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IMPACT OF ANTHROPOGENIC ACTIVITIES ON SOIL MICROBIAL POPULATIONS AND PHYSICOCHEMICAL CHANGES IN THE NATURAL FOREST-SAVANNA OF NORTHERN GHANA

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ABSTRACT: This study assessed the effects of human activities on forest soil microbial population changes in relation to soil physicochemical composition alterations in Wungu, West Mamprusi District of Northern Region, Ghana. The study was conducted in the natural forest-savanna of northern Ghana, on a comparative basis using a sacred grove and adjacent unprotected forest which is prone to human disturbances, mainly in the form of burning, logging, and grazing. Composite soil samples (0-50 cm depth) were collected in both forest sites and analysed in the laboratory using standard analytical procedures. Results showed that anthropogenic activities caused significant reduction ($P < 0$ 0.1) in soil microbial populations, soil pH, SOM, total N, as well as the concentrations of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, ions and available phosphorus. Results further indicated that the BD and the sand content of the soils were significantly greater ($P< 0.01$) in the unprotected site than the protected. The results indicate that proper forest-savanna management strategies in response to human activities are required to protect and enhance soil physicochemical properties and soil microbial communities and their ecological functions necessary for ensuring forest ecosystem long term conservation and productivity in the area and communities' livelihoods sustenance as a result.
Key words: Forest-savanna, soil microbial populations, soil physicochemical properties.

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INTRODUCTION

Microorganisms are key players in important ecological processes such as soil structure formation, decomposition of organic matter and xenobiotics, and recycling of essential elements (e.g., carbon, nitrogen, phosphorous, and sulfur) and nutrients. In addition, some microorganisms are able to have symbiotic relationships with plants helping them e.g. in nutrient uptake [19]. Therefore, the wellbeing of soil microorganisms is no doubt of considerable value as microbes play a critical role in modulating global biogeochemical cycles and influence all lives on Earth [13]. Microorganisms are the smallest organisms (< 0.1 mm in diameter) and are extremely abundant and diverse. They include algae, bacteria, cyanobacteria, fungi, yeasts, myxomycetes and actinomycetes that are able to decompose almost any existing natural material. Micro-organisms transform organic matter into plant nutrients that are assimilated by plants. Two main groups are normally found in agricultural soils: bacteria and mycorrhizal fungi [10]. Bacteria constitute the highest biomass of soil organisms.

They are adjacent and more abundant near roots, one of their food resources. There are many types of bacteria but the focus here is on those that are important for agriculture, e.g. Rhizobium and actinomycetes. Bacteria are important in agricultural soils because they contribute to the carbon cycle by fixation (photosynthesis) and decomposition. Some bacteria are important decomposers and others such as actinomycetes are particularly effective at breaking down tough substances such as cellulose (which makes up the cell walls of plants) and chitin (which makes up the cell walls of fungi). Bacteria produce (exude) a sticky substance in the form of polysaccharides (a type of sugar) that helps bind soil particles into small aggregates, conferring structural stability to soils [10]. Thus, bacteria are important as they help improve soil aggregate stability, water infiltration, and water holding capacity. However, in general their effect is less marked than that originated by large invertebrates such as earthworms [10]. Fungi are responsible for the important process of decomposition in terrestrial ecosystems as they degrade and assimilate cellulose, the component of plant cell walls. Soil fungi can be grouped into three general functional groups based on how they source their energy: Decomposers - saprophytic fungi - convert dead organic material into fungal biomass, CO_2, and small molecules, such as organic acids; mutualists-mycorrhizal fungi-which colonise plant roots through a symbiotic relationship; and Pathogens or parasites which cause reduced production or death when they colonize roots and other organisms [10]. Organic matter decomposition is the main process that recycles nutrients back into the soil. Decomposition of organic matter begins with large soil organisms like earthworms, arthropods (ants, beetles, and termites), and gastropods (slugs and snails). These organisms breakdown the organic matter into smaller pieces which can be decomposed by smaller organisms like fungi and heterotrophic bacteria. The conversion of organic matter (OM) into inorganic compounds through decomposition reactions by microorganisms is termed mineralization [14]. Two major products of the mineralization process are CO_2, which results from microbial respiration [15] and mineral N [9]. Soil organic matter is the main reservoir of major nutrients including N and as such mineralization of C and N is essential for the maintenance of ecosystem functions, particularly agricultural production and its sustainability. The turnover from this process, however, depends on a number of factors such as the quality of OM added to the soil and other environmental factors including land use practices [35, 2, 27]. Many studies have identified land use practices as one of the drivers of microbial community variation between different microhabitats [28]. It is also established that land management has an influence on the structure of bacterial communities as it affects nutrient levels and hence can shift the dominance of decomposers from bacterial to fungal [10]. Hence, microbial soil characteristics may indicate changes in resource availability, soil physicochemical characteristics and represent one important key to understanding impacts of environmental and anthropogenic factors [26, 34]. Several studies have indicated that anthropogenic factors such as large scale land conversion, slash and burn agriculture, grazing, bushfires, and mining have alterable effects on the amount and spatial distribution of soil resources and soil biota, leading to changes in productivity and nutrient cycling [29, 3, 18, 36]. Hence, an assessment of the impacts of human activies on soil microbial community dynamics in relation to ecosystem processes (decomposition, nutrient cycling, and productivity) is indispensable to understand the extent to which anthropogenic activities affect the ability of terrestrial ecosystems to sustain productivity and human needs. It is widely reported that the forest-savanna of Northern Ghana is under tremendous pressure caused by persistent bushfires and grazing on plants coupled with over exploitation of plants by people in the form of fuel wood and charcoal, timber and medicinal products as revenue resources which adversely affect forest resource conservation in the region [12, 11, 24]. Albeit many studies have indicated that this forest ecosystem continues to experience major biophysical environmental degradations as a result of these human pressures, the induced changes of these anthropogenic activities on soil microbial community in relation to nutrient cycling are not well researched on and documented. Hence, the current study seeks to assess the impact of these human activities on soil microbial population changes in relation to soil physicochemical composition alterations.

