SOIL & CROP SCIENCES | RESEARCH ARTICLE

Variability of soil physicochemical properties under different land use types in the Guinea savanna zone of northern Ghana

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Abstract: Land use change has been a major global challenge since the twentieth century, especially the conversion of natural forests to agricultural and other uses. Such land use changes are considered to be among the major threats to soil quality and sustainability. In this study, we hypothesized that the physicochemical properties of soils in the Guinea Savanna zone of Northern Ghana would vary based on the land use type; with the protected area (PA) having better soil physicochemical properties than farmlands (FL) and fallowed areas (FA). Three communities (Mognori, Jagbo-Apleyi, Tugu) with different land use types (PA, FA and FL) were selected. A total of ninety-nine composite soil samples at three depths (0–15, 15–30, 30–45 cm) were collected for physiochemical analysis. The results indicated that the soil organic carbon, nitrogen, extractable bases (Ca, Mg, K) and effective cation exchange capacity were higher (P < 0.05) in the PA than in the FA and FL and decreased with soil depth. However, bulk density was similar among the land use types but increased with soil depth. Such physicochemical properties of FA could have consequential impact on farmers’ livelihoods, since majority (70%) of them depend on crops cultivation. In addition, it could pose a threat to PA since degraded soils could trigger increased encroachment on the existing protected areas. In conclusion, farmers should cultivate crops with shallow roots (within 0–15 cm), since good soil physiochemical properties and nutrients that support crop growth had their critical concentration levels within that soil depth.

Subjects: Soil Sciences; Soil Conservation Technology; Vegetation; Agronomy

Keywords: Soil quality; Fallow; Degradation; Farmland

PUBLIC INTEREST STATEMENT

The conversion of natural forests to agricultural and other uses is considered a major threat to soil quality and sustainability. Unfortunately, in the Guinea Savanna Zone of Northern Ghana, about 80% of the population depend on agriculture as their main source of livelihood. This means policy makers would have to balance the need to conserve protected areas and either make available more lands for crops production or improve the existing cropping lands. Our findings suggest that there is a gradual deterioration of soil properties of farmed areas and this could impact on the livelihoods of the rural communities. In addition, this could pose a threat to most protected areas since lack of productive agricultural lands could trigger increased encroachment on the existing protected areas. To protect the existing forest, farmers should cultivate crops that have shallow roots (0–15 cm), since soil physiochemical properties that support crop growth had their critical concentrations levels within that soil depth.
1. Introduction
Land use change has been a major global challenge since the twentieth century, especially the conversion of natural forests to agricultural land and settlement (Bekele et al., 2021; Fetene & Amera, 2018). Such land use changes are considered to be among the main threats to soil quality (Ayoubi et al., 2010; Ayoubi & Moazzeni Dehaghani, 2020; Havaee et al., 2014; Zajicová & Chuman, 2019). For instance, about 24 billion tons of fertile soils are lost every year, while 12 million ha of land are degraded due to the effect of changes in land use management (Elias et al., 2019; Tellen & Bernard, 2018). Specifically, changes in soil properties due to land use type and management has significant influence on P, K, Ca, Mg, total nitrogen, soil carbon/organic matter and bulk density (Annan-Afful et al., 2005; Gupta et al., 2022).

In the Guinea Savanna Zone of Northern Ghana, agriculture is faced with many challenges, notably the continuous soil fertility depletion and this is influenced by both land use and the agroecological type (Atakora et al., 2019; Owoode et al., 2021). Unfortunately, the manner in which land use types affect essential physiochemical soil properties and nutrients in different ecological zones of Ghana is not well understood even though it has relevance for the design and management of soil productivity (Owoode et al., 2021).

The situation could linger longer because, in the Guinea Savanna Zone of Northern Ghana, the increasing population and the corresponding increasing demand for food have necessitated different land uses (Kermah et al., 2018; Ochire-Boadu et al., 2020b). For example, the fallow period which would allow the soil fertility to regenerate has become increasingly shorter and, in some places, does not exist due to population pressure and the growing demand for arable land (Ibrahim et al., 2019; Kühnert et al., 2019).

In addition, situations where the physiochemical properties of soils also vary with soil depth, it could have a great impact on the choice of crop farmers can grow and the appropriate and sustainable soil and land management options to adopt (Fetene & Amera, 2018; Tufa et al., 2019).

The novelty and relevance of this study is in the fact that there is a dearth of research on the subject within the context of land use types and soils in Ghana, and more seriously, in the Guinea Savanna zone of Northern Ghana where poor crops yield is associated with depleted soil fertility.

Therefore, this study aimed to assess changes in soil physiochemical properties under different land use types (Protected area, Farmlands and Fallowed areas) and soil depth in Guinea Savanna zone of Northern Ghana.

