International Journal of Agriculture and Forestry 2015, 5(3): 199-204
DOI: 10.5923/j.ijaf.20150503.04

Contributions of Microorganisms to Soil Fertility in Adjacent Forest, Fallow and Cultivated Land Use Types in Nsukka, Nigeria

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Abstract Soil chemical properties and microbial populations were determined in this study in order to compare the contributions of microorganisms to soil fertility in three land use types in an Ultisol of southeastern Nigeria. A total of 27 samples were collected from 0-20 cm depth as follows: 21 samples from a fallow land (3 replicates from 7 plots) that has been under 10-year fallow, three samples from an adjacent forestland and finally, three samples from an adjacent cultivated land owned by a farmer. These samples were air dried, passed through a 2-mm sieve before soil properties were determined following standard methods. Fresh soil samples were used to determine the number of soil microorganisms via the dilution spread plate technique using the nutrient agar for bacteria and potato dextrose agar for fungi. Results showed that the forest and fallow lands had significantly ($P < 0.05$) lower mean pH value, available P, exchangeable K and Na, but significantly higher exchangeable H and bacteria population than the cultivated land. The mean exchangeable Ca was significantly ($p < 0.05$) higher in the cultivated land than in the fallow land but similar to that from the forestland. The fungi population was significantly ($p < 0.05$) higher in the forestland than in others which are similar statistically. The mean soil organic matter, total N, exchangeable Mg, exchangeable Al and CEC were statistically similar in all the land use types. Contributions of microorganisms to soil fertility were generally more in the uncultivated lands, an indication that tillage operations may have affected the microbial populations. Significant correlations ($p < 0.05$) obtained between some soil chemical properties and microbial densities signify important roles microorganism play in soil nutrient build up.

Keywords Bacteria, Fungi, Soil fertility, Forestland, Fallow land, Cultivated land, Ultisol

1. Introduction

Microorganisms are responsible for most biological transformations that result to the development of nutrients in the soil [1]. They influence several soil functions and are key indicators of soil quality. These organisms ensure the continued existence of nutrients in the soil. Management of these nutrients through sustainable use of soil resources is a requisite for successful agriculture [2]. Identifying and quantifying soil microorganisms may be one way of determining soil nutrient status [3]. This could help in the maintenance of soil nutrients for improved crop productivity.

Several factors including the physical and chemical properties of soils can influence the type of species, number and activities of microorganisms in a soil [4]. Studies have shown that in addition to environmental factors such as temperature, moisture and CO_2 levels, soil physical disturbance (structure), soil pH and other chemical properties are major determinants of soil microbial community structure [5-8]. Land use and soil management practices can influence soil nutrients through processes such as mineralization, oxidation, leaching and erosion [9, 10]. This may affect the presence and activities of soil microorganisms and hence soil fertility. For instance, intensive tillage operations common in continuously cultivated soils may lead to increased decomposition / mineralization of available nutrients which may result to loss of nutrients from these soils.

Studies examining how different land use types influence the contributions of soil microorganisms to soil fertility are uncommon in tropical soil studies. Thus, the main objective of this research was to examine how three different land use types influence the contribution of microorganisms to soil fertility in Nsukka, Nigeria. Interrelationships between soil chemical and microbial properties were also compared.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted in Edem Nru, Nsukka located

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Published online at http://journal.sapub.org/ijaf

within latitude 6°°52′3″N and longitude 7°23′2″E. Nsukka is in the derived savannah area of southeastern Nigeria with a mean annual rainfall of about 1550 mm. It has a mean annual temperature of 22°C (minimum) and 30°C (maximum). Relative humidity and height above sea level are 60% and 447 m, respectively [11]. Soils of the area are formed from the disintegration of false-bedded sandstone and upper coal measures which give rise to sandy and clayey soils respectively [12, 13]. These soils have been classified as Ultisol [14]. They are usually prone to erosion and leaching as a result of exposure to rainfall of high intensity prevalent in the area.