MATERIALS AND METHODS

Study Area

The study was carried out at Wungu, a community located within the West Mamprusi District of Northern Region (NR) of Ghana. The District lies between latitude 9°55'N and 10°35'N and longitude 0°35'W and 1°45'W (Fig 1). The district is characterised by a single rainy season, which starts in late April with little rainfall, rising to its peak in July-August and declining sharply and coming to a complete halt in October-November [37]. Mean annual rainfall ranges between 950 mm - 1200 mm. Maximum day temperatures are recorded between March-April of about 45^0C while minimum night temperatures of about 12^0C have been recorded in December-January. The humidity level between April and October can be as high as 95% in the night falling to 70% in the day. Night humidity for the rest of the years ranges between 80% and 25% [37].

The natural vegetation of the district is classified as Guinea Savanna Woodland, composed of short trees of varying sizes and densities, growing over a dispersed cover of perennial grasses and shrubs [37]. The climatic conditions, relief features and soil texture which foster water logged conditions in the rainy season and draughty soils in the dry season tend to develop characteristically hardy tree vegetation adapted to long periods of dry spells [37]. Like in the other parts of the country, the pursuit of economic and social exploitation of forest resources in the district has led to decline in forest environmental quality [12].

The District has a generally undulating terrain characterized by gentle slopes from north-east to south-west. There are however a few isolated visible outcrops and uplands of not more than 10% slope. The soils of the study area are classified as Savannah Gleisols [7].

Selection of Study Site

The Wungu Naani sacred grove and the adjacent unprotected forest-savanna were used for the comparative study. The sacred grove is a dense primeval patch of woodlot with a woody vegetation density of 3761 trees/ha [23] kept off from human disturbances while the neigbouring unprotected forest is a woodland savanna which has continuously been subjected to human activities such as bushfires, logging, and grazing. The sacred grove and the adjacent unprotected forest were named as WP (Wungu protected forest) and WU (Wungu unprotected forest) respectively.

Soil sampling

Four 30 m x 30 m random plots were demarcated in each of the two forest types (WP and WU) for soil sampling. From each plot, soil samples were collected from within four 1m x 1m random subplots at a depth of 50 cm using a-5 cm diameter soil core sampler and separated into 10 cm layers (0 - 10, 10 - 20, 20- 30, 30- 40, 40- 50 cm).. The collected soil samples were used to make composite samples for the necessary laboratory analyses.

