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Full Length Research Paper

Comparative studies of soil characteristics in Shea parklands of Ghana

Abubakari A. H., Nyarko G., Yidana J. A., Mahunu G. K., Abagale F. K., Quainoo A., Chimsah F. and Avornyo V.

Faculty of Agriculture, University for Development Studies (UDS), Tamale, Box TL 1882, Tamale, Ghana.

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An assessment of soil physical and chemical properties was carried out in Shea parklands of northern Ghana, selected along a North-south climatic gradient in 2011. The study sites were Paga, Nyankpala and Kawampe, which are located in the transitional and Guinea savannah zones of Ghana. For each site, 9 fallows and 9 cultivated fields were used, a total of 18 plots per site. Soil samples were collected at a depth of 0 to 30 cm and analysed for particle size distribution, pH, organic matter (OM), nitrogen (N), phosphorus (P), exchangeable bases, exchange acidity and effective cation exchange capacity (ECEC). The results revealed that the soils were strongly acid to neutral in reaction. The soils at Nyankpala parkland were comparatively more acidic (pH < 6). Generally, the pH values recorded were within the desirable range for plant nutrient availability. Levels of, OM, ECEC, and total exchangeable bases (TEB) were very low, and varied across the parklands, with Nyankpala parkland showing higher levels of OM and ECEC. In spite of the low pH, the soils were highly base saturated (PBS > 80%) and deficiencies of basic cations were uncommon. Land use did not significantly influence the soil chemical properties. However, N values, were significantly higher in old fallows than in respect of new fallows and cultivated fields. Soil particle size distribution especially at Nyankpala was significantly influenced by land use, with fallow lands having more proportion of sand than that of cultivated fields. The extremely low P content (trace – 7.11 mg/Kg) of the soils might be due to P fixation which was commonly reported for soils in northern Ghana. However, if these soils were supplied with N fertilizers, seedling regeneration would be promoted due to the fact that increasing N levels and decreasing P levels in soil, results in significant increase in seedling dry weight as well as increasing uptake of total shoot N and C.

Key words: Shea tree, soil properties, land use, Shea parkland.

INTRODUCTION

The Shea tree, (*Vitellaria paradoxa*) is a tree species growing extensively in the agroforestry parklands of semi-arid Africa zone from Senegal to Uganda, where it is protected and managed (Hall et al., 1996; Maranz et al., 2004). The dried nut from the tree is used for the production of edible vegetable fat, medicinal and personal care products. The tree is therefore very important in the rural health care and the rural economies in the sudano-sahelian regions of Africa.

The distribution of the Shea tree in the savannah parkland is affected by climatic and soil factors. Critical soil factors affecting the distribution of the Shea tree appears to be soil physical and chemical properties either acting independently or in combination. An analysis of soil physical and chemical properties in shea parklands would therefore provide the necessary information that could be correlated with tree characteristics to study the distribution and the dynamics of the Shea tree in the savannah ecology of Ghana.

Most of the Shea parklands of Ghana fall within the Guinea Savannah ecological zone, which is associated with total annual rainfall of about 1,000–1,300 mm/annum, while Sudan Savannah normally records precipitation below 1,000 mm/annum (MoFA, 2011). Rainfall distribution is highly variable and therefore the regions have more distribution of small irrigation dams than any other parts in Ghana.

The nature of soils in any particular area depends on

*Corresponding author. E-mail: halim7us@yahoo.com.

