~~z~~Original Research Article

Impact of land use types and seasonal variations on soil physico-chemical properties and microbial biomass dynamics in a tropical climate, Ghana

Running Title: Microbial biomass under different land uses

ABSTRACT

Land use conversion significantly impact on sensitive soil quality parameters such as microbial biomass and soil microbial quotient. Therefore, soil microbial biomass and physicochemical properties were compared under three different land use systems namely agricultural land, degraded mine land, and an adjacent natural forest in the Newmont Gold Ghana Limited concessional areas, Kenyasi, Ghana. An area of 300 m^2 was demarcated in each land use type for soil sampling. In each of the land use type, 5 samples were collected at a depth of 0-15 cm in the dry and wet seasons respectively. Parameters measured included soil bulk density, pH, particle size distribution, organic carbon, total nitrogen, available phosphorus, microbial biomass carbon and nitrogen, and moisture content. The results revealed that land use type significantly impacted on soil microbial biomass and physicochemical properties. Microbial biomass carbon and nitrogen was higher in the forested land compared to the agricultural land and degraded mine land, which was due to relatively higher amounts of litter inputs. Microbial biomass carbon decreased between 20.23 - 88.36 % when land use changed from forested land to other land uses. Significant positive correlation was observed between soil microbial biomass and water content, soil organic carbon, phosphorus, clay, nitrogen. Generally, seasonal variation did not influence soil physical and chemical properties, however, significantly affected microbial biomass indices. Findings of this study further revealed the importance of forested area in the maintenance of soil quality parameters.

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Keywords: Land use conversion, Microbial biomass, Microbial quotient, Litter inputs, Soil quality

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1. INTRODUCTION

The increase in global population especially sub-Saharan Africa has resulted in the increase of land utilization for mankind. This has led the destruction of forest cover especially in the forest fringe communities for agricultural and other land uses [1]. Subsequently, land use change/conversion has been widely advocated to significantly impact on soil quality and characteristics [2 - 3]. Land use change impacts on many soil processes including immobilization and mineralisation processes, reduction-oxidation processes, water holding capacity. The conversion of certain land use systems has been reported to significantly influence soil properties [4]. The conversion of forest lands to agriculture or pasture lands impacts negatively on the amount of litter added to the soil, thus affecting nutrient pools and cycling, reduction in microbial activities, and loss of soil organic matter [5].

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Soil, an important aspect of the lithosphere is considered as a key component for sustaining terrestrial ecosystem through nutrient cycling, filtration and transforming of hazardous materials, conserving plant nutrients, and minerals for man's use [4, 6]. Thus, it is a natural resource that supports the maintenance of forestry, agricultural and the mining sectors around the globe. It is therefore imperative to preserve the quality of the soil to enable its continuous functioning [7]. [8] define soil quality as the capacity of a specific soil to function within managed or natural ecosystems to support plant and animal production, protect environmental quality, and promote human health. Therefore, soil quality is a direct reflection of the soil physical, chemical and biological properties.

Soil physical and chemical properties directly impact on soil quality, however, soil microbes (e.g. bacteria, fungi) and microbiological indices (e.g. microbial biomass) significantly influence litter decomposition, nutrient pools and fluxes, and organic carbon dynamics [9]. Soil microbial biomass, a key component of labile pools of soil available nutrients, consists of about 1 - 5 % of organic matter (OM) [10] and are highly sensitive to environmental changes. Soil microbial biomass is rapidly influenced by soil nutrients, types and concentrations of OM, management practices, temperature, water regimes [4]. Hence, they are widely used as sensitive indicators to soil productivity in many environmental studies and management [11, 5]. Land use conversion negatively impacts on microbial biomass and OC in the soil ecosystem, which is essential for the maintenance of soil and plant productivity [2]. Thus, vegetation cover is a critical component of our ecosystem leading to the general increase in soil fertility and enhanced microbial community. Soil microbial biomass play a catalytic role in the decomposition, transformation and cycling of soil carbon, nitrogen and phosphorus. [7] and [11] studied the distribution of microbial biomass under forest, agriculture and grassland systems. ~~They~~ The findings revealed ~~observed~~ an increase of soil microbial biomass in the forested area relative to the agricultural land or grassland.

There is limited data and low understanding on soil microbial biomass and physicochemical properties under different land uses especially in tropical regions such as Ghana. This study was therefore conducted to evaluate the impact of different land use types (i.e. degraded mine land, arable land and forest land) and seasonality on soil microbial biomass dynamics and physico-chemical properties in the concessional areas of Newmont Ghana Gold Limited (NGGL), Kenyase. Based on the goals of ~~our~~ the study, we hypothesized that: (1) different land use types and seasonal variations in rainfall affect soil physical, chemical, and soil microbial indices both in the dry and wet season; 2) soil microbial biomass indices are greater in the forest land than in the agricultural land and degraded mine land due to variations in land cover, and 3) positive relationship exist between soil microbial biomass indices and physico-chemical properties. Data on the microbial biomass and soil physicochemical properties in the study area will provide necessary information on present discussions among miners, foresters, agriculturist, and other government agencies on the best management practices with current land uses and future projections.

2. MATERIALS AND METHODS

2.1 Study Location and Sampling Site

The study was undertaken in the concession areas of Newmont Ghana Gold Limited (NGGL), located in Kenyase within the Bono Region of Ghana. NGGL concession areas lies within latitude 6°40' and 7°15' North and longitude 2°15' and 2°45' West, and 50 km away from the regional capital, Sunyani []. Kenyase is in the semi-deciduous agro-ecological zone of Ghana which experiences a bimodal rainfall pattern with annual precipitation of 1450 mm. The study area experiences a mean monthly temperature that ranges from 23.5 to 28.5 ^{0}C.

