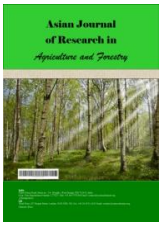

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Evaluation of Physicochemical Properties and Microbial Populations of Soil of Bagale Forest Reserve, Girei Local Government Area, Adamawa State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author GOA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MGS and EED managed the analyses of the study. Author BBM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study evaluated the relationship between selected physicochemical properties and microbial populations of the soil of Bagale Forest Reserve, Girei Local Government Area of Adamawa State, Nigeria. Five plots of 20 x 20 m were laid. Soil samples were collected from five different positions at two soil depths of 0-15 cm and 15-30 cm. The soil samples were isolated in the laboratory for microbial populations and determination of physical and chemical properties. The results obtained revealed that fungal population (7.65 x 105 cfu/ml) was the highest at the soil depth of 0-15 cm, representing 39% of the total microbial populations in the sampled soil of the study area. The results further revealed that the population (6.84 x 105 cfu/ml) of the bacteria had a positive effect on soils of the study area in terms of nitrogen fixation by Rhizobacterial spp. Chemical properties of the soil samples revealed that the available phosphorus exhibited the highest percentage (61.7%)

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at 0-15 cm soil depth. Analyses of soil physical properties recorded the highest percentage (49.0%) of sand at 0-15 cm soil depth. A similar percentage (50.0%) of sand was exhibited at the depth of 15-30 cm. These percentages accounted for the high porosity (29.0%) of the soil observed at the two soil levels in the study area and could be improved through the application of lime fertilizers. Application of appropriate fertilizers like NPK to improve the soil condition of the study area is highly recommended.

Keywords: Microbes; populations; soil properties; forest reserve.

1. INTRODUCTION

The physical properties of forest soils develop under natural conditions by the influence of permanent vegetation over a long period. They may be almost permanent properties unless modified by harvesting operations, shifting cultivation, and forest fires. Important physical properties of forest soils include texture, structure, porosity, density, aeration, temperature, water retention and movement. The physical properties of forest soils affect every aspect of soil fertility and productivity. They determine the ease of root penetration, the availability of water and the ease of water absorption by plants, the amount of oxygen and other gases in the soil and the degree to which water moves both laterally and vertically through the soil. Soil physical properties also influence the natural distribution of forest tree species, growth, and forest biomass production. Physical properties of forest soils affect every aspect of soil fertility and productivity. However, soil physical properties are largely controlled by the size, distribution and arrangement of soil particles [1].

Some plant nutrients and metals exist as positively charged ions, or “cations”, in the soil environment. Some of the most important plant nutrients that affect the growth and development of forest plant species include nitrogen, phosphorus, and potassium. Among the more common cations found in soils are hydrogen (H^+), aluminium (Al^{+3}), calcium (Ca^{+2}), magnesium (Mg^{+2}), and potassium (K^+). Soil pH, which is a measure of the active hydrogen ion (H^+) concentration, is an indication of the acidity or alkalinity of forest soils, and also known as “soil reaction”. The most important effect of pH in the soil is on ion solubility, which in turn affects microbial and plant growth [1].

Forest soil microorganisms exist in large numbers in the soil as long as there is a carbon source for energy. There are more microbes in a teaspoon of soil than there are people on the earth. Forest soils contain about 8 to 15 tons of bacteria, fungi, protozoa, nematodes, earthworms, and arthropods. The population of microbes in forest soils is determined by various factors such as soil depth, organic matter content of the soil, soil porosity, soil pH, soil moisture content and others [2].

There is a significant change in the soil colour and depletion of soil nutrients in the study site as a result of high exploitation of the resources. The microbial populations in the soil of the study area have also been affected negatively due to the high exploitation of the tree species.

The main objective of this study is to investigate the relationship between physicochemical properties and microbial populations of the soil of Bagale Forest Reserve in Girei Local Government Area of Adamawa State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

This research was carried out at Bagale Forest Reserve in Girei Local Government Area of Adamawa State. The area lies between latitudes $9^o.09$ and $9^o.33$ N and longitudes $12^o.21$ and $12^o.54$ E of the state and has an elevation of 339 meters above the sea level (Fig. 1). The study area is located within the North-Central part of Adamawa State. Bagale Forest Reserve covers a total land area of 179.746 km^2, which is equivalent to about 18 ha [3]. The major vegetation formations in Adamawa State are Southern Guinea Savannah, Northern Guinea Savannah, and Sudan Savannah. In Bagale Forest Reserve, in particular, the common tree species are eucalyptus, cassia, neem and mango [3].