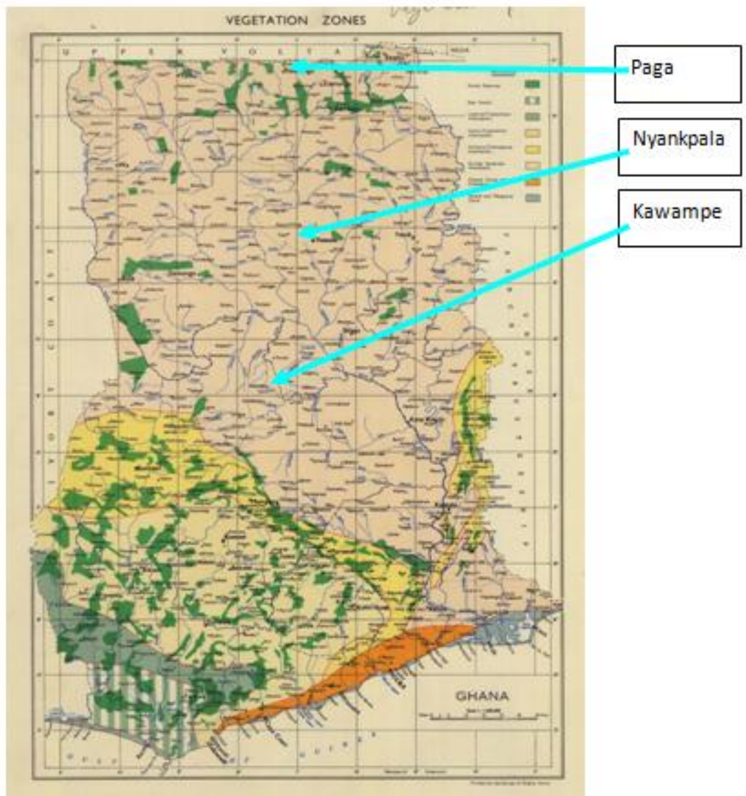

Figure 1. Map of vegetation zone in Ghana, with study locations highlighted.
Source: Wageningen University (2004).

the geological processes that led to formation of rocks and the subsequent weathering of such rocks. The soils of the Guinea Savannah part of the parklands are exhausted from extensive farming and over grazing. According to Braimoh (2004), the soils consist mainly of savannah ochrosols and groundwater laterites formed over granite and Voltaian shales. The declining soil fertility of northern Ghana is leading to increasing agricultural intensification which results in more exploitation of primary woodlands (Duadze, 2004). Soil characteristics and rainfall pattern combine to influence vegetation cover and land use pattern over time.

Cropped areas are weaved into settlements around, Navrongo, Bolgatanga and Paga. Farm areas include bush and compound farms including few isolated agro-forestry parks and few protected economic trees. In general tree populations in these areas are low as a result of extensive farming, wood extraction and over grazing. Most occurring tree species that are scattered and usually protected include *Vitellaria paradoxa, Parkia biglobosa, Acacia albida, Anogeissus leiocarpus, Adansonia digitata* (baobab), *Tamarindus indica, Mangifera indica* and *Ceiba pentandra*. These tree species appear to have a higher rate of regeneration and may be more resistant to the annual bush fires (MoFA, 2011). The soils in this shea parkland are varied because of the different geological materials and processes that served as the basis for their formation. The physical, biological and chemical composition of the soils have also undergone drastic changes over the last three decades owing to diverse and changing land uses that characterizes savannah landscapes. This therefore underscores the need for information on the physical and chemical characteristics of soils across the Shea parkland of Ghana. The objectives of the study were therefore to assess the effect of geographical gradient and land use history on soil physical and chemical properties in the Shea parkland.

METHODOLOGY

Three sites - Paga, Nyankpala and Kawampe were selected to represent each of the three geographic gradients (North, Middle and Southern) that constitute the Shea parkland, following the north-south gradient using climatic index of Ghana. Thus one site (Paga) is located in the northern limit of Shea tree distribution; Nyankpala is in the middle and Kawampe in the southern part of its distribution. The study sites are illustrated in Figure 1. For each site, 3 fields which have been left fallow for 1 to 5 years (New fallow); 6 to 10 years (Medium fallow) and more than 10 years (Old fallow); and 3 fields under cultivation for 1 to 5 years (New field); 6 to 10

Table 1. Selected chemical and physical properties of the soils at different geographical locations in the Shea Parkland.

Geographical gradient	pH	OM (%)	N (%)	P (mg/kg)	Extractable cations Ca	Mg	K	Na	TEB	Ex. acid	ECEC	PBS	Particle size distribution (%) Sand	Silt	clay	Texture
Kawampe	6.5	1.2	0.1	7.1	3.4	1.4	0.2	0.4	Trace	0.1	5.7	97.4	70.8	25.7	3.3	Sandy loam
Nyankpala	5.8	1.3	0.1	1.4	3.0	1.7	0.2	0.4	Trace	0.3	5.8	93.3	34.7	57.7	7.4	Silt loam
Paga	6.0	0.8	<0.1	1.7	2.5	1.6	0.2	0.4	Trace	0.2	5.1	93.6	68.3	26.0	5.6	Sandy loam
F-pr	<0.001	<0.001	0.004	<0.001	0.022	0.543	0.220	0.740	0.285	0.004	0.313	0.020	<0.001	<0.001	<0.001	
SED	0.146	0.121	0.007	0.818	0.299	0.277	0.020	0.044	0.527	0.135	0.515	1.561	4.407	1.840	0.618	
Df	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	
Rep	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	