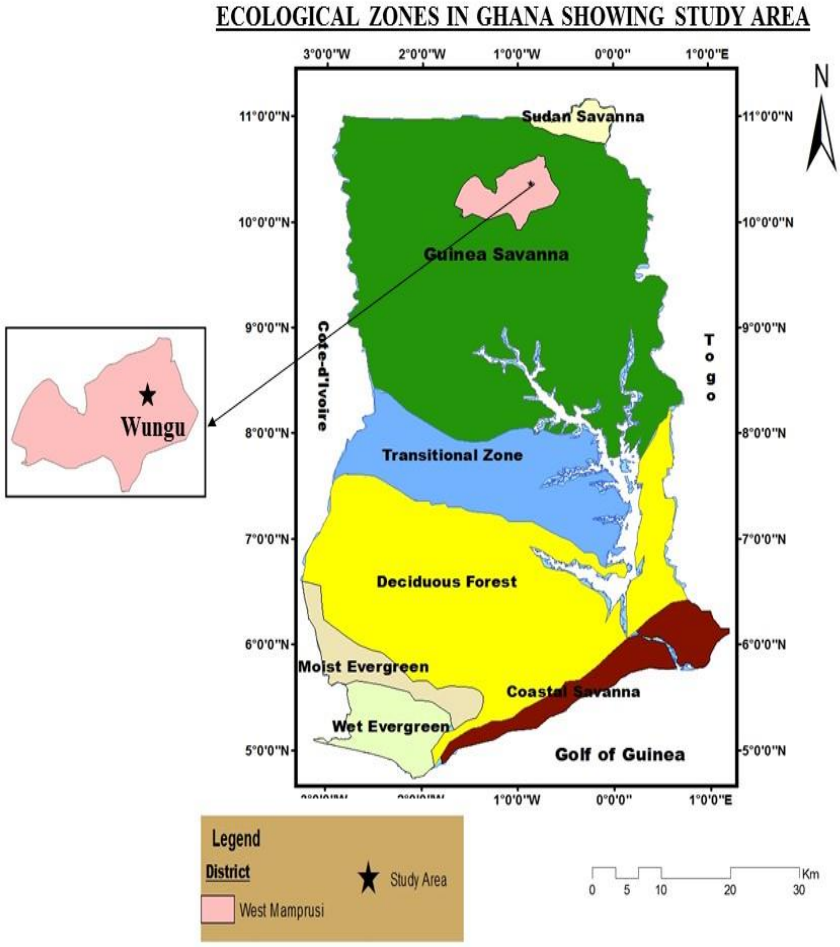

Figure 1: Map of Ghana showing the location of study area.

Soil Samples Preparation and Laboratory Analyses

Soil samples were rid of roots and other debris and air-dried for 3 days and ground with a wooden pestle and mortar to loosen the aggregates. After grinding, the samples were screened through a 2-mm mesh and mixed thoroughly. The prepared composite samples were then stored in labelled bags and taken to the laboratory for the necessary physicochemical and microbial analyses.

Soil Physicochemical Properties Analyses

Soil pH was measured using a glass-electrode pH meter. Particle size distribution of soil samples was determined using the hydrometer method [21]. Organic C contents in soil were estimated by wet digestion method using potassium dichromate $(K_2Cr_2O_7)$ as oxidant [21]. Total nitrogen was determined using the modified Kjeldahl method [33]. Available phosphorus was estimated using the Bray's method No.1 [25]; calcium and magnesium by the Ethylenediamine Tetraacetic Acid (EDTA) titration method [8]. Sodium and potassium were determined using the flame photometer method.

Soil Microbial Community Analyses

Microbial communities (bacteria and fungi) in soils were assessed using the viable plate count method. A suspension was prepared by placing 1g of air-dried soil in 99 ml of sterile distilled water in a conical flask. The suspension was thoroughly shaken for 30 minutes. After settling, the suspension was diluted serially six folds as follows: six test-tubes, each containing 9 ml of sterile water, were set in a test-tube stand. One millilitre of the suspension was taken from the conical flask aseptically and added to the first test-tube containing 9 ml of sterile distilled water. After shaking the test-tube vigorously, 1 ml of the suspension was taken from this test-tube and added to the second test-tube and shaken. This process was repeated serially until the last test-tube. One millilitre aliquot was sequentially taken from the third, fourth, fifth and sixth diluted test-tubes and inoculated into 6 petri plates; 3 petri plates for bacteria and 3 for fungi containing medium of nutrient agar and potato dextrose agar respectively. The petri plates were incubated at 35°C for 2 days and monitored for the appearance of colonies. The colonies were counted and calculation for the number of bacteria and fungi was effected as follows:
Colony forming unit (CFU) per gram of soil = count/plate dilution used [21, 22].