2.2. Land Use Types

The land use types examined were forestland, fallow land, and cultivated land. The forestland is a natural forest which has not been disturbed for at least 100 years. Although shrubs and climbers are present in the forest, the major plant species are trees such as African mango (*Sphenostylis stenocarpa*), bamboo (*Bambusa vulgaris*), oil bean (*Pentaclethra macrophylla*), and oil palm (*Elaeis guineensis*).

The fallow land had been previously cultivated for 7 years with cassava (*Manihot esculenta* Crantz)), maize (*Zea mays*) and pigeon pea (*Cajanus cajan*) either as sole crops or as crop combinations in various plots. After the years of cultivation, the land was naturally fallowed for 10 years. Species present in the fallow land include elephant grass (*Pennisetum purpureum*), guinea grass (*Panicum maximum*) and siam weed (*Chromolaena odorata*).

The cultivated land is adjacent to the forestland. Various crops had been continuously cultivated on the land for over 20 years. Some of the crops cultivated during the previous years were cocoyam (*Colocasia esculenta*), eggplant (*Solanum melongena*) pepper (*Capsicum* sp.), sweet potato (*Ipomoea batatas*) and yam (*Dioscorea* sp.). At the time of sampling, both cassava and maize were cultivated on the land.

2.3. Soil Sampling and Chemical Analysis

Sample collection was done at a depth of 0-20 cm using a soil auger. Twenty-one soil samples were collected from the fallow land (3 replicates in 7 plots), 3 samples were randomly collected from the adjacent forest and finally, 3 samples were also randomly collected from the adjacent cultivated land. This gave a total of 27 samples. These samples were air-dried and passed through a 2-mm sieve before analysis.

Chemical analyses were carried out using standard laboratory methods. Soil pH was determined with deionized water using a soil-liquid ratio of 1: 2.5. Soil organic carbon was determined using the Walkley-Black method [15]. Organic carbon values were converted to organic matter (OM) by multiplying with the factor 1.724. Total nitrogen was determined by the modified Kjeldahl method [16]. Available phosphorus was obtained using Bray II as the extractant [17]. Exchangeable cations and cation exchange capacity (CEC) were determined following the method described by [18].

2.4. Microbial Analysis

The number of soil microorganisms was determined using the dilution spread plate technique. Nutrient agar (NA) and potato dextrose agar (PDA) were used to culture bacteria and fungi, respectively. A dilution blank was prepared by dispersing 1 g of fresh soil in 9 ml of sterile water. This was a 10^{-1} dilution. After shaking, 1 ml of the dilution was transferred aseptically into another 9 ml of sterile water to give a 10^{-2} dilution. This process was repeated 5 times (each new dilution made from the previous dilution) until 7 dilutions were obtained (10^{-1} to 10^{-7}).

Dilutions 10^{-4} to 10^{-7} were inoculated on the NA plates as follows: 0.1 ml of a dilution was dropped on a plate and spread over the plate with a sterile plastic spreader. After spreading, the lid was replaced, labelled and the plate inverted for incubation which was done at 26°C for 1 week. Each inoculated plate was in triplicate. Dilutions 10^{-3} to 10^{-5} were inoculated on the PDA plates following the same procedure. After incubation, the plates were laid out for visual observation and counting of colonies. Assuming each colony was produced by a single organism, the number of bacteria and fungi in the soil samples were calculated using the formula below:

Average colony forming units (CFUs) per plate ÷ 0.1 ml ÷ dilution ÷ grams of soil per ml

2.5. Statistical Analysis

One-way Analysis of Variance (ANOVA) was used to test for differences between the land use types. Treatment means which were significantly different were separated using Tukey's family error rate. Correlation analysis was used to determine the interrelationship between soil chemical and microbial properties. All analyses were carried out on Minitab 17 statistical package.

3. Results and Discussion

Soil pH of the cultivated land was significantly higher ($p < 0.05$) than that of the other land use types (Table 1). This is evident in the lower exchangeable acidity (H and Al) of the cultivated land compared to the other land use types. The lower pH (higher exchangeable acidity) of the forestland and fallow land may be due to their higher organic matter content, since organic acids are produced as a result of OM decomposition [19]. There was no significant difference ($p > 0.05$) in total nitrogen content of the different land use type, though the cultivated land had the lowest amount of this nutrient. Available phosphorus content of the cultivated land was significantly ($p < 0.05$) higher than that of the other land use types. Lower pH of the forest and fallow land is likely to have caused phosphorus fixation by aluminium, and iron compounds thus resulting to the reduced available phosphorus content of these land use types.