2.2 Data Collection and Analysis

Thirty per cent (30%) of the total forest land area was randomly sampled. Five (5) plots of

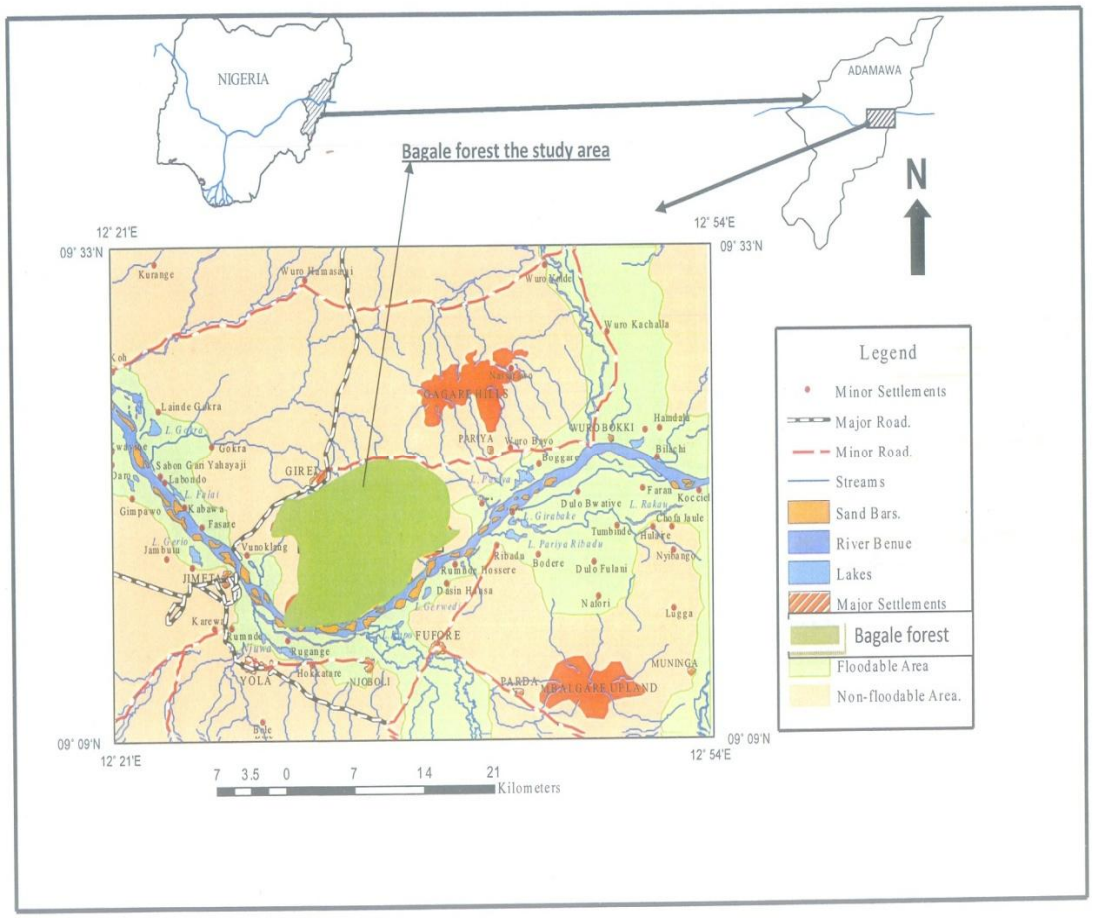

Fig. 1. Map of Girei LGA of Adamawa State showing the Study Area
Source: [13]

20×20 m were established with the aid of a measuring tape, using the field sampling method adopted by [4,5] for artificial forests. Soil samples were collected from five different positions, transferred into the soil-sampling plates and marked as A_1, A_2, A_3, A_4, A_5…E_5 in each of the plots with the aid of soil auger and sterile trowel. Soil samples from two (2) depths (0-15 cm top-soil and 15-30 cm sub-soil) were collected with the hand trowel and soil auger. A total of 50 soil samples (25 top-soil and 25 sub-soil samples) were collected, transferred into soil-sampling plates and labelled accordingly. They were transferred to the laboratory within 24 hours for analyses for the determination of physicochemical properties and microbial populations of the study area based on the method of [4,5]. The soil samples were air-dried and crushed, using a mortar and pestle and later sieved with a 2 mm-sieve. The samples that did not pass through the sieve were discarded to give fine soil aggregates. Particle size analysis (PSA), was done using the hydrometer method as described by Zhou and Chen [6].