Statistical Analysis

Soil physicochemical and biological data were subjected to statistical analysis of variance using one-way analysis of variance (ANOVA). The least significant difference (LSD) test was employed to compare the means at 0.05 and 0.01significance levels. Correlation coefficient was used to determine the relationships between soil chemical variables and microbial populations.

RESULTS AND DISCUSSION

RESULTS

Soil physicochemical properties

Tables 1 and 2 show the physicochemical properties of soils of the two study sites. Data contained in table 1 show that the textural class of the soils under protected forest is sandy loam while that of the soils under unprotected area varies from sandy loam to loamy sand. The textural analysis indicates that the sand contents were significantly ($P< 0.05$) higher in the soils under unprotected forests than the protected. In contrast, the silt contents were significantly ($P<0.01$) higher in the protected site than the unprotected (Table 4).
The data of soil bulk density (BD) values (Table 2) show significant differences ($P< 0.01$) between the protected and the unprotected forest sites, as the BD value was higher in the latter than the former. Conversely, the total porosity value was significantly higher ($P < 0.01$) in the protected site than the unprotected.

Data on soil chemical properties (Table 2) indicate that the protected site significantly ($P< 0.01$) recorded low acid pH mean value (pH = 6.7) as opposed to the unprotected site (pH = 5.9). The study data also show that soil organic matter (SOM) and total nitrogen contents were significantly ($P < 0\ 0.1$) higher in the protected site than the unprotected. The data on soil chemical properties further show that the concentrations of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, ions and available phosphorus were significantly higher ($P < 0\ 0.1$) in the protected site than the unprotected. The Concentrations of Ca^{2+} and Mg^{2+} ions were three times higher in the protected forest site than the unprotected while that of K^{+} ions was approximately twice greater. The data in Table 2 also show that the available phosphorus value was four times higher in the protected site than the unprotected.

Table 1. Soil locations and textural classes

Study sites	Composite Sample labels	Sand	Silt	Clay	Textural class
Wungu Protected Forest (**WP**)	WP_1	55	40.98	4.02	Sandy loam (SL)
	WP_2	63	34.97	2.03	Sandy loam (SL)
	WP_3	58.78	39.22	2.0	Sandy loam (SL)
	WP_4	57	40.10	3.01	Sandy loam (SL)
Wungu Unprotected Forest (**WU**)	WU_1	63.15	32.8	4.05	Sandy loam (SL)
	WU_2	67.88	30.11	2.01	Sandy loam (SL)
	WU_3	73.66	24.62	2.02	Loamy sand (LS)
	WU_4	80.36	17.60	2.04	Loamy sand (LS)

Table 2. Physicochemical properties of soil under protected and unprotected forest sites

Physicochemical Properties of soil	Protected Forest (WP)					Unprotected Forest (WU)				
	Composite soil sample labels				Mean Values	Composite soil sample labels				Mean Values
	WP_1	WP_2	WP_3	WP_4		WU_1	WU_2	WU_3	WU_4	
pH	5.93	7.07	6.98	6.82	**6.7 ± 0.52**	6.17	5.84	5.96	5.68	**5.9 ± 0.21**
Organic matter (%)	2.55	2.67	2.55	2.63	**2.60 ± 0.07**	1.59	1.4	1.59	1.4	**1.50 ± 0.11**
Organic carbon (%)	1.48	1.55	1.48	1.49	**1.50 ± 0.04**	0.92	0.81	0.92	0.81	**0.87 ± 0.06**
Total nitrogen (%)	0.13	0.13	0.13	0.14	**0.13 ± 0.00**	0.09	0.08	0.09	0.08	**0.09 ± 0.01**
Bulk density (gcm^{-3})	1.38	1.37	1.38	1.39	**1.38 ± 0.00**	1.44	1.47	1.48	1.43	**1.46 ± 0.02**
Total porosity (%)	47.9	48.3	47.9	48.02	**48.03 ± 0.19**	45.7	44.6	46	44.2	**45.13 ± 0.86**
Calcium (cmol(+) Kg^{-1})	1.1	1.9	1.5	1.5	**1.5 ± 0.4**	0.6	0.4	0.35	0.4	**0.5 ± 0.11**
Magnesium (cmol(+) Kg^{-1})	2.94	5.07	4.01	3.58	**3.9 ± 1.04**	1.6	1.07	0.94	1.07	**1.2 ± 0.29**
Potassium (cmol(+) Kg^{-1})	0.13	0.34	0.24	0.25	**0.24 ± 0.11**	0.17	0.15	0.15	0.16	**0.16 ± 0.01**
Sodium (cmol(+) Kg^{-1})	0.17	0.16	0.14	0.13	**0.15 ± 0.02**	0.12	0.12	0.1	0.11	**0.13 ± 0.01**
Available P ($mgkg^{-1}$)	5.63	10.22	12.87	9.56	**9.57 ± 4**	3.06	1.61	3.14	2.09	**2.48 ± 1**