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The ~~field~~ experimental field consisted of three (3) selected land use type namely; Degraded mine land (DL), Adjacent crop land (CL), and an Undisturbed forest land (FL) which served as the control, all in the concession areas of NGGL. The degraded mine land was located around the mining pits within the concession area of NGGL, including the Subika and Awonsu pits. These areas are highly degraded due to the mining operations of the company, and further worsened by the soil erosion processes. The forest reserves within the kenyase enclave are fragments of the Eastern Guinean

Forest and are mainly composed of evergreen and deciduous tree plants extending over 50 m above ground level and include species such as *Aframomum stanfieldi*, *Nesogordonia papaverifera*, *Sterculia rhinopetala* and Acacia spp []. The adjacent croplands in the area are mostly dominated by maize farms which have been under cultivation for over 25 years. Farmers within the concessional area employ the application of inorganic fertilizers in small quantities in the replenishment of soil nutrient lost through crop uptake and erosion.

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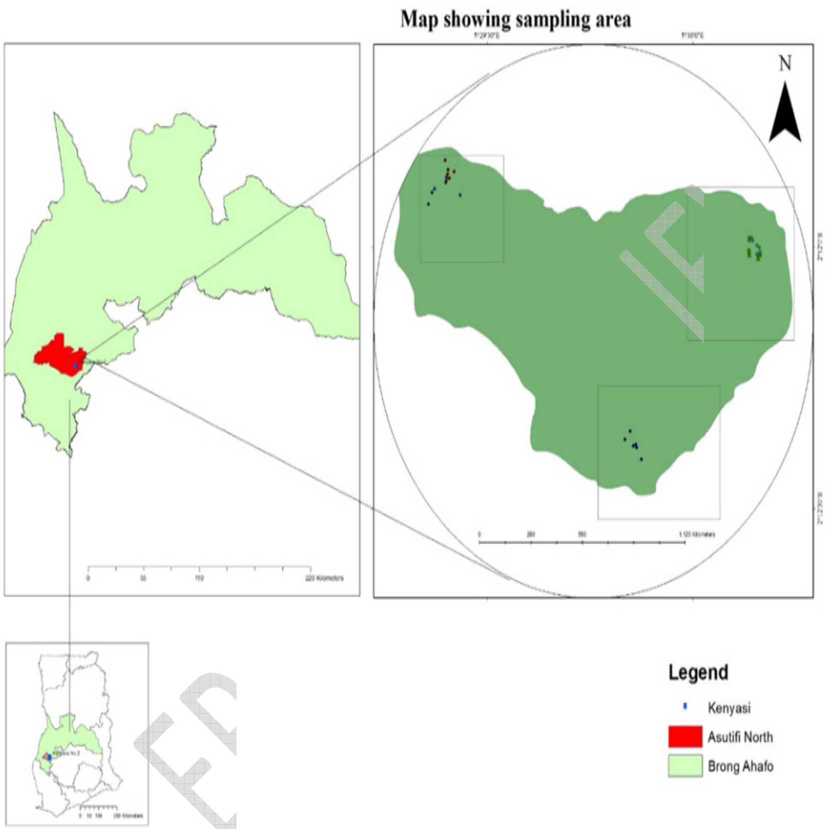

Fi~~g.~~gure 1 Map of Kenyase showing the various sampling points

2.2 Soil Sample Collection

The experimental treatments were laid using a factorial in a randomised complete block design and replicated three times. There were two experiment factors:~~The~~ land use types~~- examined in the study were 3 namely~~ degraded ~~-~~mine land (DL), adjacent crop land (CL), and an undisturbed forest land (FL) and ~~, whilst the~~ season~~- were examined at 2 levels~~, ~~that is~~ dry season and wet season. An area of 300 m^2 was demarcated in each land use type for soil sampling. In each of the 300 m^2 land use type, 5 samples were collected at 0-15 cm soil depth with a soil auger as described by [12] in each season. In microbial biomass analysis, the upper part of the soil (0-15 cm) is widely considered due to the high presence of microbes and their activities in this zone [4]. The samples were then bulked, representative of each treatment. Sub-samples were then taken from each composite sample after thorough mixing. Soil samples for analysis were collected on the 10th January, 2019 and 12th May, 2019, for the dry and wet seasons, respectively.

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2.3 Analytical Procedures/Analysis

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All field samples collected were air-dried and passed through a 2 mm sieve for chemical measurement. However, moist field samples were used in the estimation of soil microbial biomass. Measurement of soil physicochemical properties and microbial biomass characteristics was performed at the Soil Science Lab of the Soil Research Institute, Ghana.

Soil pH was performed in a 1:2.5 soil-water ratio using a pH meter. Soil organic carbon, total nitrogen, available phosphorus and exchangeable cations were determined using standard procedures as described by [13]. The C:N ratio was then calculated after the determination of total nitrogen and organic carbon of the soil. Soil texture of the 3 land use types was classified using the hydrometer method as described by [14]. Soil bulk density (BD) was determined in each of the land use types by the method described by [15]. Soil water content was estimated by the dry weight basis.