The mean exchangeable K, Na and Ca values from the cultivated land were significantly ($p < 0.05$) higher than that of the forest and fallow land use types but exchangeable Mg values were statistically similar. The CEC of the cultivated land was also higher than that in the other land use type, though the difference was not significant. On the other hand, the fallow land had the lowest concentration of these cations (except for exchangeable K) and CEC, though these values were not significantly different from those of the forestland. The higher CEC (and exchangeable bases) of the cultivated land which had low OM content is somewhat surprising, since OM is known to contribute significantly to the CEC of tropical soils [20, 21]. It is likely that the particle size fractions (clay and silt) of the soil may have also contributed to the higher CEC (and exchangeable bases) of these soils [21]. Soil management practices such as addition of wood ash to the cultivated land (which the farmer acknowledged that he used occasionally) may also be responsible for the higher exchangeable bases and CEC of the cultivated land, since wood ash has been shown to improve these soil properties [22].

Soils of the three land use types contained more bacteria than fungi which is not surprising because soil usually contain greater amounts of soil bacteria than fungi [23]. This is because bacteria are less susceptible to changes in soil and environmental conditions unlike fungi which are easily restricted by soil pH, nutrient and harsh environmental conditions [24, 25]. The number of soil bacteria across the land use types was generally lower than the expected number in 1 gram of soil i.e. 10^8 to 10^9 as reported by [23]. However, the number of soil fungi was within the range for fungi i.e. 10^5 to 10^6 as reported by the same authors. This reduction in the amount of soil bacteria may be attributed to the method employed in determining the number of soil microorganisms. Culture-dependent methods of determining soil microbial community such as the dilution spread plate technique used in this study do not give accurate results of the number of microorganisms present in the soil. It has been reported that less than 0.1% of soil microorganisms can be cultured using current culture media formulations [26].

The number of soil bacteria in the cultivated land was significantly lower ($p < 0.05$) than that in the other land use types. This is probably because of the presence of larger carbon source in the form of organic matter present in the forest and fallow land. This carbon source needed for metabolism may have increased the growth and activities of bacteria in soils of these land use types. The slightly lower pH of the uncultivated land use type may have also encouraged the growth of bacteria which strive in that level of soil pH. Soil pH has been shown to greatly influence soil microbial community [7].

Significantly higher number of soil fungi was present in the forestland compared to other land use types. This may have been because it had the highest amount of OM. It is also possible that the presence of trees in this land use type may have encouraged the presence of ectomycorrhizal fungi which colonize most tree species. Changes in soil physical properties resulting from tillage operations common in cultivated land (and that which may have occurred during the period of cultivation prior to fallow in the fallow land) may have equally contributed to the reduced number of fungi in the cultivated and fallow land use types. This is because fungi are easily influenced by changes in soil and environmental conditions [24, 25]. Hendrix et al. [5] earlier reported that fungal structure (hyphal growth) is greatly affected by conventional agricultural practices. Furthermore, the presence of trees in the forestland may have reduced the impact of heavy rainfall and other climatic variables in this land use type thus, favouring abundant growth of fungi in the forestland.

Significant correlation existed between some soil chemical properties (Table 2). For instance, positive relationships were recorded between pH and some soil nutrients (available phosphorus, exchangeable K and Ca); while a negative relationship existed between pH and available Al. Increase in soil pH has been shown to increase phosphorus availability in soil [27, 28]. This is mainly because with increasing soil pH, phosphorus fixation (by iron and aluminium compounds) common in highly weathered tropical soils is usually reduced. Both exchangeable K and Na (especially K) had the highest number of significant correlations with other soil nutrients. These correlations highlight the complex interrelationship that exists among soil nutrient properties [29].