The protected areas consisted of areas that were well monitored and secured from human disturbances. The fallow lands were agroforestry parklands that had been left fallow for not less than 5 years while farmlands were lands that have been under cultivation continuously for at least the past 5 years.

We hypothesized that the physiochemical properties of soils in the Guinea Savanna zone of Northern Ghana would vary based on the land use type and the soil depth; with the protected area (PA) having better soil physiochemical properties than farmlands (FL) and fallowed areas (FA).

2. Materials and methods

2.1. Study area
Three communities of the Guinea Savanna zone of Northern Ghana were selected for the study. The communities were Mognori in the Mole National Park in the West Gonja District (9° S 5’0” N, 1° 49’ 0” W), Jagbo-Apleyi near the Chinfoyiri Sacred Grove in the Tolon District (9° 26’ 0” N, 1° 4’ 0” W).
and Tugu, near the Sinsablegbinnni Forest Reserve (9° 24’ 30.31” N, 0° 50’ 25.63” W), in the Tamale Metropolis (Figure 1).

The vegetation of the Guinea Savanna zone of Northern Ghana is predominately tall grasses with scattered trees and shrubs with well-defined wet and dry seasons of about equal durations. The mean annual rainfall ranged 900–1100 mm. The wet season starts in March and ends in October, with maximum rainfall occurring around the month of August to September. The dry season usually starts in November and ends around March/April.

2.2. Soil classification, geology and landforms in study area

The Guinea Savanna like many tropical agroecosystems, where land cover depletion far outstrips natural regeneration, the soils are susceptible to degradation and erosion with a large proportion of sand in the topsoil causing weak aggregation as a result of the low quantities of organic matter (Bessah et al., 2016; Owusu & Essondoh-Yeddu, 2018). The physical constraints to soil tillage are further exacerbated in the gravel soils or soils with shallow depth overlying plinthic or the “iron pan” layers (Adjei-Nsiah et al., 2019). The soils in Northern Region are generally classified as plinthic luvisols but the type around Tolon is dominated by ferric luvisols (Atakora & Kwakye, 2016). The parent material is Voltaian clay and they are well to moderately drained soils. They have a low accumulation of organic matter in the surface horizon owing to high temperatures, which results in a rapid rate of decomposition (Franke et al., 2018).

The mean monthly temperatures are high throughout the year ranging from 25°C to above 33°C. Relative humidity ranges from 75% in the raining season to 35% in the dry and hot periods (Nketia et al., 2018b).

2.3. Sampling procedure

A reconnaissance survey was carried out in July and August during which the study plots were identified. The study sites were identified based on the availability of protected areas that were well monitored and secured from human disturbances and it also had fallow lands which were agroforestry parklands that had been left fallow for not less than 5 years. In the first comparative studies, soil samples were taken (at 0–15 cm) using a soil augur to compare the soil physicochemical properties of the three land use types at the three different locations. Thus, a total of forty-five
(45) quadrats of 30 m × 30 m each were laid randomly following the process of Perez-Salicrup et al. (2001), which consists of nine (9) quadrats each, laid in the protected areas (PA), fallow lands (FL) and farmlands (FA) in the three communities.

The Protected areas consisted of lands that were secured from human disturbances. For instance, the sacred groves are protected, conserved and maintained through a mechanism of beliefs, taboos, prohibitions and restrictions. Burning, cutting of grass and fuelwood are prohibited in these areas. The Fallow lands were agroforestry parklands that had been left fallow for not less than 5 years while Farmlands were lands that have been under cultivation continuously for at least the past 5 years (Supplementary material 1).

The main factor consisted of the three (3) Land use types (protected, fallow and farmlands) and the second factor was the three (3) different locations giving a total of nine (9) treatments.

For each quadrat, five soil samples were obtained from 5 m × 5 m nested quadrats which were placed at each of the four corners and one in the centre. For each quadrat, the five samples were thoroughly mixed and two subsamples were taken for soil analysis in duplicates giving a total of 90 samples. The samples were air-dried (105 °C for 24 hours), ground to break the aggregates into fragments, sieved with a 2-mm mesh to remove extraneous materials like roots and pebbles and mixed thoroughly.

In the second comparative study, the main factor was the three land use types (PA, FL and FA) and the sub-factor was the three levels of soil depths consisting of 0–15, 15–30 and 30–45 cm giving a 3 × 3 factorial experimental set up resulting in nine (9) treatments.

For each of the three (3) land use types, six (6) of the 30 m × 30 m quadrats were randomly laid giving a total of 18 quadrats. In each quadrat, soil samples were taken from five (5) subplots at the three (3) different soil depths. Samples at the same depth were thoroughly mixed and two (2) subsamples were taken for soil analysis in duplicates giving a total of 108 samples.