Microbial biomass carbon (MBC or C_{min}) and microbial biomass nitrogen (MBN or N_{min}) were determined using the chloroform fumigation and extraction (CFE) method as detailed by [16]. Fresh soil samples (10 g each) in a crucible were placed in 2 separate desiccators. With this, alcohol-free chloroform (30ml) was placed in only 1 of the desiccators, and both covered for 5 days in a dark room as proposed by [17]. MBC and MBN were then extracted after fumigation. This procedure was also performed on the non-fumigated soil. In the calculations of MBC/C_{min} and MBN/N_{min}, k-factors were used and expressed in Equations 1 and 2 below:

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$$\text{MBC or } C_{min} \text{ (mg)} = E_C/K_C \quad (1)$$

$$\text{MBN or } N_{min} \text{ (mg)} = E_N/K_N \quad (2)$$

Where MBC or C_{min} is microbial biomass carbon; MBN or N_{min} is microbial biomass nitrogen; E_C and E_N are the difference in C and N extracted from fumigated and non-fumigated soil respectively; K_C = 0.35 [18]; and K_N = 0.45 [19]. After the calculation of MBC and soil organic carbon, microbial biomass quotient (MBQ) was then determined using the ratio of microbial biomass carbon (MBC) to soil organic carbon (OC) [20].

2.4 Data Analysis

All data collected on soil physico-chemical properties and microbial biomass under the various land use types under different seasonal variations were subjected to analysis of variance (ANOVA) using R software. The treatments were tested at $P < 0.05$. Measured soil parameters were subjected to principal component analysis (PCA) by the R software to find out their spatial distribution under the land use types and seasonal variations. Multivariate analysis (cluster analysis) was done using the R software to assess the comparison between the sampling locations based on soil physico-chemical attributes and microbial biomass indices. Correlation analysis (Pearson) was conducted to ascertain the associations among key parameters measured.

3. RESULTS

3.1 Soil Physical Attributes

~~A Two-way ANOVA~~The results revealed that all the soil physical attributes were significantly influenced ($P < 0.01$) by land use, whilst seasons and their interaction did not statistically influence ($P > 0.05$) soil physical properties with the exception of moisture (%) (Table 1). With reference to land use, highest soil bulk density (BD) were observed in degraded mine land (1.43 g cm^{-3}), followed by crop land (1.22 g cm^{-3}), with the forest land recording the least BD of 1.10 g cm^{-3} ($P < 0.01$). As observed from Table 2, porosity decreased in the order of forest land (58.5 %) > crop land (53.95 %) > degraded mine land (46.2 %). Soil moisture content were significantly influenced by land use, seasons and their interactions (P < 0.001) (Table 1). Consequently, the mean values (seasonal variations) of soil moisture content were significantly higher in the forest land (13.14 – 18.77 %) relative to the crop land (12.65 – 16.29 %) > degraded mine land (9.87 – 10.43 %). Generally, sand (%) dominated the particle size distribution of the various land uses (Table 1). Degraded mine land generally recorded a higher sand and lower silt and clay percentage (P < 0.001) as compared to the forest and crop lands (Table 1). Overall, sand, silt and clay fractions of the various land uses did not differ with respect to seasonal variations (P > 0.05) (Table 1).

Table 1. ~~Two-way ANOVA of land~~ Effects of Land use types and seasons on soil physical properties

Land use type	Season	Particle Size Distribution			BD	Porosity	Moisture
		Sand (%)	Silt (%)	Clay (%)	(g cm^{-3})	(%)	(%)
Degraded mine land	Dry	53.18	14.92	31.90	1.46	44.9	9.87
	Wet	54.03	12.76	33.21	1.39	47.5	10.43
Crop land	Dry	34.64	34.60	30.76	1.23	53.6	12.65
	Wet	35.04	33.12	31.84	1.21	54.3	16.29
Forest land	Dry	20.95	31.71	47.34	1.12	57.9	13.14
	Wet	19.79	33.63	46.58	1.08	59.1	18.77
Two Way ANOVA	Land use	LSD = 2.06***	LSD = 1.78***	LSD = 1.62***	LSD = 0.19**	LSD = 7.13**	LSD = 0.98***
	Season	NS	NS	NS	NS	NS	LSD = 0.80***
	Interaction	NS	NS	NS	NS	NS	LSD = 1.39***

Values are means of three replicates; ***= significant at P <0.001; **= significant at P <0.01; NS= Not significant; BD= Bulk density, P= Level of significance; LSD= Least significant difference.

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3.2 Soil Chemical Attributes

Similarly, all soil chemical attributes statistically differed (P < 0.001) in terms of land use type (Table 2). However, seasons and their interactive effect did not significantly influence (P > 0.05) soil chemical properties, except total nitrogen (TN) and available phosphorus (P < 0.001) which were influenced by seasons and interactive effect respectively (Table 2). Analysed soil samples from the different land use types were typically acidic ranging from 4.43 to 6.41 (pH < 7) (Table 2). With land use type as the main factor, organic carbon content (OC) increased by 153.66 % when land use changed from degraded mine land to crop land (0.382 % to 0.969 % OC), and further increased by 156.45 % when land use changed from crop land to forest land. Total nitrogen (TN) content followed similar trend as OC such that, land use types significantly impacted (P < 0.05) TN and ranged from forest land (0.243 – 0.287 %) > crop land (0.200 – 0.217 %) > degraded mine land (0.123 – 0.183 %) (Table 2). Soil available phosphorus content decreased in the order of degraded mine land (4.37 mg kg^{-1}) < forest land (6.56 mg kg^{-1}) < crop land (17 mg kg^{-1}). Recorded values of exchangeable potassium (Ex. K) were higher in the forest land (0.387 cmol$_c$ kg^{-1}) and crop land (0.289 cmol$_c$ kg^{-1}) than in the degraded mine land (0.10 cmol$_c$ kg^{-1}) (Table 2) (P < 0.001). Mean soil carbon to nitrogen ratio (C:N ratio) were significantly higher in the forest land (9.65) than in the crop land (4.68) and degraded mine land (2.63) (Table 2).

