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Original Article

Soil Physical and Chemical Properties under Shea Tree (*Vitellaria paradoxa*) at Different Stages of Growth

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ABSTRACT

Shea tree (Vitellaria paradoxa), is one of the dominant agro-forestry species in Otuke district of Northern Uganda. Due to its economic importance and, in line with the numerous threats the tree is faced with, there is an urgent need for measures to conserve this species, for example, through incorporating annual food crops in the Shea tree parkland. This, however, requires a better understanding of tree-soil-food crop interactions. A number of studies of this aspect either considered only the mature Shea tree gardens or did not provide a clear distinction between the physiological states of the Shea tree. This was the motivation for this study where we compare variation in soil properties under mature and young Shea tree gardens with sites not having trees in Okwang sub-county, Otuke district. Five soil samples (up to 15 cm deep for top soil and 15-30 cm for sub-soil) were obtained per treatment using a soil auger. Our results show that in the top soil, only percent sand varied among the treatments, while, in the sub-soil, only percentage nitrogen and average phosphorus varied among the treatments. We also found that percentage top soil organic matter and percentage of sub-soil sand had negative strong correlations with maize and soybean yields, while percentage sub-soil clay had a strong positive correlation with maize and soybean yield. We conclude that variations in soil physical and chemical properties under Mature and Young Shea gardens only occur for those properties that have a direct link to tree residues.

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INTRODUCTION

Agro-forestry parklands are a common site in sub-Saharan Africa where trees contribute to improving the fertility and consequential yield of crops (Verbree *et al.*,2014; Muthuri *et al* 2023). Tree species in these parklands vary considerably across localities. *Vitellaria paradoxa* and *Parkia biglobosa* are among the dominant tree species that occupy the agro forestry parklands in the Sudano-sahelian belt (Adamou *et al.*, 2021). *Vitellaria paradoxa*, commonly known as Shea tree, is integral to food systems of Ugandan communities where it is grown since its pulp is edible, thereby meeting food needs, especially in times when the staple crops are not ready for harvest (Odoi *et al.*, 2021). In Otuke district of Northern Uganda, for instance, farmers have for long benefited from the Shea tree and the *Otuke-shea* trees are appraised for their high oil content (Odoi *et al.*, 2022). The tree is a source of butter (Masters, 2021) which is rich in essential amino acids and other nutritional components (Abdul-Mumeen *et al.*, 2024; Anhwange and Ese, 2022). With its nutrient composition, shea butter has a wide range of industrial applications including in food, cosmetic and pharmaceutical industries (Gwali *et al.*, 2012; Abdul-Mumeen *et al.*, 2024).

However, due to factors such as population pressure and the use of Shea tree for charcoal burning, there is an increasing threat to *V. paradoxa* (Boffa, 2015). Conservation efforts are centered around protecting this tree species, by devising alternative source of energy to replace charcoal from this tree, and by encouraging farmers to incorporate food crops in agro-forestry parklands (Gwali *et al.*, 2012; Esagu *et al.*, 2023). This later conservation effort is of greater significance since Agro-forestry tree species are known to alter soil physical and chemical properties in their localities (Verbree *et al.*, 2014). This however varies with the agro-forestry tree species (Pinho *et al.*, 2012; Buba, 2015) and variety (Githae *et al.*, 2011, Jacquelyn *et al*., 2022). The magnitude of the effect of agro-forestry species depends on the tree density and diversity (Meetei *et al.*, 2020) and varies with location of the agro-forestry parkland (Abubakari *et al.*, 2012; Esagu *et al*., 2023). It was also seen to depend on the farming practices under the agro-forestry parkland (Verbree *et al.*, 2014).

Understanding of the influence of *Vitellaria paradoxa* on soil physical and chemical properties is necessary in advocating for conservation of these economically important agro-forestry tree species. A number of studies on the influence of *Vitellaria paradoxa* on the soil physical and chemical properties generally agree that the tree has some effect on the level of soil nutrients (Buba, 2015). Most studies on the influence of *Vitallaria paradoxa* on soil physical and chemical properties have not differentiated on the physiological difference of the tree and how the soil physical and chemical properties are related to crop production. This undermines the temporal aspect of the tree crop interaction. It is against this background that current study was conducted to investigate the variations in soil physical and chemical properties under mature and young Vitellaria paradoxa gardens. We also correlated soil physical and chemical properties with maize and soybean yields from the study sites.

