy season (February/March – November) and dry season (November – February/March). Annual rainfall in the state ranges from 3000 mm along Atlantic coast to 2000 mm in the hinterland. Average annual temperature of the state ranges from 25 to 27˚ C.

Soil Sampling and Laboratory Analysis

Soil samples were collected from three pedons in each of the areas; urban, surburban and rural. Soils profiles were described and sampled according to the guidelines of FAO (2006). Soil samples were collected from the bottom-most horizon to the topmost to avoid contamination of soils from horizons. All the sampled soils were bagged in fresh clean polythene bag and were prepared for analyses in the laboratory by air drying and sieving using a 2mm sieve.

Standard routine methods were used in the laboratory to analyze, with the inclusion of other physical properties, the important elements that are active in the soil ecological stoichiometry. Particle size was analyzed using the Bouyoucous hydrometer method (Gee and Or, 2002). Bulk density was determined using the core method as described by Blake and Hartge (1986). Moisture content was obtained gravimetrically by the simple oven drying method. Hydraulic conductivity was determined using the constant head permeameter method as described by Topp and Dane (2002). Exchangeable base cations (Ca, Mg, K, and Na) were extracted with 1 N NH_4OAc (pH 7) (Thomas, 1982). Exchangeable calcium and magnesium were determined by ETDA complexio-metric titration while exchangeable potassium and sodium were determined by flame photometry (Jackson, 1962). Exchangeable acidity was determined by titration method (Mclean, 1982). Effective Cation Exchange Capacity (ECEC) was obtained by the summation of all exchangeable cations. Base saturation was calculated as a percentage of the value of the summation of exchangeable bases over cation exchange capacity. Soil organic carbon was analyzed by Walkley and Black wet digestion method (Nelson and Sommers, 1982). Soil carbon stock was calculated using a mathematical formula; soil carbon stock = percentage organic carbon × bulk density × soil depth (Batjes, 1996). Soil pH was measured potentiometrically in both water and 0.1 N KCl at the soil-liquid ratio of 1:2.5. Total nitrogen was determined by micro Kjedahl digestion method (Bremner and Mulvaney, 1982) and available phosphorous was determined by Bray II method (Olsen and Sommers, 1982).

Results And Discussion

Table 1 shows result of the descriptive statistics of the soil properties of the studied soils. The normality of distribution of the measures of central tendency of the soil properties was mostly symmetric in the urban soils with the exception of clay, K, exchangeable acidity and moisture content. In the suburb soils, the distribution of soil carbon stock, bulk density, hydraulic conductivity and phosphorous were as well asymmetric. It was obvious that the changing land use gradient from urban to a suburb affected the carbon stock of the latter soils (mean = 6.59 Mg C ha^{-1}) because of the trending presence of organic matter as we travel in space off from the urban areas. According to Craul (1985) soils in urban and peri-urban areas are interrupted from the cycles by various factors; leaf litter is often swept up as trash, or very little litter falls on urban soils because of the low amount of biomass produced by the plants. This was not the case for the suburb soils. The trending presence of organic matter that affected the carbon stock of the suburb soils as well affected the phosphorous contents (mean = 23.39 g kg^{-1}) which could be because of the availability of phosphorous from the organic phosphates. In the rural soils, most of the soil properties were neither skewed nor kurtous with the exception of phosphorous, Ca, Mg, K, Na and bulk density. The distribution of the carbon stock of the rural soils were not skewed but kurtous which could be adduced to availability of more carbon pool (mean = 8.63 Mg C ha^{-1}) in the whole area as a result of the thick vegetation made up of trees and shrubs. The soil properties varied in the areas. Moisture content, hydraulic conductivity and K varied highly (CV ≥ 45% ≤ 150%) in most of the soils, base saturation, Mg, Ca, organic carbon, Nitrogen, clay and silt varied moderately (CV ≥ 17% ≤ 39%) while the bulk density, ECEC, exchangeable acidity, P, pH and sand had a low variability (CV ≥ 3% ≤ 13%). Soil carbon stock varied moderately in the suburb and rural soils. The carbon stock (SCS) in the rural soil was highest (mean SCS = 1.65 Mg C ha^{-1}) followed by suburb (mean SCS = 6.59 Mg C ha^{-1}) and then urban soils (mean SCS = 8.63 Mg C ha^{-1}) in that order.