Table 2. ~~Two-way ANOVA of~~ Effects of land use types and seasons on some selected soil chemical properties

Land use type	Season	pH	OC (%)	TN (%)	Av. P (mg kg^{-1})	Ex. K ($cmol_c$ kg^{-1})	C:N ratio
Degraded mine land	Dry	5.02	0.377	0.123	5.61	0.081	3.12
	Wet	4.54	0.387	0.183	3.13	0.110	2.13
Crop land	Dry	6.43	0.907	0.217	14.99	0.300	4.19
	Wet	6.39	1.030	0.200	19.64	0.278	5.16
Forest land	Dry	6.45	2.227	0.243	6.88	0.343	9.70
	Wet	6.02	2.743	0.287	6.24	0.430	9.60
Two Way ANOVA	Land use	LSD = 0.74***	LSD= 0.27***	LSD = 0.034***	LSD = 0.66***	LSD = 0.11***	LSD = 2.28***
	Season	NS	NS	LSD= 0.028***	NS	NS	NS
	Interaction	NS	NS	NS	LSD = 0.94***	NS	NS

Values are means of three replicates; ***= significant at P <0.001; NS= Not significant; LSD= Least significant difference; OC= Organic carbon; TN= Total nitrogen; Avail. P= Available P; Ex. K= Exchangeable potassium; C:N ratio= total organic carbon to total nitrogen ratio.

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3.3 Soil Microbial Biomass

As observed from the analysed results, land use types, seasonal variations and their interaction impacted on four measured soil microbial attributes ($P < 0.05$) (Table 3). In terms of land uses, highest level of microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were recorded under the forest land (259.95 mg kg^{-1} and 89.8 mg kg^{-1} respectively), whilst the degraded mine soil observed the least MBC (57.2 mg kg^{-1}) and MBN (30.25 mg kg^{-1}). Highest MBC:MBN ratio (2.98) was recorded under the forest land ($P < 0.05$) whilst the crop land recorded the highest microbial biomass quotient (MBQ) with a mean value of 2.07 % ($P < 0.001$). With regards to seasonal variations, the wet season generally recorded the highest MBC (281.77 mg kg^{-1}), MBN (109.50 mg kg^{-1}) and MBQ (2.31 %) ($P < 0.001$). Significant differences ($P < 0.05$) were observed between seasons x land uses with the interactive effect of forest soils in the wet season recording the highest MBC (429.3 mg kg^{-1}) and MBN (150.3 mg kg^{-1}), whilst that of degraded mine soil x dry season recorded the least MBC and MBN. Highest MBC: MBN was recorded in the wet season x forest land (3.10) relative to the other interactive effects. With regards to MBQ, the interactive effect of crop land x wet season recorded the highest value of 3.24 % and statistically differed from the rest of the interactions ($P < 0.001$).

Table 3. ~~Two-way ANOVA of~~Effects of land use types and seasons on microbial biomass indices

Land use type	Season	MBC (mg kg^{-1})	MBN (mg kg^{-1})	MBC: MBN	MBQ (%)
Degraded	Dry	31.9	16.7	1.91	0.84
mine land	Wet	82.5	43.8	1.88	2.13
Crop land	Dry	76.5	28.8	2.65	0.84
	Wet	333.5	134.4	2.49	3.24
Forest	Dry	90.6	29.3	3.10	0.41
land	Wet	429.3	150.3	2.86	1.57
Two Way	Land use	LSD = 13.90***	LSD = 9.70**	LSD = 0.39*	LSD = 0.34***
ANOVA	Season	LSD = 11.35***	LSD = 7.92***	LSD = 0.32**	LSD = 0.28***
	Interaction	LSD = 19.66***	NS	LSD = 0.56*	LSD = 0.48***

Values are means of three replicates; ~~;~~ LSD= Least significant difference; ***= significant at P <0.001; **= significant at P <0.01; *= significant at P <0.05 MBC= Microbial biomass carbon; MBN= Microbial biomass nitrogen; MBC: MBN= Microbial biomass carbon to microbial biomass nitrogen; Microbial biomass quotient (MBQ) = MBC:OC = Microbial biomass carbon to organic carbon ratio.

3.4 Cluster, Principal Component and Correlation Analysis

A cluster analysis showing the hierarchical dendrogram of the soil properties between the various sampling locations (land use type x seasons) is presented in Figure 2. ~~From Figure 2, T~~The analysis revealed two main clusters based on the sampling locations (Figure 2). Soil parameters from the forest land and the crop land, both in the wet season were dominant and this was included in the first cluster (Figure~~.~~ 2). The second cluster of soil properties included degraded mine land x wet season. However, a smaller sub-cluster based on sampling locations and season was observed which included the forest and crop land in the dry season.