Significant correlation was recorded between soil microbial number and exchangeable cations. This relationship was negative for exchangeable bases (mostly K and Na) and positive for exchangeable acidity (H). Agricultural management practices such as type and method of fertilizer application can directly affect the number of soil microorganisms. For instance, application of soil amendments in bands as opposed to broadcasting can reduce homogeneity in soil nutrient availability and this may negatively affect growth of soil microorganisms, especially fungal growth [8]. Positive correlation equally existed between soil microorganisms and soil OM as well as total nitrogen, though these relationships were not significant. This suggests that the higher the amount of nutrients (carbon and nitrogen), the greater the number of soil microorganism, though this will require more detailed research, especially for nitrogen.

Negative but insignificant correlation was observed between soil microorganisms and available phosphorus. Sidhu [30] reported that microorganisms immobilize phosphorus in their cells in order to build their population during which they may create phosphorus deficiency in soil. In addition, recall that the cultivated land which contained the highest amount of available phosphorus also had the lowest number of microorganisms. These may explain the inverse relationship between number of bacteria/fungi and available phosphorus recorded in this study.

Table 1. Chemical and microbial properties of soils from the different land use types

Land use type	pH	SOM (g/kg)	Total N (g/kg)	Av. P (mg/kg)	Exc. K ($cmol_c$/kg)	Exc. Na ($cmol_c$/kg)	Exc. Ca ($cmol_c$/kg)	Exc. Mg ($cmol_c$/kg)	Exc. H ($cmol_c$/kg)	Exc. Al ($cmol_c$/kg)	CEC ($cmol_c$/kg)	Bacteria per gram of soil	Fungi per gram of soil
Cultivated	5.17a	1.92a	0.06a	17.0a	0.67a	0.80a	4.80a	1.33a	3.60b	0.53a	8.93a	8.5×10^6b	1.0×10^6b
Fallow	4.33b	2.38a	0.14a	7.6b	0.15b	0.26b	1.64b	1.20a	4.42a	1.20a	8.23a	15.2×10^6a	1.1×10^6b
Forest	4.37b	2.72a	0.10a	7.8b	0.10b	0.27b	2.13ab	1.47a	4.27a	0.93a	8.53a	14.4×10^6a	2.0×10^6a

SOM: soil organic matter; Av.: available; Exc.: exchangeable. Means that share a letter are not significantly different ($\alpha = 0.05$).

Table 2. Correlation between soil chemical and microbial properties

	pH	SOM (g/kg)	Total N (g/kg)	Av. P (mg/kg)	Exc. K (cmolc/kg)	Exc. Na (cmolc/kg)	Exc. Ca (cmolc/kg)	Exc. Mg (cmolc/kg)	Exc. H (cmolc/kg)	Exc. Al (cmolc/kg)	CEC (cmolc/kg)	Bacteria per gram of soil	Fungi per gram of soil
pH	1												
SOM (g/kg)	-0.636	1											
Total N (g/kg)	-0.572	0.171	1										
Av. P (mg/kg)	0.884**	-0.317	-0.448	1									
Exc. K (cmolc/kg)	0.787*	-0.638	-0.507	0.758*	1								
Exc. Na (cmolc/kg)	0.664	-0.622	-0.470	0.608	0.966**	1							
Exc. Ca (cmolc/kg)	0.966**	-0.714*	-0.571	0.807**	0.855**	0.778*	1						
Exc. Mg (cmolc/kg)	0.391	0.195	-0.209	0.619	0.129	0.032	0.248	1					
Exc. H (cmolc/kg)	-0.244	0.316	0.552	-0.178	-0.686*	-0.779*	-0.407	0.298	1				
Exc. Al (cmolc/kg)	-0.780*	0.703*	0.523	-0.483	-0.486	-0.464	-0.776*	-0.330	0.124	1			
CEC (cmolc/kg)	-0.216	-0.057	0.087	-0.170	0.292	0.456	-0.001	-0.287	-0.524	0.230	1		
Bacteria per gram of soil	-0.624	0.505	0.625	-0.531	-0.891**	-0.947**	-0.730*	0.037	0.838**	0.469	-0.369	1	
Fungi per gram of soil	-0.452	0.596	0.312	-0.387	-0.802**	-0.772*	-0.530	0.379	0.726*	0.112	-0.256	0.726*	1

SOM: soil organic matter; Av.: available; Exc.: exchangeable.