(Medium field) years and more than 10 years (Old field) were selected as representative of the area, giving a total of 18 plots. This was replicated 3 times in each site and thus a total of 54 plots were selected. Soil samples were collected at a depth of 15 to 30 cm. The samples were air dried for physical and chemical analyses to determine texture, pH, total Carbon, total nitrogen, total and available phosphorus, total and available potassium, and effective cation exchange capacity (ECEC).

Physical analysis

Particle size distribution was determined using the Bouyoucos Hydrometer method as modified by Day (1965).

Chemical analysis

pH (1:1 H_2O)

The soil pH was determined in water with a glass electrode at a soil to water ratio of 1:1. The extractable bases were determined by the Ammonium acetate (NH_4OAc) method using neutral 1M NH_4OAc pH 7 solution. Calcium (Ca) and magnesium (Mg) contents were determined using EDTA titration, while sodium (Na) and potassium (K) were determined by flame photometer.

The exchange acidity

The exchange acidity was determined by Mehlich's barium chloride-triethanolamine extraction, buffered at pH 8.2 (Mehlich, 1938). The soil was leached with an unbuffered salt solution (1M KCl solution) and Al in the leachate measured by titration (Coleman et al., 1959; Lin and Coleman, 1960; Mc Lean, 1965).

Effective cation exchange capacity (ECEC)

Effective Cation Exchange Capacity (ECEC) was calculated by sum of the acidic and basic cations.

Percentage base saturation (PBS) and Exchangeable sodium percentage (ECEC)

Percentage base saturation (PBS) was derived by expressing the total extractable bases (TEB) as a percentage of the ECEC, while exchangeable sodium percentage (ESP) was calculated by expressing extractable sodium as a percentage of the ECEC.

Organic matter

Organic carbon content of the soil was determined using the Walkley and Black (1935) procedure. Organic carbon content was converted to organic matter content by multiplying the organic carbon values with 1.824 Van Bemmelen factor.

Available phosphorus

Available phosphorus was determined using the Bray 1 procedure (Bray and Kurtz, 1945).

Exchangeable potassium

The ammonium acetate procedure was used to determine the amount of Potassium of the soil.

Data analysis

Data was subjected to analysis of variance (ANOVA) using Genstat (Discovery Edition 3) statistical package and treatment means were compared using the standard error of difference (SED) at 5%.

RESULTS

There were no significant (NS) differences in the interactive effect of geographical gradient, land use class and land use history. There were some significant differences in the interaction between land use class and land use history on selected soil chemical properties as well as in the interactive effect of land use class and geographical location on soil texture shown in Tables 1 and 2.

As shown in Table 1, significant differences were observed in all the selected soil chemical properties except CEC, TEB, PBS and the

Table 2. Selected chemical and physical properties of soils in different land use types in the Shea Parkland.

Land use history	pH	OM (%)	P (mg/kg)	Extractable cations				Ex.	ECEC	PBS	Particle size distribution (%)			
				Ca	Mg	K	Na	acid			Sand	Silt	Clay	Texture
New fallow	6.1	1.2	1.7	3.1	1.7	0.2	0.4	0.2	5.9	95.5	58.8	34.2	6.9	Sandy loam
Medium fallow	6.0	0.9	1.8	2.6	1.2	0.1	0.4	0.2	4.7	94.3	57.2	37.8	4.9	Sandy loam
Old fallow	6.3	1.4	6.0	3.5	1.6	0.28	0.6	0.2	6.4	95.8	58.1	35.7	6.0	Sandy loam
New field	6.1	1.0	2.9	2.7	1.4	0.2	0.4	0.2	5.1	94.8	57.4	37.4	5.1	Sandy loam
Medium field	6.0	1.1	2.9	3.0	2.0	0.2	0.4	0.2	6.0	93.9	58.7	35.8	5.3	Sandy loam
Old field	6.1	1.0	5.2	2.9	1.5	0.2	0.4	0.2	5.3	94.4	57.6	37.9	4.4	Sandy loam
F-pr	0.611	0.057	0.400	0.187	0.790	0.160	0.060	0.837	0.063	0.944	0.777	0.339	0.160	
SED	0.206	1.079	1.160	0.423	0.390	0.028	0.060	0.093	0.729	2.207	3.067	2.602	0.874	
Df	34	34	34	34	34	34	34	34	34	34	34	34	34	
Rep	9	9	9	9	9	9	9	9	9	9	9	9	9	