To conduct physical and chemical analyses, the samples from both the first and second comparative studies were air-dried to determine the soil texture, pH, soil organic carbon, total nitrogen, available phosphorus, extractable bases (Ca, Mg, K), exchangeable acidity (EA) and effective cation exchange capacity (ECEC).

2.4. Physical analysis of soil samples
The particle size distribution of the soil was determined for each land use type using the pipette method. Soil samples were dispersed with a dispersing agent (sodium pyrophosphate solution). The soil suspension was then poured onto a 0.05 mm fine sieve to separate the sand fraction, while the clay and silt fractions were washed into a sedimentation cylinder. To determine the clay content a constant volume suspension was extracted with a pipette and dried after which the soil textural categories were established using the USDA Soil Textural Triangle (Huluka & Miller, 2014).

Soil bulk density was determined by driving a stainless-steel core sampler of known volume ($V = 384.9 \text{ cm}^3$) and weight ($W_s$) into the vertical face in each plot with a wooden mallet. The soil samples obtained were dried in an oven at 105°C for 48 hours and the bulk density calculated according to the recommendation of Rai et al. (2017).

2.5. Chemical analysis of soil samples
The pH of the soil samples was determined in water using a glass electrode with equal proportions of soil and water in a ratio of 1:1. The extractable bases were also obtained using the Ammonium acetate (NH4OAc) method with neutral 1 M NH4OAc solution of pH 7 (Kumar & Rao, 2017).
The exchangeable cations, Ca and Mg contents were determined using EDTA titration, while K were obtained using the flame photometer (Kumar & Rao, 2017).

The exchangeable acidity was obtained using the extraction of Mehlich’s barium chloride-triethanolamine, which was buffered at pH 8.2. The soil samples were leached with an unbuffered salt solution of 1 M KCl and Al in the leachates were measured by titration (Lin & Coleman, 1960; McLean, 1965).

Soil organic carbon was obtained with a modified Walkley and Black wet oxidation method described by Nelson and Sommers (1996). The process comprises wet combustion of the organic matter using a mixture of acidified potassium dichromate after which the excess dichromate was titrated against 1.0 M ferrous sulphate using diphenylalanine indicator (Jha et al., 2014).

Available phosphorus, \( P_{av} \) was extracted with HCl:NH\(_4\) mixture using Bray’s no. 1 method as described by Bray and Kurtz (1945). The phosphorus in the extract was then obtained using a spectronic 21D spectrophotometer by blue ammonium molybdate method with ascorbic acid as a reducing agent (Rodriguez et al., 1994).

The cation exchange capacity (CEC) was found by adding the exchangeable bases (\( Ca^{2+}, Mg^{2+}, K^+, Na^+ \)) to the exchangeable acidity (\( Al^{3+} \) and \( H^+ \)). Percentage base saturation (PBS) was calculated as a fraction of the total extractable bases to the CEC expressed as a percentage (Hazelton & Murphy, 2016).

2.5.1. Data analysis
The data were subjected to two-way analysis of variances (ANOVA) using the “car” and “MASS” packages of the R statistical software version 3.4.1 to test for significant differences between means with a 5% significance level. Where there were significant interactions, Tukey’s HSD post hoc tests for multiple comparisons were carried out to show significant differences in the means of the various treatments \( (P < 0.05) \). Pearson’s product-moment correlation analysis was used to establish correlation between physical and chemical soil properties on the various depth of the different Land use types.

3. Results

3.1. Effect of land use type on the physicochemical properties of soils at different locations (community) in the Guinea Savanna of Ghana
The \( pH \) values ranged between 5.28 to 6.66 and was significantly influenced \( (P = 0.015) \) by land use type in the three communities (Table 1). Generally, the \( pH \) values in the PA and FL were higher than FA while PA and FL had similar \( pH \) values in Jagbo and Tugu communities (Table 1).

The soil organic carbon (SOC) in the three communities ranged from 0.14% to 1.10% (Table 1). In each community, land use type significantly \( (P = 0.000) \) influenced SOC. The SOC of PA was significantly higher \( (P < 0.05) \) than both FL and FA across the three communities, however, FL and FA land use types in Jagbo and Tugu communities were similar (Table 1). Similar pattern was observed in the total nitrogen (TN), except in Mognori and Tugu where FL was significantly higher \( (P = 0.015) \) than the FA. For example, in Tugu community, FA and FL had TN content of 0.01% and 0.03, while in Mognori FA and FL was 0.05 and 0.08 respectively (Table 1).