4. Summary and Conclusions

This study carried out in southeastern Nigeria on the contribution of microorganisms to soil fertility in three land use types showed that the forestland had the highest OM content and exchangeable Mg, the fallow land had the highest total nitrogen and exchangeable acidity, while the cultivated land had the highest pH, available phosphorus, exchangeable bases (except for exchangeable Mg) and CEC. The cultivated land equally had the lowest number of microorganisms while the uncultivated land use types (forest and fallow) had greater amounts of microorganisms probably due to OM accumulation and zero tillage. It can be deduced that soil management practices and tillage operations may have reduced the contribution of microorganisms to soil fertility on the cultivated land. This means that even though the cultivated land may appear to have more nutrients compared to the forest and fallow land, these nutrients may not be sustained for a long time due to the lower number of microorganisms in this land use type.

Significant correlations which existed among soil chemical and microbial properties indicate that the presence of one nutrient may affect the presence of another in the soil. These correlations equally signify the complex interrelationship that exists between soil nutrient contents and microorganisms. Using more accurate soil microbial community analysis i.e. culture-independent techniques such as phospholipid fatty acid (PLFA) analysis, nuclei acid techniques, phylogenetic analysis, fluorescent in situ hybridization (FISH) in addition to including other microbial analyses such as microbial biomass, microbial respiration and enzyme activity may improve the reliability of this experiment and thus allow for better conclusions to be drawn on the contributions of microorganisms to soil fertility.

REFERENCES

[1] Schulz, S., Brankatschk, R., Dümig, A., Kögel-Knabner, I., Schloter, M., and Zeyer, J., 2013. The role of microorganisms at different stages of ecosystem development for soil formation. Biogeosciences, 10, 3983-3996.

[2] Kiflu, A., and Beyene, S., 2013. Effects of different land use systems on selected soil properties in south Ethiopia. Journal of Soil Science and Environmental Management, 4(5), 100-107.

[3] Zhang, J.E., Liu, W.G., and Hu, G., 2002. The relationship between quantity index of soil microorganisms and soil fertility of different land use systems. Soil and Environmental Science, 11(2), 140-143.

[4] Lombard, N., Prestat, E., van Elsas, J.D., and Simonet, P., 2011. Soil-specific limitations for access and analysis of soil microbial communities by metagenomics. FEMS Microbiol. Ecol., 78, 31-49.

[5] Hendrix, P.F., Parmelee, R.W., Crossley, D.A., Coleman, D.C., Odum, E.P., and Groffman, P.M., 1986. Detritus food webs in conventional and no-tillage agroecosystems. Bioscience, 36, 374-380.

[6] Grayston, S.J., Campbell, C.D., Bardgett, R.D., Mawdsley, J.L., Clegg, C.D., Ritz, K., Griffiths, B.S., Rodwell, J.S., Edwards, S.J., Davies, W.J., Elston, D.J., and Millard, P., 2004. Assessing shifts in microbial community structure across a range of grasslands of differing management intensity using CLPP, PLFA and community DNA techniques. Appl. Soil Ecol., 25(1), 63-84.

[7] Ibekwe, A.M., Poss, J.A., Grattan, S.R., Grieve, C.M., and Suarez, D., 2010. Bacterial diversity in cucumber (*Cucumis sativus*) rhizosphere in response to salinity, soil pH, and boron. Soil Biol. Biochem., 42, 567-575.

[8] Strickland, M.S., and Rousk, J., 2010. Considering fungal:bacterial dominance in soils - Methods, controls, and ecosystem implications. Soil Biol. Biochem., 42, 1385-1395.

[9] Celik, I., 2005. Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. Soil Tillage Res., 83, 270-277.

[10] Liu, X.L., He, Y.Q., Zhang, H.L., Schroder, J.K., Li, C.L., Zhou, J., and Zhang, Z.Y., 2010. Impact of land use and soil fertility on distributions of soil aggregate fractions and some nutrients. Pedosphere, 20(5), 666-673.

[11] Asadu, C.L.A., Obasi, S.C., and Dixon, A.G.O., 2010. Variations in soil physical properties in a cleared forestland continuously cultivated for seven years in eastern Nsukka Nigeria. Communications in Soil Science and Plant Analysis, 41(2), 123-132.