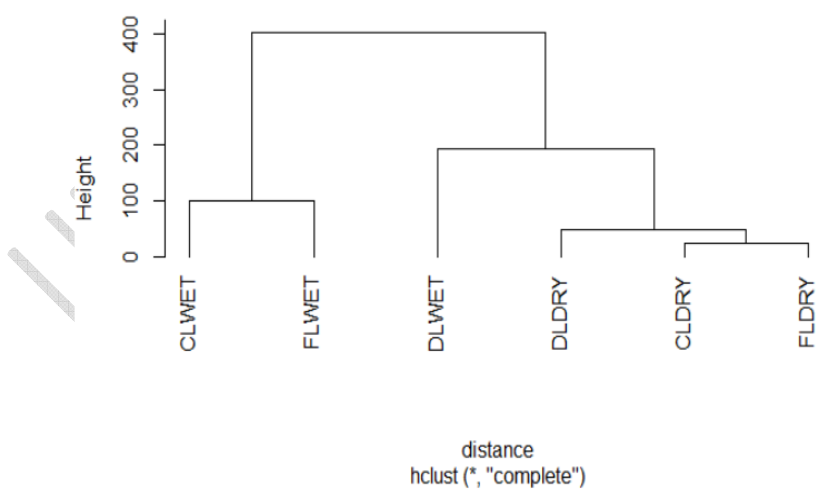

Fig. 2. Hierarchical cluster analysis of the soil properties based on land use and seasonality.

To evaluate the distribution of the 16 selected soil properties based on land use, seasonal variations and their interaction, the PCA analysis in Table 4 revealed that 4 principal components (PCs) were selected based on their eigenvalues greater than (>) 1. These 4 selected PCs were associated with 90.39% of the total variance (Table 4). From the table, the highest weighted eigenvectors/loadings in PC1 were three (total nitrogen, organic carbon, and silt), three for PC2 (MBN, MBC:MBN ratio, and microbial biomass quotient), two for PC3 (available phosphorus and sand), and two for PC4 (bulk density and porosity) (Table 4).

In the assessment of association between the soil physico-chemical attributes and microbial indices, the PCA biplot was used. The biplot revealed the distribution of the 16 soil parameters measured according to land use and seasonal variations, and highlighted further that the first two components (Comp. 1 and Comp. 2) accounted for 68.19% of the total variance (Fig. Figure 3). Basically, PC1 (axis 1) was dominated by the wet season with forest land and crop land being the main land use types. The positive axis of PC1 was discriminated towards MBC, MBN, GMC, TN, Av.P, Porosity, K, Silt, pH, OC, CN and MBC:MBN ratio, whilst sand, clay, BD and MBC:OC ratio was discriminated towards the negative part of that axis (FigFigure. 3). In PC2 however, the positive axis was discriminated towards MBC, MBN, TN, AvP, MBC:OC ratio, Clay, GMC, Porosity, whilst K, OC, C:N ratio, pH, MBC:MBN ratio, Sand, Silt and BD discriminated towards the negative part of that axis (Fig. Figure 3).

Table 4. Principal component analysis of the measured soil physico-chemical and biological properties.

Principal components	**PC1**	**PC2**	**PC3**	**PC4**
Eigenvalues	2.82	1.72	1.59	1.01
Percentage variance (%)	49.75	18.44	15.76	6.44
Cumulative percentage	49.75	68.19	83.95	90.39
Eigenvectors/loadings				
TN	**0.300**	0.080	-0.111	-0.147
AvP	0.106	0.118	**0.575**	0.105
K	0.299	-0.001	0.023	0.141
OC	**0.320**	-0.078	-0.228	0.076
C:N ratio	0.284	-0.147	-0.182	0.133
pH	0.282	-0.054	0.174	0.198
MBC	0.193	0.432	-0.140	0.213
MBN	0.113	**0.523**	-0.149	0.145
MBC:MBN ratio	0.129	**-0.435**	-0.004	0.300
MBQ (MBC:OC ratio)	-0.174	**0.474**	-0.114	-0.025
Sand	-0.164	-0.080	**-0.537**	-0.001
Silt	**0.328**	-0.035	0.209	0.035
Clay	-0.251	0.150	0.393	-0.048
BD	-0.280	-0.026	-0.012	**0.578**
Porosity	0.280	0.026	0.012	**0.578**
GMC	**0.308**	0.207	0.008	0.235