The available phosphorus (\( P_{av} \)) of the soil ranged from 1.11 mg kg\(^{-1}\) to 6.75 mg kg\(^{-1}\) in the Guinea Savanna zone of Ghana (Table 1). The soil \( P_{av} \) yielded a significant \( (P < 0.05) \) interaction between community and land use type. The \( P_{av} \) in the PA was significantly higher \( (P < 0.05) \) than in the FL and FA across the various communities (Table 1).
Table 1. Effect of land use type on selected physicochemical properties of soils in three communities in the Guinea Savanna zone of Northern Ghana

| Treatment Community | Landuse type | pH   | SOC (%) | TN (%) | P<sub>av</sub> (mg kg<sup>-1</sup>) | Extractable bases (cmol kg<sup>-1</sup>) | ECEC | Particle size distribution % |
|---------------------|-------------|------|---------|--------|---------------------------------|---------------------------------|------|-----------------------------|
|                     |             |      |         |        |                                 | Ca               | Mg  | K     | Sand | Silt | Clay | Texture |
| Mognori             | PA          | 6.66<sup>a</sup> | 1.10<sup>a</sup> | 0.17<sup>a</sup> | 6.75<sup>a</sup> | 3.14<sup>a</sup> | 1.18<sup>a</sup> | 0.50 | 6.10<sup>ab</sup> | 70.74 | 17.89 | 3.56 | SL      |
|                     | FL          | 6.16<sup>b</sup> | 0.42<sup>c</sup> | 0.08<sup>b</sup> | 5.87<sup>b</sup> | 3.30<sup>cd</sup> | 0.97<sup>bc</sup> | 0.29 | 5.70<sup>cd</sup> | 69.82 | 18.34 | 3.84 | SL      |
|                     | FA          | 5.52<sup>d</sup> | 0.24<sup>d</sup> | 0.05<sup>d</sup> | 5.33<sup>c</sup> | 3.42<sup>bc</sup> | 0.86<sup>ab</sup> | 0.16 | 5.48<sup>ab</sup> | 70.62 | 17.75 | 3.82 | SL      |
| Jagbo               | PA          | 6.27<sup>b</sup> | 0.70<sup>b</sup> | 0.13<sup>b</sup> | 4.12<sup>d</sup> | 3.46<sup>bc</sup> | 1.10<sup>a</sup> | 0.42 | 6.22<sup>ab</sup> | 34.60 | 40.31 | 7.74 | SL      |
|                     | FL          | 6.12<sup>b</sup> | 0.27<sup>d</sup> | 0.04<sup>d</sup> | 2.87<sup>a</sup> | 3.54<sup>b</sup> | 0.59<sup>bc</sup> | 0.12 | 6.08<sup>b</sup> | 33.22 | 41.44 | 7.34 | SL      |
|                     | FA          | 5.50<sup>d</sup> | 0.22<sup>ab</sup> | 0.04<sup>d</sup> | 2.94<sup>f</sup> | 2.28<sup>f</sup> | 0.45<sup>a</sup> | 0.33 | 5.64<sup>cd</sup> | 35.08 | 40.29 | 7.24 | SL      |
| Tugu                | PA          | 6.08<sup>bc</sup> | 0.74<sup>b</sup> | 0.12<sup>b</sup> | 4.98<sup>e</sup> | 4.18<sup>f</sup> | 0.60<sup>bc</sup> | 0.23 | 6.32<sup>a</sup> | 66.12 | 19.57 | 5.78 | SL      |
|                     | FL          | 5.82<sup>e</sup> | 0.27<sup>d</sup> | 0.03<sup>bc</sup> | 1.29<sup>f</sup> | 2.66<sup>f</sup> | 0.58<sup>bc</sup> | 0.16 | 5.78<sup>a</sup> | 67.90 | 18.59 | 5.34 | SL      |
|                     | FA          | 5.28<sup>d</sup> | 0.14<sup>e</sup> | 0.01<sup>e</sup> | 1.11<sup>e</sup> | 2.30<sup>f</sup> | 0.49<sup>a</sup> | 0.07 | 5.40<sup>d</sup> | 69.70 | 17.47 | 5.20 | SL      |
|                     | SE          | 0.015 | 0.000   | 0.015 | 0.000 | 0.000 | 0.001 | 0.995 | 0.001 | 0.624 | 0.902 | 0.338 | SL      |

Means in the same column followed by the same letter are not significantly different at p ≤ 0.05; SOC = soil organic carbon, TN = soil total nitrogen, P<sub>av</sub> = available phosphorus, Ca = calcium, K = potassium, ECEC = effective cation exchange capacity, cmol (+) kg<sup>-1</sup>, BD = bulk density, SL = Sandy loam, SiL = Silty loam. PA = Protected Area/forests, FL = Fallow land and FA = farmlands.
In addition, the land use type significantly (P = 0.01) influenced extractable bases of soil in each community except extractable K which was 0.07−0.50 cmol kg⁻¹ (Table 1). Generally, PA and FL tended to have higher content of the extractable bases than the FA, except for calcium (Ca) which recorded a higher (P = 0.003) content in the Mognori PA than the FA or FL but PA and FL were similar in both Jagbo and Tugu communities (Table 1). For instance, the Ca content ranged from 2.28 cmol kg⁻¹ in the Jagbo FA to 4.18 cmol kg⁻¹ in the Tugu PA while magnesium (Mg) was from 0.49 cmol kg⁻¹ in the Tugu FA to 1.18 cmol kg⁻¹ in the Mognori PA, however, Mg was similar in PA and FL in Tugu community (Table 1).