[12] Akamigbo, F.O.R., and Asadu, C.L.A., 1983. The influence of parent materials on the soils of south-eastern Nigeria. East Africa Agricultural and Forestry Journal, 48, 81-91.

[13] Asadu, C.L.A., 1990. Comparative characterization of two-foot slope soils in Nsukka area of eastern Nigeria. Soil Science, 150, 527-533.

[14] Igwe, C.A., 2001. Effects of land use on some structural properties of an Ultisol in south-eastern Nigeria. Int. Agrophysics, 15, 237-241.

[15] Nelson, D.N., and Sommers, L.E., 1982. Total organic carbon and organic matter, In: Page, A.L., Miller, R.H., and Keeny, D.R. (Eds.), Methods of Soil Analysis, Part II, pp. 539-579. American Society of Agronomy and Soil Sci. Soc. of Am., Madison W.I.

[16] Bremner, J.M., 1965. Total nitrogen, In: Black, C.A. (Ed.), Methods of Soil Analysis, Part II, Amer. Soc. Agron., 9, 1149-1178.

[17] Olsen, S.R., and Sommers, L.E., 1982. Phosphorus, In: Page, A.L., Miller, R.H., and Keeny, D.R. (Eds.), Methods of Soil Analysis, Part II, pp. 15-72. American Society of Agronomy and Soil Sci. Soc. of Am., Madison W.I.

[18] Peech, M., Alexander, LT., Dean, L.A., and Reed, J.F., 1947. Methods of soil analysis for soil fertility. United States Department of Agriculture Circular 767. US Government Printing Office, Washington DC.

[19] Bot, A., and Benites, J., 2005. The Importance of Soil Organic Matter: Key to Drought-Resistant Soil and Sustained Food Production. FAO, UN, Rome.

[20] Asadu, C.L.A., and Akamigbo, F.O.R., 1990. Relative contributions of organic matter and clay fractions to cation exchange capacity of soils in southeastern Nigeria. Samaru Journal of Agricultural Research, 7, 17-23.

[21] Asadu, C.L.A., Diels, J., and Vanlauwe, B., 1997. A comparison of the contributions of clay, silt, and organic matter to the effective CEC of soils of sub-Saharan Africa. Soil Science, 162, 785-794.

[22] Saarsalmi, A., Mälkönen, E., and Piirainen, S., 2001. Effects of wood ash fertilization on forest soil chemical properties. Silva Fennica 35(3), 355-368.

[23] Sylvia, D.M., Fuhrmann, J.J., Hartel, P.G., and Zuberer, D.A., (Eds.) 2005. Principles and Applications of Soil Microbiology, 2nd Ed. Prentice Hall, New Jersey.

[24] Jin, Z.Z., Lei, J.Q., Xu, X.W., Li, S.Y., Fan, J.L., and Zhao, S.F., 2010. Characteristics of the soil microbial population in forest land irrigated with saline water in the desert area. Journal of Arid Land, 2(2), 107-115.

[25] Sui, X., Feng, F., Lou, X., Zheng, J., and Han, S., 2012. Relationship between microbial community and soil properties during natural succession of forest land. African Journal of Microbiology Research, 6(42), 7028-7034.

[26] Atlas, R.M., and Bartha, R., 1998. Microbial Ecology: Fundamentals and Applications. Benjamin/Cummings, Redwood City, CA.

[27] Eze, O.C., and Loganathan, P., 1990. Effects of pH on phosphate sorption of some Paleudults of southern Nigeria, Soil Science, 150, 613-621.

[28] Sato, S., and Comerford, N.B., 2005. Influence of soil pH on inorganic phosphorus sorption and desorption in a humid Brazilian Ultisol. R. Bras. Ci. Solo, 29, 685-694.

[29] Ranade-Malvi U. 2011. Interaction of micronutrients with major nutrients with special reference to potassium. Karnataka J. Agric. Sci., 24(1), 106-109.

[30] Sidhu, G.S., 1998. Role of Microorganisms in Soil Fertility. Ultra Gro Food Company, Madera, California.