extractable bases. The results indicate that soils in Shea parklands of Nyankpala are slightly acidic (5.8), have higher %OM (1.3), than the soils at Kawampe and Paga. The soils at Nyankpala also had higher Exchange acidity (0.37) compared to those at Kawampe. Soils at Kawampe were found to have the highest PBS (97.49) than those at Nyankpala and Paga. The results further indicate significant differences in soils at all locations with respect to %N, P and Ca. There were no significant differences in soils at all the locations with reference to Mg, K and Na. Soils at Nyankpala had the highest amount of N (0.65 %), whilst soils at Kawampe recorded the highest levels of P and Ca. Paga recorded the lowest values of all the parameters measured.

The effect of interaction between land use and land use history on selected soil chemical properties are shown in Table 2. The results indicate no significant differences between land use and land use history interaction with respect to selected chemical properties (pH, Base saturation, OM, OC, CEC, Exchange acidity and TEB).

There were also no significant differences in the interactive effect of geographical gradient and land use history on soil chemical properties. However, there was a significant effect of land use history on soil N as shown in Figure 2. Figure 2 indicates NS difference in nitrogen content between new fallow and new cultivated land as well as medium fallow and medium cultivated land.

There were no significant differences in the interactive effect between land use and land use history on soil particle size. Cultivated fields at Nyankpala contain more silt (61.04%) compared to 54.54% for fallow field in the same location, though this was not significant. The distribution of silt in fallow land and cultivated field at both Kawampe and Paga was quite similar. There was no significant variation in the clay contents in fallow land and cultivated land in all the locations. This is illustrated in Figure 3.

DISCUSSION

The location of Shea parklands had significant effect on soil physical and chemical properties irrespective of the land use class and the land use history. This is obvious from the variations in the levels of pH, OC, OM, CEC and exchange acidity of the Shea parkland studied. Differences in soil physical properties are expected as those parklands are located in different agro ecological zones with different geological formation and different land use systems. The values of the soil chemical properties obtained at Nyankpala and Kawampe were slightly higher than values reported for soil in the Volta river basin of mainland Ghana, which is covered mainly by the Guinea and Sudan savannah agro ecological zones (Braimoh, 2004; Compaore, 2006; Duadze, 2004). Braimoh (2004) reported that soils of the guinea savannah part of the Volta river basin have PBS between 60 to 90% and mean effective CEC of 4.42. This was attributed to the Ca as the dominant exchangeable cation as well as the effect of clay mineralogy. In general, the pH reported for the three parklands in this study could be described as mild to neutral pH and this is ideal for most crops (MSU extension, 2011). The