Figures 1 give the graphs of soil carbon stocks against depths in the urban-rural land use gradients. It could be seen that at the depth of 20 cm, soil carbon stock in the rural soils (8.5 Mg C ha^{-1}) were highest when compared among the other gradients. When monitored at the depth of 40 cm, the carbon stock in all the areas neared equals (8.0 Mg C ha^{-1} - 8.2 Mg C ha^{-1}). This could be because the land use in the urban and suburban areas had not so deteriorated the carbon pool in these areas. The soil carbon stock showed a great difference having at least 4 Mg C ha^{-1} greater pool in the rural soils than the other two areas.

Conclusion

Most of the soil properties of the three land use gradients had a symmetric distribution. The changing land use of the suburb soils might have resulted to the asymmetric distribution of the soil carbon stock, phosphorous and bulk density in the areas. The rural soils had the greatest carbon pool which affected the availability of phosphorous in a direct proportion. Ecological stoichiometry has had a diverse study; its importance is in the mitigation of the global climate change and for exactitude in soil management.

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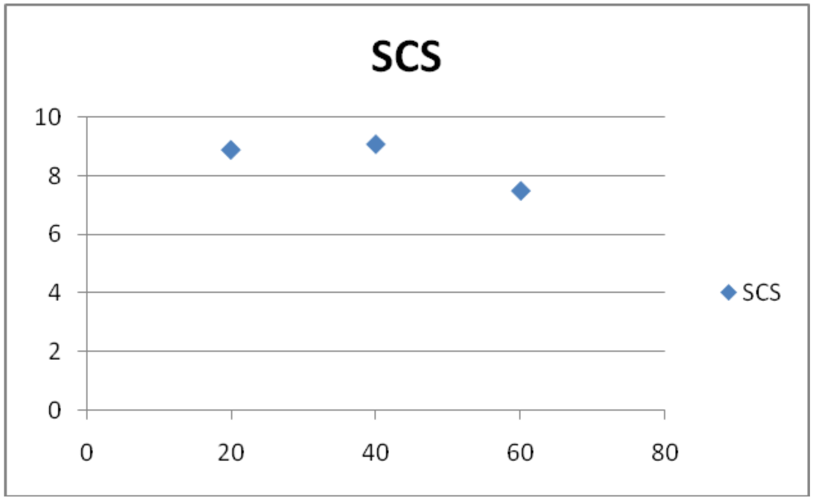
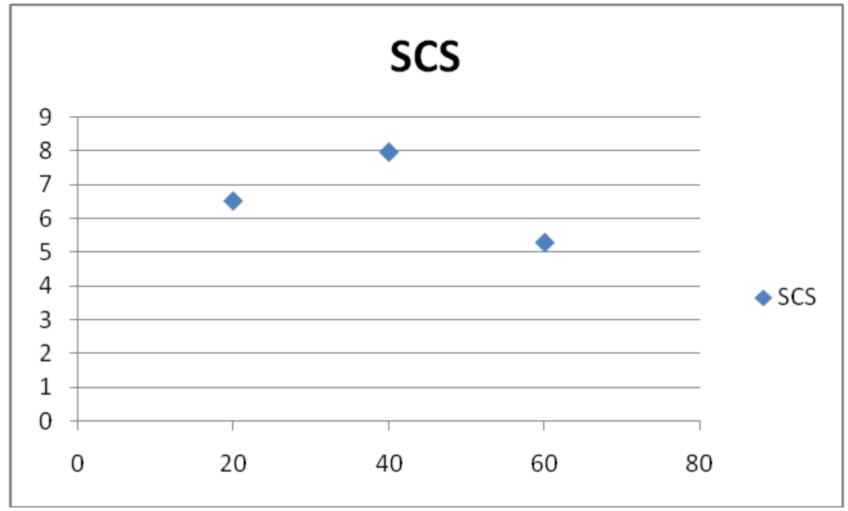
Table 1: Descriptive Statistics of Soil Properties of the Studied Areas