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Maize and soybeans were specifically selected due to their importance for food and income in the study region.

For purposes of this study, we classified the Mature Shea tree as one that is already producing nuts, while the young Shea tree has not produced any nuts. We hypothesized that soils and physical properties in the study area vary significantly for the site with no Shea trees (control), young Shea trees and Mature Shea trees. We also hypothesized that differences in maize and soybean yields across mature Shea, Young Shea and control sites were influenced by the soil physical and chemical properties that would be significantly different across the treatments.

MATERIALS AND METHODS

Study Area.

A detailed description of the study area was presented in our previous study (Ogwok *et al* 2019). Precisely, however, the study was conducted in Okwang sub-county, Otuke district in Northern Uganda (N 2031'46.145, E 3306'48.203). The area has a rainfall pattern with two rainy seasons from late March to May and July to November, with a long dry spell stretching from December to early March. The Average annual rainfall for the district varies between 1000 mm– 1600 mm (Ogwok *et al* 2019). The mean temperature is between 22˚C–26˚C. However, temperatures may be as high as 40˚C during certain periods of the long dry season (Ogwok *et al* 2019). The natural vegetation is mainly savannah woodland with scattered trees dominated by Shea trees (*Vitellaria paradoxa*). Other prominent tree species include *Terminalia Cambretum sp*, *Ficus sp*, *Accacia sp* and *Phoenixma linareclinata* (Ogwok et al 2019). The soils are categorized as ferruginous sandy loam and vulnerable to erosion. Otuke district is generally flat with an average elevation of 1057.94 meters (3470.93 feet) above sea level. The district was purposively selected due to its uniqueness in terms of both maize and soya production in addition to importance attached to Shea tree. The study was conducted in the first and second rainy (planting) seasons.

Experimental design and data collection

All experiments were conducted on privately owned land after seeking permission from the land owners. Soils were sampled diagonally as depicted in Figure 1, from all the treatments sites of 10 by 15 meters using a soil auger. Soils were extracted 30 cm deep. In each treatment site, five soil samples were extracted diagonally and aggregated into one core sample. This was done separately for the top soil from the surface up to a depth of 15 cm and for the subsoil from 15– 30cm depth. The same process was repeated for all the treatment sites. Since there were four sites for each treatment, we had four core samples which again aggregated into one composite sample. This was done for all the treatments giving a total of four composite samples.

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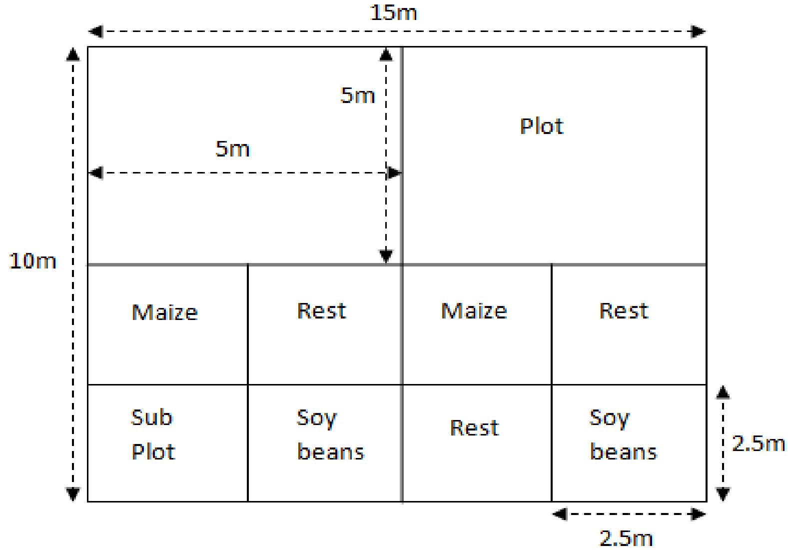
Fig. 1 Experimental Layout (Modified from Ogwok et al 2019)