Bulk density was determined using the core method [6] with a given formula:

$$\text{Bulk density} = \frac{\text{Mass of Oven-dried soil}}{\text{Volume of core sampler}} \times 100$$

Total porosity was calculated from the bulk density value, using the formula:

$$F = 1 - \frac{Db}{Dp} \times 100$$

where:

F = total porosity
Db = Bulk density

Soil pH was determined, using the 1:2.5 soil-water ratio with a pH electrode and the values were read out from the pH meter [7]. Electrical Conductivity (EC) was determined by the summation method of [8]. Organic Carbon (OC) was determined by the dichromate wet oxidation method of Walkey and Black [9]. Total Nitrogen (TN) was determined by the Macro Kjeldahl procedure as described by Jaiswal [10]. Available Phosphorus (Av-P) was determined by the [1] method while Potassium (K) in the extract was determined using flame photometer [11]. Soil microbial populations were estimated by standard spread plate dilution method described by Seeley and Van Demark [12].

3. RESULTS

3.1 Microbial Population Analysis of Soil in the Study Area

The result of the analysis of microbial populations in the study site is presented in Table 1. The result revealed that the fungal population of 7.65 x 10^5cfu/ml was the highest at the soil depth of 0-15 cm, representing 39.0% of the total microbial populations in the soils of the study site. This was followed by bacteria with an average population of 6.84 x 10^5cfm/ml, which was represented by the mean percentage of 35.0% at 0-15 cm soil depth. Coliform population was recorded at 5.21 x 10^5cfu/ml with the mean percentage of 26.0% at 0-15 cm soil depth. The results further revealed that fungi still constituted the highest population 4.49 x 10^5cfu/ml with 41.0% of the total microbial populations in the soil of the study area at 15-30 cm soil depth. This was followed by bacteria with the average number of 3.43 x 10^5cfu/ml and the mean percentage of 32.0%, while the coliform population of 2.92 x 10^5cfu/ml was found to be lowest with the mean percentage of 27.0% at 15-30 cm soil depth.

3.2 Selected Physical Properties of Soil in the Study Area

The result of the physical properties of soil in the study area is shown in Table 2. The result revealed that sand dominated the study site with a mean percentage of 49.0%. Porosity was high with a mean percentage of 29.0%, while the percentage of silt was recorded at 10.0%. Also, the percentage of clay was 10.0% compared to the percentages of texture and bulk density shown by the values of 1.0% and 1.0% respectively at 0-15 cm soil depth. The result further showed that sand constituted the highest percentage at the depth of 15-30 cm represented by the value of 50.0%. This was followed by porosity with a mean percentage of 29.0%. The result further revealed that clay had a mean percentage of 10.0%, which was greater than the percentage of silt represented by 9.0%. The texture was found to have a mean percentage of 1.0% equal to the percentage of bulk density of 1.0% at 15-30 cm soil depth.

3.3 Selected Chemical Properties of Soil in the Study Area

The result in Table 3 showed some selected chemical properties of soil in the study area. The result revealed the highest percentage of available phosphorus (AV-P) with the mean value of 61.7% at 0-15 cm soil depth. This was followed by the soil pH which was found to have the mean percentage value of 31.8%. The percentage of organic carbon (OC) was 2.9%, which was slightly higher than the mean percentage value (2.7%) of potassium (K). Furthermore, the electrical conductivity (EC) was found to have an average percentage of 0.5%, while the total nitrogen (NT) had the lowest mean percentage of 0.2% at 0-15 cm soil depth. The result further revealed that available phosphorus (AV-P) was found to have the highest mean percentage of 57.8% at a soil depth of 15-30 cm. Also, the pH (soil reaction) value of soil samples at 15-30 cm was 35.4%, which was followed by potassium (K) with a mean percentage of 4.9%. Further analysis revealed that organic carbon (OC) had a mean percentage of 1.5%, which was higher than the electrical conductivity (EC) with a mean percentage of 0.3%. The least mean percentage was recorded in the total nitrogen (TN) indicated by the value of 0.1% at the soil depth of 15-30 cm (Table 3).