Soil microbial populations

Table 3 shows estimates of bacterial and fungal populations of the soils under protected and unprotected forest sites in the study area. The counts of bacteria and fungi are expressed as log of colony forming unit CFU per 1 g dry soil. Data contained in Table 3 show that the bacterial populations were significantly higher ($P < 0\ 0.1$) in the protected site than the unprotected. Bacterial populations ranged from 4.14 to 4.30 log of CFU per 1 g dry soil in the protected site while the unprotected site recorded values ranging from 3.61 to 3.95 log of CFU per 1 g dry soil. Table 3 further shows a significant difference ($P < 0\ 0.1$) in the population of fungi between the protected and the unprotected forest sites. The populations of fungi ranged from 5.27 to 5.45 log of CFU per 1 g dry soil and from 4.98 to 5.23 log of CFU per 1 g dry soil in the protected and unprotected site respectively.

Table 3. Average counts of microorganisms of soil under protected and unprotected forest sites

Type of microorganisms	**Microorganisms counts** (Log CFU of microorganisms/g of soil)									
Bacteria	**Protected Forest (WP)** Log CFU of bacteria/g of soil					**Unprotected Forest (WU)** Log CFU of bacteria/g of soil				
	WP_1	WP_2	WP_3	WP_4	**Mean Values**	WU_1	WU_2	WU_3	WU_4	**Mean Values**
	4.14	4.30	4.19	4.23	**4.21 ± 0.07**	3.61	3.95	3.67	3.69	**3.73 ± 0.15**
Fungi	Log CFU of fungi/g of soil					Log CFU of fungi/g of soil				
	WP_1	WP_2	WP_3	WP_4	**Mean Values**	WP_1	WP_2	WP_3	WP_4	**Mean Values**
	5.45	5.37	5.27	5.40	**5.37 ± 0.076**	5.23	5.20	4.98	5.10	**5.12 ± 0.11**

Table 4. Summary of the analysis of variance (ANOVA) outputs of soil between protected and unprotected sites.

Ecosystem component	**F– Value**	**P – Value**	**Outcome**	**Level of variance**
Soil physicochemical properties				
Sand	11.11	0.015	P< 0.05	Significant
Silt	22.63	0.003	P< 0.01	Significant
Clay	3.15	0.12	P > 0.05	Not significant
Bulk density	42.67	0.00	P< 0.01	Significant
Porosity	61.41	0.00	P< 0.01	Significant
pH	35.905	0.000	P< 0.01	Significant
Soil OM	207.22	0.000	P < 0.01	Significant
Soil OC	208.76	0.000	P< 0.01	Significant
Total N	157.43	0.000	P< 0.01	Significant
Available P	32.22	0.001	P < 0.01	Significant
Exchangeable Ca	58.73	0.000	P< 0.01	Significant
Exchangeable Mg	59.24	0.000	P< 0.01	Significant
Exchangeable K	27.29	0.001	P< 0.01	Significant
Exchangeable Na	27.96	0.001	P< 0.01	Significant
Soil microbial populations				
Bacteria	29.38	0.002	P< 0.01	Significant
Fungi	23.15	0.003	P< 0.01	Significant