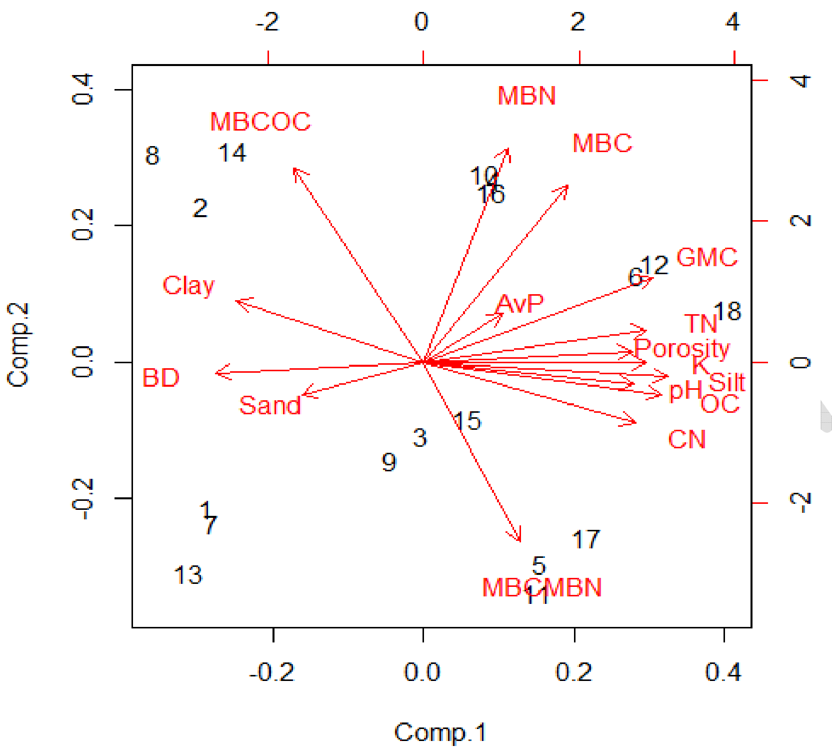

Fig. 3: Principal component analysis (biplot) showing of ordination of soil parameters across the various land uses and seasons. PCA of axis 1 and axis 2 represent 49.7% and 18.4% of the total variance respectively.

Soil organic carbon (OC), soil microbial biomass carbon and nitrogen (MBC and MBN) were negatively correlated with soil bulk density (BD) under all the various land use types (Table 5). Similarly, significant correlations were also observed between OC, MBC and clay content of the various land use types. From Table 5, total porosity was inversely correlated with soil bulk density, whilst sand was also inversely correlated with almost all parameters measured. Generally, soil physico-chemical properties (including TN, AvP, K, OC, GMC etc.) of the various land use were significantly correlated with soil microbial biomass (Table 5).

Table 5. Pearson correlation analysis between some measured soil parameters

	TN	AvP	K	OC	pH	MBC	MBN	Sand	Silt	Clay	BD	PT	GMC
TN	1.00												
AvP	0.07*	1.00											
K	0.77**	0.28*	1.00										
OC	0.77**	-0.08*	0.76*	1.00									
pH	0.62*	0.49*	0.67*	0.62	1.00								
MBC	0.52**	0.14*	0.41*	0.48*	0.33	1.00							
MBN	0.37**	0.08*	0.25*	0.26	0.14	0.94*	1.00						
Sand	-0.26*	-0.93*	-0.42*	-0.12	-0.53	-0.16	-0.06	1.00					
Silt	0.72**	0.57*	0.78*	0.74	0.81	0.38	0.16	-0.73	1.00				

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Clay	0.68*	0.39*	0.56*	0.89*	0.47	0.33**	0.14*	-0.25	0.48*	1.00			
BD	-0.71**	-0.21*	-0.54*	-0.65*	-0.51*	-0.37*	-0.22	0.37	-0.70*	0.50*	1.00		
PT	0.71*	0.21*	0.54*	0.65*	0.51	0.37*	0.22	-0.37	0.70*	-0.50*	-1.00*	1.00	
GMC	0.73*	0.37*	0.71	0.73	0.66	0.82**	0.64*	-0.46*	0.79*	-0.52*	-0.58*	0.58*	1.00

4. DISCUSSION

4.1 Impact of Land Uses on Soil Physico-chemical Properties

Based on ~~our~~ the first hypothesis, the 12 measured soil physico-chemical properties were all significantly impacted by land use types (Tables 1 and 2) ($P < 0.05$), which corroborate with other previous studies [21 – 22]. However, different seasons and the interactive effects of land use and seasons x land use did not significantly influence ($P > 0.05$) physico-chemical properties except moisture content (%) and that of total nitrogen (%) (Tables 1 and 2). Soil bulk density (BD) showed major differences and thus significantly ($P < 0.05$) increased when land use changed from forest land (1.10 g cm^{-3}) to agricultural land (1.22 g cm^{-3}), then increased further to 1.43 g cm^{-3} in degraded mine land soil, with its accompanying decrease in total porosity (Table 1). The decomposition of litter in the forested area resulted in increased organic matter content which in turn increased porosity (pore spaces) and reduced bulk density, confirming results of other related studies [23 – 24]. In their studies on degradation and tillage operations, [25], [26], [27] and [28] also observed high soil bulk density in agricultural and degraded lands which was due to cultivation, management and tillage operations in such areas.

Particle size distribution impacts on soil productivity by influencing soil moisture content and chemistry (e.g. nutrient supply) [4]. According to [4], ~~the authors,~~ the proportions of sand, silt and clay of a particular soil is significant in determining the soil texture quality [4]. Based on ~~our results~~findings, both the cropped and degraded mine land recorded generally lower silt and clay contents as compared to the forest land. This could be as a result of washing away of silt and clay particles by excess overland flow in the rainy season compounded by loss of vegetation cover [29]. This attests to the findings of [30] ~~who~~ where ~~observed~~ similar results on forested and cultivated lands and associated it to the removal of silt and addition of sand particles through water erosion was observed.

~~As observed from our results~~ The results revealed ~~, high~~that high water content in the forested land (13.14 – 18.77 %) relative to the degraded land (9.87 – 10.43 %) and agricultural land (12.65 – 16.29 %). This could be associated to high canopy cover in the forested area, low soil bulk density with its associated increased porosity, high litter content at the forest floor impacting on the amount and type of clay particles and organic matter resulting in increased water holding capacity. Similar results were ~~observed~~ reported by [31] and [4], ~~who recorded~~ where varied moisture content values in different land uses and associated it to high litter produced in the forested ecosystem impacting on soil particle size distribution, thereby increasing the moisture holding capacity.