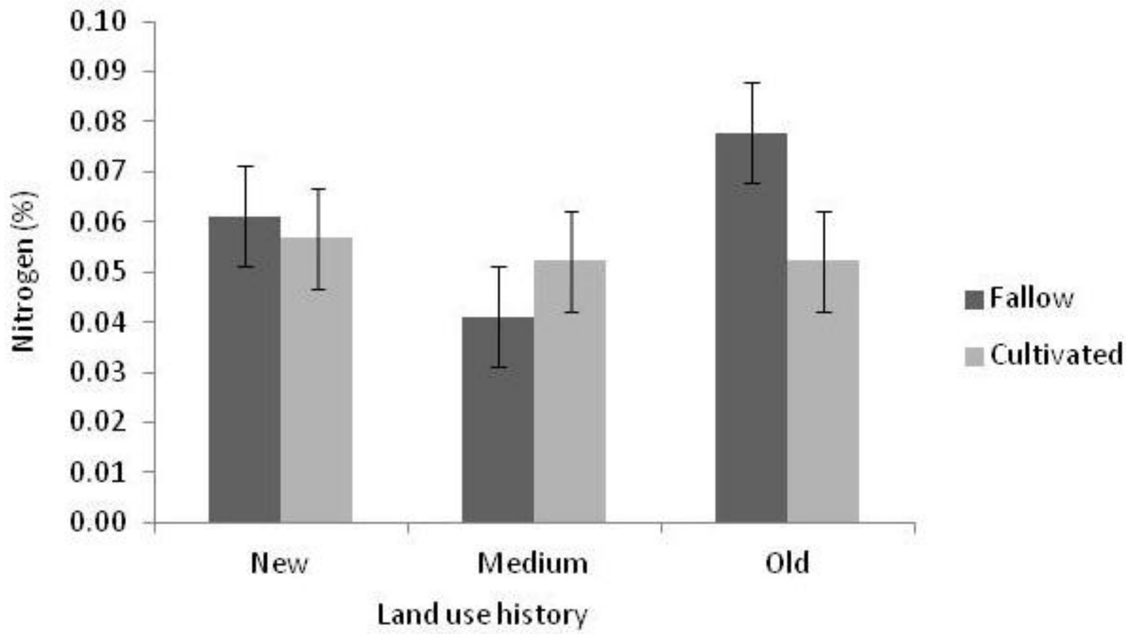

Figure 2. Effect of the interaction between type of land Use and Age of land Use e on soil nitrogen level (bars represent SED).

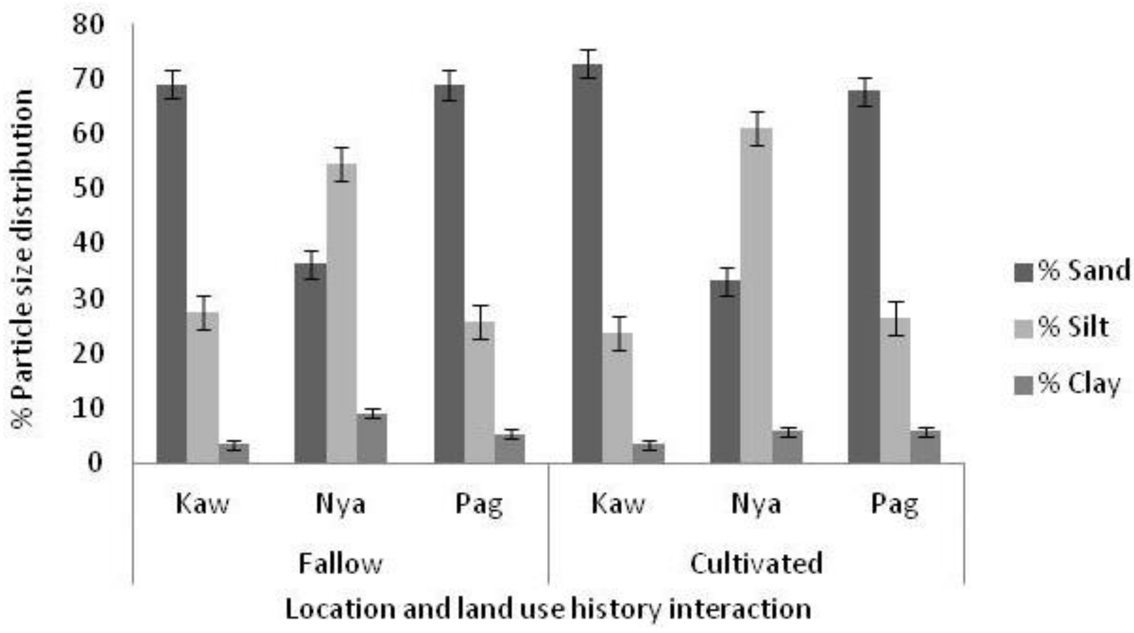

Figure 3. Effect of the interaction between type of land Use and location on soil Particle Size Distribution (bars

soils at Nyankpala are however slightly acidic compared to others and this could result in toxicity of some elements such as Al, Co, Cu, Fe, Mn and Zn and deficiency of other elements (such as Ca, K, Mg, N and P) (Compaore, 2006). The ECEC values less than 4 and TEB values less than 20 are considered as very low and may be indicative of nutrient stress soils. As shown in Table 1, the ECEC and TEB obtained at all the locations and especially the TEB value at Paga may be indicating soils of declining nutrient reserves. Mean organic carbon levels for soils in the guinea savannah are reported to be 0.3 to 0.5% (Braimoh, 2004; MOFA, 2011). The values obtained for soil chemical properties at Paga were similar as compared to the mean values reported for the savannah areas of northern Ghana. The OC and OM levels at Nyankpala and Kawampe could be considered as moderately good levels compared to the average figure for the savannah areas of Ghana. However, optimum levels of OM in soils must be more than 2%. According to Braimoh (2004), soil OM is associated with higher nutrient reserves because they are associated with higher levels of ECEC (150 - 200 C mol kg^{-1}) and also the soil N reserves and part of P were related to OM content.