3.4 Pearson's Correlation of Microbial Populations with Selected Physical

3.4.1 Properties of soil in the study area

Table 4 revealed the result of the relationship between microbial populations and the selected soil physical properties in the study area. The result indicated that all the isolated microbes (Bacteria, coliforms and fungi) had no significant relationship with soil physical properties at 0-15 cm soil depth. Although the bacteria population had a very low positive correlation with sand, silt,

and bulk density with their respective correlation coefficients ranging from 0.017, 0.081 to 0.088, a low negative correlation was exhibited on clay, textural class, and porosity ranging from -0.081, -0.116 to -0.132. Similarly, the coliform population had a positive correlation with silt, clay, textural class, and porosity; however, it had a low negative correlation with sand and bulk density. A low positive relationship was observed between the fungal colony, sand and bulk density, ranging from 0.189 to 0.235, while a negative correlation occurred with silt, clay, textural class and porosity, ranging from -0.182, -0.191, -0.249 to -0.256.

Table 1. Microbial populations of soil in the study area

Soil depth	Minimum statistics	Maximum statistics	Mean (cfu/ml)	(%)	Std error
(0-15 cm)					
TBC	$4.66x10^5$	$8.69x10^5$	$6.84x10^5$	35.0	23864.12
TCC	$3.22x10^5$	$9.66x10^5$	$5.21x10^5$	26.0	32920.81
TFC	$1.04x10^5$	$9.69x10^5$	$7.65x10^5$	39.0	33126.87
(15-30 cm)					
TBC	$1.99x10^5$	$5.1x10^5$	$3.43x10^5$	32.0	81151.60
TCC	$1.06x10^5$	$4.72x10^5$	$2.92x10^5$	27.0	20915.35
TFC	$2.56x10^5$	$6.11x10^5$	$4.49x10^5$	41.0	14101.80

TBC = Total bacteria count; TCC = Total coliform count; TFC = Total fungi count

Table 2. Descriptive statistics of selected physical properties of soil in the study area

Soil depth (cm)	Minimum statistics	Maximum statistics	Mean	(%)	Std error
0-15					
Sand	50.00	94.00	70.4400	49.0	3.46751
Silt	2.00	29.00	15.0000	10.0	1.89824
Clay	4.00	28.00	14.5600	10.0	1.72345
Texture	1.00	3.00	1.9200	1.0	0.17243
B. Density	1.39	1.75	1.5460	1.0	0.02845
Porosity	34.00	48.00	41.7200	29.0	1.06383
15-30					
Sand	50.00	94.00	72.4400	50.0	3.53651
Silt	2.00	26.00	13.2000	9.0	1.75689
Clay	4.00	28.00	14.3600	10.0	1.90865
Texture	1.00	3.00	1.9200	1.0	0.19079
B. Density	1.39	1.75	1.5588	1.0	0.02995
Porosity	34.00	48.00	41.3200	29.0	1.11612

Table 3. Descriptive statistics of selected chemical properties of soil in the study area

Chemical properties	Minimum statistics	Maximum statistics	Mean	(%)	Std error
(0-15 cm)					
pH	6.12	7.10	6.4868	31.8	0.05495
EC	0.06	0.16	0.1008	0.5	0.00571
OC	0.42	0.74	0.5980	2.9	0.1635
TN	0.04	0.07	0.0600	0.2	0.00163
AV-P	10.65	14.96	12.5840	61.7	0.24072
K	0.30	1.10	0.5584	2.7	0.04779
(15-30 cm)					
pH	5.55	6.94	6.1456	35.4	0.07802
EC	0.03	0.10	0.0500	0.3	0.00408
OC	0.15	0.61	0.2600	1.5	0.02842
TN	0.00	0.06	0.0124	0.1	0.00428
AV-P	7.75	14.48	10.0476	57.8	0.37791
K	0.20	1.90	0.8480	4.9	0.10364

Table 4. Correlation analysis of microbial populations with selected physical properties of soil in the study area