Soils under permanent cultivation and the degraded land recorded lower levels of soil organic carbon (OC) and general nutrient status, with the exception of soil pH and available phosphorus which recorded higher values in the cropped land than soils under both forested and degraded land. It ~~is~~ was reported that about 50 – 80 % of OC decreases when forested areas ~~are~~ were converted to permanent cultivation or degraded [32, 11]. ~~In their studies~~ Studies on different land uses in the Mediterranean regions, [33] observed about 50 – 60 % reduction on soil OC when a coniferous was converted to a permanent cropping system, and [34] report similar results of reduced 50 – 70 % OC in soils under cultivation than an afforested land in China. In comparing soil OC in the different land uses, the significant reduction in OC concentrations in the cropped and degraded soils in our current study could be due to accelerated decomposition resulting from high temperatures and tillage

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operations, superficial washing away of the topsoil by erosion, burning of biomass, and decreased inputs of litter (organic matter) [35, 11]. Soils in Ghana are inherently poor in nutrient status [36 – 37] with farmers applying fertilizers in the maintenance of fertility. Despite the addition of organic manures and inorganic fertilizers on the cropped land in the study area, soil OC was still lower compared to that of the forested area. These results could also be associated with higher output of soil OC from the cropped land as opposed to OC inputs [38]. Similarly, total N also recorded higher values in the forested area (0.243 – 0.287 %) relative to the crop land (0.200 – 0.217 %) and degraded mine land (0.123 – 0.183 %) and this could be due to nitrogen fixation in the forested area by some N-fixing trees (e.g. Acacia) and relatively high production of litter (residues) [39].

Soil pH in the different land use types were typically acidic ranging from 4.43 to 6.41 (pH < 7). Forested area and the degraded land were more acidic than the pH of the cropped land. This could be associated to several factors which includes leaching of the basic cations in the rainy seasons and parent materials from which the soils were formed. Residue burning in the agricultural land was associated with increased ash content comparable to that of the forested land, which might also be a reason for the high pH in the agricultural land [39]. In ~~our~~ the present study, chemical properties in the agricultural land were comparable to that of the forested area due to the fertilization of the soil. This attested to previous studies of [40] and [41] on land use change ~~who observed~~where improvements in soil chemical properties under areas of permanent crop production were obseved. The ~~authors~~ studies recorded high levels of soil chemical properties, especially available phosphorus,[……………..] which corroborates with ~~our~~ the findings of the study.

Comment [CK14]: Where are the citations which support your findings

4.2 Soil Microbial Indices

The microbial biomass has been recognised as a key component of soil microbial activity influencing many soil processes [42]. They characteristically impact on soil quality thereby influencing the vegetation in a given area [43]. The microbial biomass is however, sensitive to environmental changes as well as land-use conversion. ~~From our~~The present study, land uses impacted on microbial biomass and generally increased in the order of degraded mine land < agricultural land < forest land, confirming our first and second hypothesis. This ~~is~~ was consistent with other studies indicating that soil microbial biomass decreased when forested lands were converted to agricultural land or degraded by tillage implements [44……………].

Comment [CK15]: Since you said studies, then you need to add more sources as one is not many

The increase in microbial biomass carbon and nitrogen in the forest land relative to the agricultural land and degraded mine land could firstly be attributed to the varied plant species of the forest ecosystem which adds organic matter to the soil upon the decomposition of diverse litter. The forest ecosystem is made up of different vegetation species including trees (e.g. *Aframomum stanfieldi*, *Nesogordonia papaverifera* and *Sterculia rhinopetala*), shrubs and herbaceous plant which adds different forms of decomposed plant residues ~~(e.g. leaves)~~ with its associated increase in soil organic matter. [45] noted that diverse plants in a natural forest produces different exudates which helps attracts soil microbes to the plants root zone (rhizosphere) thereby increasing microbial biomass. [46] also established that land use conversion from forest ecosystem to other land uses significantly impacted on soil microbial biomass due to litter amounts and nutrient compositions. In ~~our~~ the present study, MBC decreased about 20.23 % when land use changed from forested land the agricultural land, and further decreased by 88.36 % when land use changed from forested land to degraded mine land. ~~In their works,~~ [47] and [11] observed a decrease in soil microbial biomass when forested lands were converted to agricultural land and was due to the reduction in different plant diversity and litter quality. Therefore, an increase in soil MBC and MBN in the forest ecosystem relative to the degraded mine and agricultural land use types are due to the increased plant residues and soil properties especially SOC and N [48, 46]. Soil microbial biomass carbon ~~is~~ was the C found in the living portion of soil OC. Therefore, forested areas with its associated larger amounts of litter serves as key source of nutrients and labile C required by soil microbial biomass, hence, increase in microbial community

Comment [CK16]: How about the ones that repel the microbes

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and activities [21]. In the forested ecosystem, measured organic carbon, total nitrogen and potassium (2.49 %, 0.27 %, and 0.89 $cmol_c$ kg^{-1}, respectively) were generally higher than those recorded under the cropped land (0.97 %, 0.21 %, and 0.29 $cmol_c$ kg^{-1}, respectively) and degraded mine land (0.38 %, 0.15 %, and 0.10 $cmol_c$ kg^{-1}, respectively). Similar findings have demonstrated that soil microbial biomass C and N are closely related with soil OC and total N [42, 46].