On the soil ECEC, the values ranged from 5.40 to 6.32 (cmol c/kg), with the PA having higher values than those of FL and FA, but there was no significant difference between the values for PA in Jagbo and Tugu communities (Table 1).

Generally, the sand proportions were higher than the other soil separates across the communities except in Jagbo where the silt proportion appeared to be slightly higher than the sand proportion. The sand proportion ranged between 37.03% in Jagbo and 76.28% in Mognori (Figure 2). The proportion of silt in Jagbo was also higher than that of clay across the various communities and it ranged between 18.15% and 40.23%. The proportion of clay was the least across the various communities and it also ranged between 3.63% and 20.77%. The textural class at Mognori and Tugu were sandy-loam (SL) while that of Jagbo was silty-loam (SiL) (Table 1 and Figure 2).

3.2. Physicochemical properties of soils at different depths under different land use types

Soil depth in the various land use type significantly (P < 0.05) influenced all the soil physicochemical properties, except ECEC, BD and the clay content (Table 2). The soil depth × land use type interaction had varied influence on the SOC content and TN. For instance, there were no significant differences in the SOC under the different land use types at depths of 15–30 cm and 30–45 cm but at soil depth of 0–15 cm, the SOC of PA was significantly (P < 0.05) higher than that of the FL and FA (Table 2). The SOC at 0–15 cm depth in the PA was 1.20% which decreased to 0.03% at the depth of 30–45 cm in the FA. In addition, at soil depth of 0–15 cm, soil TN content of PA was significantly higher than in the FL and FA but the TN content did not differ at the soil depths 15–30 and 30–45 cm across the land use types (Table 2).
Table 2. Effect of soil depth on selected physicochemical properties of soils under three land use types in the Guinea Savanna zone of Northern Ghana

| Soil depth (cm) | Land use Type | SOC (%) | TN (%) | \(P_{av}\) | Ca | Mg | K | EA | ECEC | BD | Sand | Silt | Clay |
|----------------|--------------|---------|--------|------------|----|----|----|-----|-----|-----|------|------|------|------|------|
| 0–15           | PA           | 1.20^a  | 0.08^a | 11.92^a   | 3.38^a | 0.66^cd | 0.20^bc | 0.21^ab | 5.73 | 1.34 | 76.28^a | 18.15^d | 3.63 |
|                | FL           | 0.45^b  | 0.05^b | 7.60^b    | 3.12^a | 0.68^cd | 0.24^ab | 0.27^a  | 5.22 | 1.44 | 76.30^a | 17.96^d | 3.63 |
|                | FA           | 0.38^bc | 0.04^bc | 7.41^bc  | 3.42^a | 0.86^bc | 0.30^a  | 0.19^bc | 5.10 | 1.53 | 76.67^a | 17.85^d | 3.91 |
| 15–30          | PA           | 0.25^cd | 0.04^cd | 6.41^b   | 2.32^bc | 0.58^a  | 0.18^ab | 0.16^bc | 4.98 | 1.39 | 59.7^a   | 22.33^c  | 16.67 |
|                | FL           | 0.12^de | 0.02^de | 3.66^c   | 2.38^b  | 0.90^f  | 0.10^d  | 0.11^bc | 4.70 | 1.52 | 56.2^b   | 23.93^c  | 17.25 |
|                | FA           | 0.10^de | 0.02^ce | 3.30^cd  | 2.40^b  | 1.02^d  | 0.22^c-c | 0.11^bc | 4.76 | 1.60 | 53.9^c   | 26.15^b  | 18.56 |
| 30–45          | PA           | 0.14^de | 0.02^ce | 2.67^cd  | 2.01^c  | 0.98^f  | 0.14^cd | 0.07^c  | 3.12 | 1.50 | 37.03^d  | 40.23^a  | 20.77 |
|                | FL           | 0.07^e  | 0.01^e  | 2.80^cd  | 1.60^f  | 1.06^db | 0.10^f  | 0.11^c  | 2.77 | 1.58 | 39.33^d  | 38.00^a  | 21.53 |
|                | FA           | 0.03^g  | 0.01^g  | 1.72^d   | 1.59^d  | 1.26^a  | 0.10^d  | 0.10^c  | 2.86 | 1.69 | 37.49^d  | 40.33^a  | 22.44 |
| p-value        |              | 0.000   | 0.014   | 0.000    | 0.003   | 0.023   | 0.001   | 0.030   | 0.090 | 0.853 | 0.008    | 0.004    | 0.06   |
| SE             |              | 0.06    | 0.005   | 0.04     | 0.10    | 0.05    | 0.02    | 0.02    | 0.2   | 0.02 | 1.61     | 0.96     | 0.49   |