DISCUSSION

The dominant organisms which are responsible for the decomposition of organic matter and associated mineralisation of C and N and other soil nutrients are soil microorganisms, such as bacteria, fungi, and protozoa [5]. According to Zack et al. [38] bacteria and fungi are the major types of microorganisms found in soil and play an essential role in nutrient transformations and litter decomposition rates. It is also established that factors affecting the mineralisation of organic matter depend on the interaction between physical, chemical, and biological processes which are influenced by local environmental conditions [1]. This case study, which was conducted in the natural forest-savanna of northern Ghana, demonstrated that anthropogenic factors such as bush burning, overgrazing and logging, have alterable effects on the amount and spatial distribution of soil resources and soil biota, leading to changes in nutrient cycling. The study data of the textural analysis of soils indicate that the sand contents were significantly (P< 0.05) higher in the soil under unprotected forests than the protected. This finding could be due to the adverse effect of human activities mainly in the form continued removal of the vegetation cover in the under unprotected forest site which in turn would have exposed the soil under this forest to severe erosion and leaching. This situation could be used to further explain the differences in the physicochemical parameters and bacterial and fungal populations observed between the soil under protected and unprotected forest sites.

For it is established that soil texture as abiotic factor is an important factor that influences the distribution of minerals, organic matter retention, microbial biomass and other soil properties [31, 13]. Bulk density values were higher in the unprotected site than the protected. In contrast, the porosity percentage values were lower in the unprotected site than the protected. This could be attributed to the negative effects of human activities, as it is established that anthropogenic activities such as deforestation leaves the land more susceptible to soil degradation including higher soil bulk density, lower hydraulic conductivity, and higher soil erosion [32, 6]. Besides it is indicated that soils in the savanna ecological zone of northern Ghana are very susceptible to erosion as well as compaction [4]. The difference in bulk density and porosity values between the protected and unprotected sites could explain the observed variation in soil bacterial and fungal populations between these two sites as it is established that pore space distribution and the small soil pore space has a major impact on the abundance of bacteria and fungi [17]. The organic matter and total nitrogen contents and the concentrations of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, ions and available phosphorus were found to be higher in the protected sites than the unprotected. This could be associated with the continued removal of organic matter from the unprotected sites mainly in the form of grazing, logging and burning, which subsequently resulted in low nutrients inputs in the soils under these forests. Indeed, positive correlations were observed between soil bacterial and fungal populations and soil organic matter ($r = 0.937$, $r = 0.139$) and total nitrogen ($r = 0.936$, $r = 0.054$) in the protected site, suggesting that soil microbial abundance and activity are limited by the availability of soil organic matter. This inference was further substantiated by the variation in the contents of soil organic matter, total nitrogen, and soil microbial populations between the two forest sites. These findings are in line with results reported by Jalal et al. [16] who indicated that soil microbial biomass is a sensitive indicator of changes in total SOM given that it more readily responds to alterations in plant vegetation or land use**.** Hence, this study indicates that soil microbial community represents one important key to understanding the impacts of environmental and anthropogenic factors on changes in resource availability and soil physicochemical characteristics [26, 34]. It further emphasises the extent to which soil microbes are of high interest in driving forest ecosystem ecological processes and dynamics, since they are responsible for most biological transformations and drive the development of stable and labile pools of carbon (C), nitrogen (N) and other nutrients, which facilitate the subsequent establishment of plant communities [30]. Vice versa, the soil matrix as well as chemical and physical properties of soils, like quality and amount of soil organic matter, pH, and redox conditions, have a pronounced influence on the dynamics of the microbial community structure and function in soils [20]. Hence this study indicates the need for proper monitoring and regulation of anthropogenic activities across the forest-savanna of northern Ghana. Such a move would help maintain and protect the close interplay between soil abiotic conditions and soil microbial populations necessary to sustain the productivity of this forest ecosystem and communities' livelihoods in the region as a result. Besides, such measures would go a long way in enhancing the carbon sequestration potential of this forest ecosystem in the face of the fight against the global climate change.

CONCLUSION

This study shows that anthropogenic activities have significant alterable effects on soil microbial community populations and nutrient cycling in the forest-savanna of northern Ghana. In view of the important role played by soil biological and chemical components in forest ecological processes and productivity there is the need to evolve and implement management strategies in response to these human-driven forest-savanna ecosystem biogeochemical degradations. Such measures would help restore and maintain the complex soil-plant-microorganisms system and thereby ensure forest ecosystem long term conservation and productivity and communities' livelihoods sustenance. For forest resource makes an important tangible contribution to the quality of community and individual life in Ghana [12].

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