Secondly, the reduction in microbial biomass in both agricultural and degraded mine land of ~~our~~ the study may be attributed to soil disturbances arising from tillage operations (e.g. soil preparation, soil management practices) and mining activities which interrupts soil structure, functions and processes, thereby affecting microbial habitat. Tillage operations and management practices from agricultural and mining activities significantly impacts on the quantity and quality of litter causing a reduction in microbial biomass [49]. In ~~our~~ the current study, the degraded mine and agricultural land use types have been under disturbance for several years resulting in the decline of MBC and MBN in these land uses. ~~In their studies~~ Studies on soil microbial biomass composition as influenced by land uses, [50] asserted that modification of the soil structure by the action of different tillage implements was a major factor impacting soil microbial biomass, thus, creating an unfavourable soil conditions for microbial biomass[]. Furthermore, tillage operations that leads to destruction of the soil structure causes accelerated water and wind erosions, soil compaction, reduced water infiltration and water holding capacity, thus resulting in decreased residue decomposition and subsequent decrease in microbial biomass [7]. [46] further concluded that zero or minimum tillage practices, which is evident in forested areas is associated with good soil aggregation shaped by complex mycelia networks in the solum.

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Thirdly, soil moisture variations have been found to significantly impact on soil microbial biomass [5]. Regardless of the land use type, it could observe from our results (Table 3) that MBC and MBN was generally higher in the wet season than the dry season, accompanied with large quantities of litter in the wet season within the forested land, supporting our hypothesis. These results are in agreements with other studies stressing the importance of water on microbial biomass ~~(~~[4, 51]. This decline in microbial biomass in the dry season relative to the wet season could be associated to slow microbial activities due to limited water in the dry season, as conditioned by higher soil temperature within the periods of mid-November to mid-March at the study area. ~~Our results~~The findings in the study were justified by positive correlations between moisture content and microbial biomass carbon (0.82**) and moisture content and microbial biomass nitrogen (0.64*) (Table 5). It could be deduced from ~~our results~~ the findings that higher microbial biomass activity is directly related to increasing soil moisture content [52].

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The microbial biomass quotient (MBQ) (MBC to OC ratio) has been regarded as an important indicator to monitor changes in microbial activities resulting from land use change [18, 53, 7]. It represents the degree to which soil OC is utilised by soil microorganisms [11] or the input of MBC to Soil OC [4]. Under ~~our~~ the current study, ~~we observed~~ MBQ values ranging from 0.41 – 3.24 % was observed under the 3 land use types as affected by seasonal variations, which has been reported in other previous studies [54, 54, and 56]. These variations in MBQ values in the different land uses could be as a result of OC immobilised into soil microbial tissues as suggested by [4]. Hence, lower MBQ values is as a result of inhibition of microbial immobilisation whilst higher MBG values could be associated with OC immobilisation [4].

4.3 Cluster, Principal Component and Correlation Analysis

~~From our present~~In the study, land use types impacted on soil physicochemical properties and microbial indices. The principal component analysis (PCA) revealed the distribution of the 16 soil parameters were measured according to land use and seasonal variations, and highlighted further that the first two components (PC 1 and PC 2) accounted for 68.19% of the total variance (Fig. 3). However, the PCA analysis in Table 4 revealed that 4 principal components (PCs) had ~~their~~

eigenvalues greater than (>) 1. These 4 selected PCs were associated with 90.39% of the total variance (Table 4). The axis 1 in the PCA accounted for 49.75 % of the total variation whilst that of axis 2 in PCA also accounted for 18.44 % of the total variation (Table 4). It could be observed from Figure 3 the effects of land use conversion (e.g. forested ecosystem to degraded mine land or cropped land) on soil properties. The biplot revealed that soil properties especially microbial biomass is highly sensitive to land use type and season. As such, significant relationship was observed between microbial indices, OC and other soil properties (Table 5), confirming our hypothesis. [4] report similar findings and noted that activities of soil MBC is significantly affected by soil physicochemical properties.

Significant correlations were observed among key parameters measured in ~~our~~ the study. For example, ~~our results~~the findings revealed a negative correlation between soil OC and bulk density (-0.65*). At higher soil bulk density, soil OC decreased due to the fact that, OC was made less available in the soil matrix [24]. As such, OC was lower in the forested land compared to the crop and degraded mine land. Percentage clay has been found to significantly impact on the amount of soil OC due to its physical protection against soil microbes [57]. Clay content varied under all the land use types ($P < 0.05$) studied and was positive correlated with soil OC (0.89*), confirming previous studies. ~~In their~~A study on the effects land uses on soil physicochemical properties, [58] observed an increase in soil OC when clay content also increased (0.75*).

5. CONCLUSION

Land use change significantly impacts on soil microbial indices, chemical properties and soil OC in the semi-deciduous zone of Ghana. ~~Our~~ The finding revealed that soil microbial biomass indicators and chemical attributes significantly decreased when forested area was converted to other land use forms. The multivariate analysis (Principal Component Analysis) further confirmed the relative effect of land use change on soil physicochemical and biological properties, which discriminated between the forested zone and the other land use types. Effect of seasonal variations significantly impacted on only soil microbiological parameters. Microbial biomass carbon decreased about 20.23 % when land use changed from forested land to agricultural land, and further decreased by 88.36 % when land use changed from forested land to degraded mine land. These results reveal the alarming rate in soil microbiological and chemical properties decline after land use conversion. Thus, this data will support the management decisions of Mining Companies and Forest Division Services on afforestation projects and management of forested areas.

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