Means in the same column followed by the same letter are not significantly different at p ≤ 0.05; % OC = percentage organic carbon, TN = total nitrogen, \(P_{av}\) = available phosphorus, Ca = calcium, K = potassium, EA = exchangeable acidity, ECEC = effective cation exchange capacity, cmol (+) kg\(^{-1}\), BD = bulk density. PA = Protected Area/forests, FL = Fallow land and FA = farmlands, SE = Standard error.
3.3. Relationship between selected physical and chemical properties of soil at 0-45 cm depth under different Land use types

Pearson’s product moment correlation coefficients were computed to relate the selected soil parameters to one another (Table 3). Soil depth showed strong significant but negative correlation with $P_{av}$ ($r = -0.83$, $P = 0.000$), TN ($r = -0.71$, $P = 0.000$), SOC ($r = -0.72$, $P = 0.000$) and ECEC ($r = -0.89$, $P = 0.000$) and also correlated positively but strongly with clay ($r = 0.92$, $P = 0.000$) and moderately with soil bulk density ($r = 0.45$, $P = 0.000$).

SOC also showed strong significant correlation with $P_{av}$ ($r = 0.86$, $P = 0.000$) and TN ($r = 0.82$, $P = 0.000$) but moderately with pH ($r = 0.59$, $P = 0.000$).

There was also a strong significant correlation between TN and $P_{av}$ content of the soil ($r = 0.87$, $P = 0.000$). The clay content correlated strongly but negatively with $P_{av}$ ($r = -0.85$, $P = 0.000$), TN ($r = -0.73$, $P = 0.000$), SOC ($r = -0.74$, $P = 0.000$), ECEC ($r = -0.77$, $P = 0.000$) and a moderate correlation with pH ($r = -0.44$, $P = 0.000$).

4. Discussion

Land use and management practices have a significant impact on the physiochemical properties of soils and are usually considered to be among the main threats to soil quality (Panday et al., 2019; Zajícová & Chuman, 2019). Our objective in this study was to assess how different land uses such as lands considered PA, FA and FL influenced the soil physiochemical properties of three communities in the Guinea Savanna Zone of Northern Ghana. Such land use types are known to induce changes in nutrients availability and play a critical role in sustaining soil quality and crop productivity (Emadi et al., 2008; Shehu et al., 2016).

Our result showed that the soil pH under the land use types ranged from 5.2 to 6.6 with decreasing values at lower soil depth in all locations (Table 1).

The pH values fall within the range (5.5–6.5) where most nutrient element are usually available for plants uptake (Hazelton & Murphy, 2016) and also consistent with previous studies in Northern Ghana (Rahman et al., 2019). The decreased pH (from 6.19 to 5.86) at lower soil depth suggests that most of the extractable bases were leached from the top layers of the soil, making acidic cations to dominate the exchange complex as the depth increased. Kugbe and Zakaria (2015) and Fetene and Amera (2018) also found a strong and positive relationship between pH and basic cations which usually increases soil pH from top to down the soil profile. In addition, the highest soil pH was in the PA and it decreased in the FL and FA, giving an indication that land use changes from forest to crop land can lead to reduction of soil pH due to the depletion of basic cations in crop harvest or immobilization of the exchangeable bases. This observation varied with previous

| Variables | Ph  | $P_{av}$ | TN  | % SOC | ECEC | Clay | BD |
|-----------|-----|----------|-----|-------|------|------|----|
| $P$       | 0.578*** |         |     |       |      |      |    |
| TN        | 0.541*** | 0.879*** |     |       |      |      |    |
| %SOC      | 0.596*** | 0.865*** | 0.822*** |      |      |      |    |
| ECEC      | 0.355**  | 0.764*** | 0.642*** | 0.628*** |      |      |    |
| Clay      | -0.449*** | -0.858*** | -0.734*** | -0.748*** | -0.775*** |      |    |
| BD        | 0.252ns  | -0.209ns  | -0.113ns  | -0.084ns  | -0.409**  | 0.454*** |    |
| Depth     | -0.384**  | -0.838*** | -0.712*** | -0.727*** | -0.893*** | 0.929*** | 0.454*** |

Asterisks denote statistical significance of correlations: ** $P < 0.01$, *** $P < 0.001$ and ns = non-significance.
suggestions by Abbasi and Tahir (2012) that farmers use of organic source of manure or decomposition of waste in FL and FA land use types increase the soil pH.