Variable	**Urban Soils**	Mean	SD	Min.	Max.	CV	Skewness	Kurtosis	**Suburb soils**	Mean	SD	Min	Max	CV	Skewness	Kurtosis
Sand (gkg^{-1})		792.67	26.46	766.00	846.00	3.34	0.88	0.73		786	43.59	726.00	846	5.55	0.19	-1.27
Silt (gkg^{-1})		58.89	22.61	30.00	90.00	38.39	0.18	-1.17		65.56	16.67	40.00	80	25.42	-0.75	-0.99
Clay (gkg^{-1})		140.27	55.37	10.40	184.00	39.47	-1.91	3.83		148.4	46.67	74.00	194.00	31.44	-0.46	-1.44
pH H_2O		5.02	0.27	4.60	5.50	5.34	0.35	0.23		4.57	0.26	4.20	5.10	5.76	0.78	0.95
pH KCl		3.93	0.27	3.50	4.40	6.85	0.19	0.09		3.54	0.31	3.00	4.00	8.71	-0.21	-0.09
P ($mgkg^{-1}$)		21.42	2.78	18.60	25.60	12.96	0.76	-1.51		23.39	3.73	18.60	31.20	15.94	1.05	1.59
N (%)		0.07	0.01	0.05	0.09	19.80	-0.13	-0.78		0.07	0.02	0.05	0.10	21.56	0.27	-0.51
OC (gkg^{-1})		8.70	1.55	6.40	11.20	17.84	0.0005	-0.58		9.20	2.24	6.20	13.00	24.40	0.53	-0.55
Ca ($Cmolkg^{-1}$)		1.50	0.27	1.10	1.93	17.89	-0.02	-0.57		2.46	0.53	1.80	3.40	21.46	0.49	-0.67
Mg ($Cmolkg^{-1}$)		1.89	0.56	1.00	2.80	29.53	-0.10	-0.09		1.56	0.57	0.80	2.40	36.80	-0.12	-1.39
K ($Cmolkg^{-1}$)		0.98	0.44	0.40	2.00	45.10	1.62	3.99		0.08	0.01	0.07	0.11	16.86	0.64	-0.54
Na ($Cmolkg^{-1}$)		0.08	0.01	0.06	0.10	16.36	0.60	0.91		0.09	0.02	0.06	0.12	20.86	0.48	0.21
EA		0.08	0.01	0.07	0.10	11.76	1.47	3.28		1.19	0.18	0.88	1.48	14.71	-0.15	0.39
ECEC ($Cmolkg^{-1}$)		1.22	0.14	1.04	1.48	11.57	0.74	0.03		5.38	0.95	4.21	6.91	17.60	0.17	-1.32
BS (%)		4.24	0.87	3.01	6.03	20.51	0.86	1.68		76.70	7.21	64.85	87.26	9.40	-0.24	-0.90
BD (gcm^{-3})		69.75	9.23	50.83	82.75	13.23	-0.86	1.46		1.27	0.60	0.02	1.83	47.13	-1.47	1.47
HC ($cmmin^{-1}$)		0.12	0.06	0.04	0.24	50.96	0.58	-0.01		0.07	0.08	0.0003	0.21	109.28	1.17	0.003
SCS (Mg C ha^{-1})		1.65	0.24	1.17	1.90	14.52	-0.99	0.72		6.59	3.25	0.16	10.79	49.28	-1.07	0.89
MC (g/g)		0.19	0.28	0.01	0.81	150.72	1.77	2.31		15.01	5.49	9.20	25.1	36.59	0.64	-0.57
	Rural soils															
Sand (gkg^{-1})		827.11	35.51	776.00	886.00	4.29	0.21	-0.48								
Silt (gkg^{-1})		47.78	14.81	30.00	70.00	31.01	-0.11	-1.30								
Clay (gkg^{-1})		125.11	31.80	84.00	164.00	25.42	-0.19	-1.56								
pH H_2O		5.07	0.34	4.70	5.70	6.62	1.04	0.19								
pH KCl		4.06	0.36	3.60	4.80	8.90	1.10	1.32								
P ($mgkg^{-1}$)		25.4	4.72	20.60	35.60	18.57	1.33	1.94								
N (%)		0.09	0.02	0.07	0.12	18.61	0.13	-0.82								
OC (gkg^{-1})		11.03	2.33	8.00	14.80	21.08	0.31	-1.03								
Ca ($Cmolkg^{-1}$)		3.29	0.63	2.60	4.80	19.26	1.93	4.55								
Mg ($Cmolkg^{-1}$)		2.68	0.32	2.00	3.10	11.78	-1.28	2.19								
K ($Cmolkg^{-1}$)		0.10	0.01	0.09	0.13	13.64	1.28	0.83								
Na ($Cmolkg^{-1}$)		0.19	0.26	0.08	0.88	140.48	2.98	8.95								
EA		0.94	0.22	0.52	1.20	24.03	-0.80	-0.34								
ECEC ($Cmolkg^{-1}$)		7.11	0.74	5.97	8.67	10.43	0.81	2.25								
BS (%)		86.43	4.09	79.89	94.00	4.74	0.41	0.54								
BD (gcm^{-3})		1.36	0.51	0.82	2.54	37.35	1.63	3.62								
HC ($cmmin^{-1}$)		0.06	0.04	0.002	0.14	61.77	0.64	0.93								
SCS (Mg C ha^{-1})		8.63	2.19	5.36	12.95	25.40	0.65	1.09								
MC (g/g)		14.44	4.59	10.00	23.20	31.79	0.74	-0.12								