Soil depth	Isolated organism	Statistics	Sand	Silt	Clay	Texture	Bulk density	Porosity
(0 -15 cm)	TBC	Pearson Correlation	0.017	0.088	-0.132	-0.116	0.081	-0.081
		Sig. (2-tailed)	0.934	0.677	0.531	0.582	0.701	0.702
	TCC	Pearson Correlation	-0.291	0.248	0.312	0.232	-0.303	0.295
		Sig. (2-tailed)	0.158	0.232	0.129	0.265	0.141	0.153
	TFC	Pearson Correlation	0.235	-0.256	-0.191	-0.249	0.189	-0.182
		Sig. (2-tailed)	0.259	0.218	0.361	0.230	0.364	0.384
(15 -30 cm)	TBC	Pearson Correlation	0.433*	-0.504*	-0.339	-0.394	0.394	-0.394
		Sig. (2-tailed)	0.030	0.010	0.098	0.051	0.051	0.051
	TCC	Pearson Correlation	-0.238	0.194	0.263	0.220	-0.261	0.240
		Sig. (2-tailed)	0.251	0.352	0.205	0.290	0.208	0.248
	TFC	Pearson Correlation	0.035	-0.068	-0.001	-0.046	0.012	-0.015
		Sig. (2-tailed)	0.870	0.747	0.994	0.827	0.955	0.943

**Correlation is significant at the 0.05 level (2-tailed). TBC = Total bacterial count; TCC = Total coliform count; TFC = Total fungal count*

Table 5. Correlation analysis of microbial populations with selected chemical properties of soil in the study area

Soil Depth	Isolated organisms	Statistics	pH	EC	OC	TN	AV-P	K
0– 15 cm	TBC	Pearson Correlation	0.455*	0.041	-0.179	-0.183	0.184	0.328
		Sig.(2-tailed)	0.022	0.844	0.391	0.381	0.379	0.110
	TCC	Pearson Correlation	0.403*	0.091	0.149	0.094	-0.199	-0.078
		Sig.(2-tailed)	0.046	0.664	0.476	0.655	0.341	0.711
	TFC	Pearson Correlation	0.309	-0.238	0.112	0.213	0.312	0.185
		Sig.(2-tailed)	0.133	0.252	0.595	0.307	0.129	0.376
15-30 cm	TBC	Pearson Correlation	-0.057	-0.019	-0.077	-0.088	-0.012	-0.050
		Sig. (2-tailed)	0.785	0.927	0.713	0.675	0.954	0.813
	TCC	Pearson Correlation	-0.261	-0.300	-0.233	-0.237	-0.053	-0.081
		Sig. (2-tailed)	0.208	0.145	0.263	0.255	0.801	0.699
	TFC	Pearson Correlation	-0.379	0.118	-0.006	-0.040	0.214	-0.005
		Sig. (2-tailed)	0.062	0.573	0.976	0.850	0.305	0.979

**Correlation is significant at the 0.05 level (2-tailed)*

TBC = Total bacterial count; TCC = Total coliform count; TFC = Total fungal count

3.5 Pearson's Correlation of Microbial Populations with Selected Chemical

3.5.1 Properties of soil in the study area

Table 5 shows the result of the correlation of microbial populations with selected soil chemical properties in the study area. The result revealed a significant relationship ($p < 0.05$) among the bacterial population, coliform population, and the soil chemical properties at 0-15 cm soil depth, but fungal population showed no significant difference among the soil chemical properties. The result further revealed that at 15-30 cm soil depth, none of the isolated microbes had a significant effect on the soil chemical properties in Bagale Forest Reserve. This indicated that the sub-soil horizon was dominated by inactive microbes, unlike the fungal group.

4. DISCUSSION

4.1 Relationship between Microbial Populations and Selected Soil Properties

Soil microbes play vital roles such as decomposition of organic matter, nitrogen fixation, and nutrient cycling. The effects of soil microbes are influenced by their populations [14]. Microbial populations in forest soils are determined by both physical and chemical properties of soils [2].