The soil organic matter content (SOC) was higher in the PA than the FL and FA, with decreasing amounts at lower soil depth (Table 1 and 2). Cultivated lands are generally known to have lower SOM content than forest or protected lands because harvests decrease its inputs to soil (Zhu et al., 2012).

Moreover, large quantities of litterfall, plants debris and decaying roots are usually found in the surface soils in PA land use system, thus, there is a high tendency to have decomposition and the addition of SOC than FL and FA systems. Earlier researchers have reported higher SOC in forested/protected lands than cultivated land use type (Bizuhoraho et al., 2018; Fetene & Amera, 2018; Zajícová & Chuman, 2019) and on upper surface soil (Takele et al., 2014). The lower SOC content in FA and FL could also indicate that longer period of time is required to build the SOC of FL and FA land use systems, especially in high temperature regions. For instance, the Guinea Savanna Zone of Northern Ghana is characterized by high (36–40°C) temperatures during off-seasons when vegetation cover is reduced (Owoade et al., 2021). Thus, the partial exposure of soil to such high temperature under both FL and FA can increased waste decomposition and mineralization which reduces SOC.

The total N (TN) in the PA, FL and FA was lower than the critical N concentration (0.15% N) level for crop requirement in the Guinea Savanna Zone of Northern Ghana (Atakora et al., 2019) except for PA in Mognoi community. Comparing our result to the findings of Bizuhoraho et al. (2018) shows similarities on the differences observed in TN among the land use systems (forest, cultivated and farmland), however, contrary to Bizuhoraho et al. (2018) who reported that farmland had the highest TN followed by forest, our result showed the reverse. Similarly, TN decreased with increasing soil depth, for example, the mean TN in the top layer of soil was more than twice the value recorded for 15–30 cm depth, and more than three times the value for 30–45 cm in each of the land use types. This confirms Emadi et al. (2008) findings of a reduced SOC and TN at 10–20 cm compared to 0–10 cm. Based on the above observation, we speculate that the positive relationship ($r = 0.822$) established between SOC and TN (Table 3) could be due to large amount of biomass and other plant debris that remain in the top surface soil compared to the lower soil depths.

On the available phosphorus in soils under all the land uses and at different soil depths (Table 1 and 2), the concentration level was below the threshold of 11 mg/kg suggested by Adeoye and Agboola (1985). This may not be too surprising has soils in the study area was moderately acid (Table 1 and 2) and this causes P-fixation (Tellen & Bernard, 2018). In addition, our result differs from previous works by Aytenew and Kibret (2016b) and Chemada et al. (2017) who reported higher available P in cultivated land than forest/protected lands, however, we agree with Takele et al. (2014), Tufa et al. (2019), and Tellen and Bernard (2018) where higher available P was obtained in forest land compared to cultivated land, even at soil depth of 0–10 cm, 10–20 cm and 20–30 cm.

The extractable bases decreased with increasing depth except for the magnesium content which appeared to increase with increasing depth, which is consistent with other reports (Kugbe & Zakaria, 2015; Tanko, 2018). Contrary to the result of Fetene and Amera (2018), exchangeable Ca and Mg were affected by the land use type (Table 2). These magnesium levels recorded in the study could be classified as low to moderate according to the levels suggested by Metson (1961).

Even though Fetene and Amera (2018) observed similar pattern of exchangeable Ca and Mg in forest and cultivated land, they associated it to the increase of clay particles in the soil sub surface. However, differences in our study could be due to the sandy-loam and loamy-sand soil in our selected sites (Table 2). Therefore, we suggest that magnesium content of the soils has been strongly leached to lower depths due to the loosely held acidic sandy soils with very low levels of exchangeable bases including magnesium and calcium. Generally, the soil concentration level of
both Ca and Mg in all the three land use systems in the three selected communities were higher (Table 1) than their critical levels of 0.2 cmol/kg and 0.5 cmol/kg (Tellen & Bernard, 2018) respectively.

Finally, the soil K⁺ levels were significantly higher than the critical K⁺ concentration of 0.12 cmol/kg soil required for plant growth (Tellen & Bernard, 2018) and the K⁺ content of the soils was affected by the different land use system. FA had the highest K level contrary to the findings of Fetene and Amera (2018) and Duguma et al. (2010) where exchangeable K content was higher in the forest/protected land and low in the cultivated land. Such a difference could be due to the high ash content of the soil in the study area since many authors (Amoako et al., 2018; Ochire-Boadu et al., 2020b) have previously indicated that slash and burn method is widely used during land preparation in the Guinea Savanna Zone of Northern Ghana.

In respect to the soil physical properties, Javad et al. (2014) and Ayele et al. (2013) indicated that it can be used as an indicator for evaluating soil degradation under different land use systems and this consequently influences the availability of essential nutrients for plants uptake.