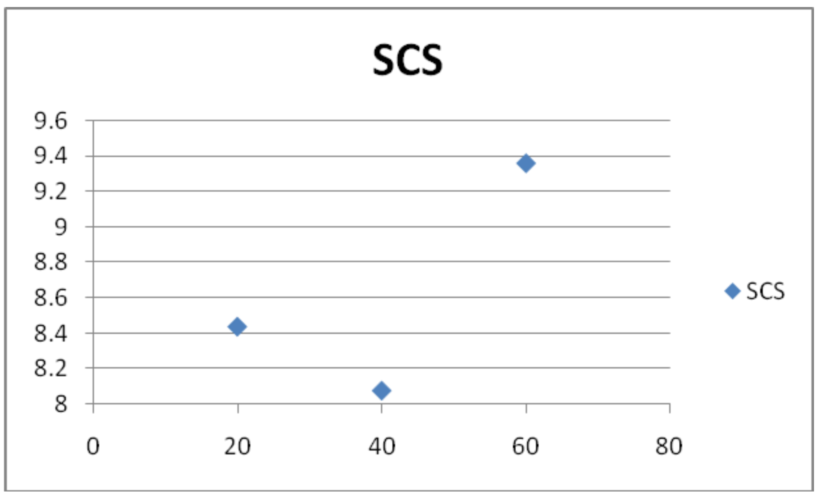
SD- Standard Deviation, CV- Coefficient of Variation, OC- Organic Carbon, EA- Exchangeable Acidity, ECEC- Effective Cation Exchange Capacity, BS- Base Saturation, BD- bulk density, HC- Hydraulic Conductivity, SCS- Soil Carbon Stock, MC- Moisture Content.



Urban Soils



Suburb soils



Rural Soils

Figures 1: Graphs of Soil Carbon Stock against depths in the various land use gradients