4.2 Microbial Populations and Soil Physical Properties

All the isolated microbes had a relationship with the soil physical properties both at the top-soil and sub-soil levels. The dominant and structural organisation of sand textural class in the study provided a spatially heterogeneous habitat for the fungal community because of smaller size fractions (silt and clay) host higher bacterial community than larger size particles (sand). This agreed with the findings by [6,15], that the nature of physical properties of forest soils determined the population and type of microbes in the soils. Although the bacterial populations had a low positive correlation with sand, silt, and bulk density, a low negative correlation was exhibited with clay textural class and soil porosity. Similarly, the coliforms population had a positive correlation with silt, clay textural class, and soil porosity, whereas coliforms had a low negative correlation with sand and bulk density. Also, a low positive relationship was obtained between the fungal colony, sand, and bulk density indicated by the figures 0.235 and 0.189 respectively; whereas a negative correlation occurred with silt, clay textural classes and porosity. The insignificant relationship of most microbes with some soil physical properties at 0-15cm soil depth implies that the microbes were inactive at this soil level, this could be due to the low population of bacterial and coliforms. This conforms with [1] report who highlighted that the physical properties of forest soils are influenced by the microbial populations within the soils. Similarly, at 15-30cm soil depth, the bacterial population had a significant relationship ($p < 0.05$) with the soil physical properties, moderate positive correlation with sand and moderate negative correlation with the silt particles of the soils. Coliforms showed no significant relationship ($p > 0.05$) with the soil physical properties in the study. The study is comparable with [15-22], they observed higher levels of the microbial population in the finer (silt and clay) fractions of soils, with lower values in the sand fraction.

4.3 Microbial Populations and Selected Soil Chemical Properties

The soil pH of the study area contained a considerable amount of alkaline at 0-15cm soil depth, this could be as a result of the depletion in soil nutrients of the study site. Furthermore, as the depth of forest soils increases, the availability of organic carbon decreases, increasing the mineral layer. However, Comerford [23] observed that the thickness of each forest soil layer varies depending on topography, vegetation, parent materials in which the forest has been established. The mean percentage (2.7%) of Potassium (K) observed in the study can be used to promote the growth and development of young plants, and it is essential for neutralization of organic acid in plants [1]. The electrical conductivity (EC) was found to have a mean percentage of 0.5%, while the total nitrogen (TN) had the lowest percentage of 0.2% at 0-15 cm soil depth. Nitrogen is important in plants for growth and development or reproduction, it promotes the uptake of potassium and phosphorus from the soil, and it also promotes chlorophyll formation in plants leaves. The above importances are in line with the discovery of Brady and Weil [1].

The correlation between microbial populations and selected soil chemical properties at 0-15 cm

and 15-30cm soil depths revealed a significant effect ($p < 0.05$) on bacteria and coliform at 0-15 cm soil depth, except fungal population which showed no significant difference ($p > 0.05$) among the soil chemical properties. The results further revealed that at 15-30 cm soil depth, none of the isolated microbes had a significant effect on the soil chemical properties at the depth of 15-30 cm. This indicates that the sub-soil horizon of the study site is dominated by inactive microbes. This study is similar to Kennedy et al. [2] findings, they pointed out that the populations of microbes and their effects on forest soils are determined by various factors such as soil depth, organic matter content of the soil, soil pH, soil porosity and others.

5. CONCLUSION

The high population of fungi in the soil of Bagale Forest Reserve has a significant effect in terms of organic matter decomposition. Similarly, the population of bacteria has a positive effect on the soil of the study area in terms of nitrogen fixation by *Rhizobacterial spp.* The highest mean percentage values of sand in the soil samples and the porosity at the two levels of soil depths have shown that the study area is characterized by sandy soil. The analysis of selected chemical properties of soil samples revealed the highest percentage of the available phosphorus, which is good enough for the effective performance of the tree species in the study site. However, the high percentage of the soil pH (soil reaction) indicated a considerable amount of alkaline in the soil depth of 0-15 cm. The significant relationship between the soil microbes and soil physical properties indicated that most of the microbes were inactive at the soil depth of 0-15 cm. However, since bacteria population had a significant relationship ($p < 0.05$) with soil physical properties but fungi and coliform showed no relationship ($p > 0.05$) with soil physical properties, this indicates that forest soil microbes play a vital role in the decomposition of organic matter and nutrients cycling. Since none of the isolated soil microbes had a significant effect on the selected soil chemical properties of the study site at 15-30 cm soil depth, it indicates that the sub-soil horizon is dominated by inactive microbes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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