Considering that most of the soil physiochemical properties and nutrients that support crop growth had their critical concentrations levels within the soil depth of 0–15 cm (Table 2), it will be prudent for farmers to cultivate crops with shallow rooting system in order to maximize the current soil condition.

Generally, the particle size distribution showed a relatively higher proportion of sand and low proportions of clay in both Mognori and Tugu communities and rather high proportions of silt and clay in the Jagbo community (Figure 2).

The soils in the Mognori and Tugu communities were classified as sandy-loam but that of Jagbo was classified as silty-loam. The high proportion of sand can be ascribed to the fact that lands/soils of Guinea savanna zone of Northern Ghana usually have little soil cover and organic matter, thus, most of the finer particles of the soil could have been washed away by erosion or leached to deeper soil layer resulting in the sandy texture of the soil, especially under the FA land use type. For example, Fetene and Amera (2018) and Chemada et al. (2017) observed that the higher sand and lower clay fraction in cultivated land most likely arise from disturbance during plowing and selective removal of clay particles by erosion leaving behind the sand fractions. Previous studies (Abubakari et al., 2012; Kugbe & Zakaria, 2015) within the Northern part of Ghana where our communities were selected found similar result.

In addition, the soil texture had an influence on the fertility status of the soils in the three locations, for instance, CEC is an important way to measure the capacity of the soil to supply nutrient cations to the soil solution for plant uptake (Petersen et al., 1996), thus, soils with high CEC retain more nutrients than low-CEC soil. Our result suggests that the texture of the soil in each land use type influenced the CEC (Table 1). For instance, soil texture in Mognori and Tugu communities was sandy-loamy and their CEC was similar and lower than Jagbo community which soil texture was silty-loam (Table 1). This could be attributed to the fact that the fine-textured silty-loam soils have more soil particle surface area, so their CEC is greater (Fooladmand, 2008; Petersen et al., 1996). In addition, it proved that soil texture and CEC are closely related and can be used to make predictions about each soil property (Fooladmand, 2008; Mokhtari Karchegani et al., 2011).

Moreover, unlike the findings of Fetene and Amera (2018) where soil bulk density (BD) was significantly affected by land use (forest, cultivated and grazing), but not with soil depth (0–20, 20–40), we found that both land use type and soil depth influenced the BD of the soils in all the selected communities (Table 2). Our result was also within the productive BD (1.1 to 1.5 g/cm3) of natural soils (Kolay, 2000).
PA had the lowest bulk density while FA had the highest. This may be associated with the use of tractors and animal traction during land preparation method in the Guinea savanna zone of Northern Ghana, thereby causing compaction of the top soil. This is further explained by the fact that, among the land use types, the BD increased with soil depth, with both 0–15 cm and 15–30 cm depth being similar but lower than soil depth at 30–45 cm.

Lastly, among the physiochemical properties, BD was not significantly different except for ECEC, but was negatively \( (r = -0.40) \) correlated (Table 3). This observation could be attributed to the frequent fire outbreak and low soil tillage which is characteristic of the Guinea Savanna region of Northern Ghana (Amoako et al., 2018), thus, making the SOM lower while bulk density is less disturbed. Tanveera et al. (2016) reported a positive correlation between sandy soil and the soil BD \( (r = 0.60) \) while clay content was negatively \( (r = -0.41) \) correlated with BD. In the present study, two sites had sandy-loam while one site had silty-loam. Such varied results are not uncommon in literature (Sakin et al., 2011) and usually attributed to the soil type and soil sampling depth.

5. Conclusions
The study established that both land use type and soil depth influenced the physicochemical properties of soils in the Guinea Savanna zone of Northern Ghana. The soil fertility in the continuously cultivated farm area (FA) was considerably lower than the protected area (PA) and fallow land (FL) and this decreased with soil depth. Such a gradual deterioration of the physical and chemical properties of farm area (FA) has consequential impact on the livelihoods of the rural communities since majority of them depend on Agriculture as source of livelihoods and this could ultimately make them more impoverished.

In addition, the current situation could pose a threat to most protected areas (PA) since lack of productive agricultural lands could trigger increased encroachment on the existing protected areas and sacred groves leading to deforestation and further worsening the depleted land and soil cover in the Guinea savanna zone of Northern Ghana.

To maximize the current soil condition, it is recommended that farmers within the zone cultivated crops that have shallow roots, within 0–15 cm soil depth, since the physiochemical soil properties that support crop growth and most of the essential nutrients had their critical concentrations levels within that soil depth. Finally, urgent need for intensive use of enriched organic manure is needed to improve the organic matter content of the soils as well as the nutrients.

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Data availability statement
Data related to the study will be made available by the corresponding author upon request.

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