Nitrogen, P and K are needed by plants in larger quantities and their deficiencies are also very critical and symptomatic. Nitrogen is critical for the development of green leaves and is made available to plants as nitrate (NO_3^-) and ammonia (NH_4^-). Nitrate is also produced by mineralization of OM and can also easily be leached (MSU extension, 2011).

In general the levels of N, P, K, Ca and Mg were very low in the savannah Shea parklands of northern Ghana as indicated in Table 1. The extremely low P content (trace – 7.11 mg/Kg) of the soils might be due to P fixation which was commonly reported for soils in northern Ghana. Although, little information was reported on the importance of macro nutrient in the nutrition of woody plant species, Dianda et al. (2009), was able to show that Shea seedlings were very responsive to N and P, and that limiting N growth conditions were the major constraints to seedling biomass accumulation. Dianda et al. (2009) further reported that responses to N additions in plant parts, shoot N and C uptake were strongly dependant on P rates, and that under conditions of P shortage about 12 mg Kg^{-1} of N should be applied. Also, the macro nutrients especially a balance ratio of N and P was reported to be critical for regeneration of Shea seedlings. Although, the role of N in Shea seedling regeneration is appreciated, its role on the mature Shea tree is not comprehensively reported. Moore (2008), however reported negative correlation (though not significant) between soil N levels and mature Shea characteristics (plant height, DBH, seed width and seed length). N was only positively correlated (again not significant) with Shea tree density which still reflects the role N in regeneration. According to the reports of Moore (2008), P levels in the soil was also negatively (and significantly) correlated with plant height, DBH, kernel width and kernel length. However, P was also positively correlated (not significant) with Shea tree density.

When the land use in the three parklands was contrasted, N and Na showed significantly pronounced differences between fallow lands and cultivated lands. In fallow lands N levels in old fallows were slightly higher than those of new fallows. This was not the case in cultivated land where the N level remains similar irrespective of the duration of cultivation (Figure 2). Similar pattern was shown for Na levels. In both fallow and cultivated lands P levels were slightly higher for old fallows and old cultivated lands. These results would have serious implication for Shea seedling regeneration and the productivity of the Shea tree as the ratio of N to P affects seedling biomass and Shea tree characteristics (Dianda et al., 2009).

As shown in Figure 3, the soils at Kawampe irrespective of whether in fallow or cultivated land, contained more sand and could be described as sand loamy. This may be characteristic of the parent materials from which they are formed. Kawampe is also located close to the forest-savannah transitional zone and may be typical of closed savannah wood land. These ecological zones have vast areas of uncultivated lands and may not have greater number of prolonged fallow lands. These soils may be typical of well drained soils with high water holding capacity. The cultivated soils at Nyankpala in Figure 3, shows more silt and less clay, whilst the fallow soils of same contain slightly less silt and more clay. The cultivated and fallow soils at Nyankpala contain the same proportion of sand. The soils in the fallow land at Nyankpala could be described as loamy whilst that of the cultivated lands as silt loam. These soils may be well drained but prone to leaching of some nutrients. In both cultivated and fallow lands at Paga, there are higher proportions of sand and lesser proportions of silt and clay. As a result the soils at Paga could be described as sandy or sandy loam and thus very susceptible to wind and soil erosion.

Conclusions

Although, the levels of OM, N, P and K, as shown in this study were not adequate to classify as very fertile soils, they were slightly higher for Nyankpala and Kawampe than Paga. The extremely low P content (trace – 7.11 mg/Kg) of the soils might be due to P fixation which is commonly reported for soils in northern Ghana. Land use did not significantly influence the soil chemical properties, however, values for pH, N and P, were slightly higher in old fallows than new fallows and cultivated fields. However, low levels of P in soils require higher levels of N for optimum Shea seedling development and hence Shea regeneration in the parkland could still benefit from N supplementation.

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