Soils from both top and sub soils were extracted from mature Shea tree site, Young Shea tree site and the Control site (where there was no shea plant). This was done in a diagonal fashion and the samples aggregated for each treatment to form composite samples. The depth considered for the top soil was from the surface up to 15 cm, while subsoil was taken from the depth 15 – 30 cm. The top soil and sub soil composite samples were taken to Makerere University, College of Agriculture and Environmental sciences, laboratory for analysis of selected soil physical and chemical properties. The study analyzed percentage organic matter content, soil texture, bulk density, pH, percentage Nitrogen, average Phosphorus, percentage Calcium, percentage Magnesium, and percentage potassium from the top and sub soils samples using standard laboratory procedures specified by Estefan, Sommer, & Ryan, (2013). The various soil physical and chemical properties analysis methods used are summarized in Table 1.

Table 1: Summary of analytical methods applied for soil analysis

Soil parameters	Analysis Method
pH	Potential determination in water solution ratio of 1:2:5 (Estafan *et al*., 2013)
Bulky density	Oven dried at 105°C for 2 days then weigh (w2) $\text{BulkDensity} = \frac{w2-w1}{V}\text{cm}^{-3}$ (Estafan *et al*., 2013)
Nitrogen Phosphorus Calcium Magnesium And Sodium	Total N determined by Kjeldhal digestion; Extraction P by Bray P1 method; Exchangeable bases from an ammonium acetate extract by flame photometry (K^+ , Na^+) and atomic absorption spectrophotometer (Ca^+ , Mg^{2+}) (Estafan *et al*., 2013)
Soil texture	The Bouyoucos hydrometer adopted from Gee and Baunder (Estafan *et al*., 2013)
Organic matter content	Organic matter by potassium dichromate wet acid oxidation method. (Estafan *et al*., 2013)
Potassium	The photoelectric flame photometer was used to determine the soil potassium after extraction with neutral ammonium acetate. (Estafan *et al*., 2013)

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Data generated from laboratory analysis was further analyzed for statistical significance using correlation analysis. This was tested for significance at 5% level of significance. The data was compared among the treatments using Analysis of Variance (ANOVA) at 5% level of significance.

More detailed information to ascertain whether variation in soil physical and chemical properties had a significant association with crop yield (Table 5 was sourced from our previous study (Ogwok et al 2019). We experimentally planted maize and soybean under Mature Shea site, Young Shea site, and control site. Maize and Soybeans were planted in seasonal and experimental replicates in the same sites where soil samples were taken from. The number of replicates for each crop was four, for each of the two seasons. These experiments were run from March – July for the first planting season and from July – November for the second planting seasons. Planting of maize and soybeans was alternating each other with rest plots in between. In the second season, the rest plots were planted alternately with maize and soybeans.

Crop yield (maize and soy beans) was tested for association with soil physical and chemical properties, using Pearson correlation coefficient for the two seasons under study to ascertain whether there was a significant association between soil properties and crop yield under *Vitellaria paradoxa* and Control sites.

RESULTS

Topsoil physical properties

The study analyzed a number of soil physical and chemical properties at study sites for mature Shea site, Young Shea site and the Control site. Analysis of variance of top soil physical and chemical properties reveals that no top soil chemical property showed significant variation under the two treatments and Control sites, while in the case of top soil physical properties, only percentage sand showed significant variations among the treatments and Control at 95% confidence level (Table 2).

Table 2: Variation of top soil properties in the treatment sites

Soil properties in top soil composite	Treatment (Mean ± SD)			P value
	Mature Shea	Young Shea	Control	
pH	6.05±0.06	6.5±0.29	6.05±0.42	0.098
Organic matter	3.33±0.31	3.5±0.64	2.5±0.74	0.087
Nitrogen (%)	0.29±0.06	0.21±0.04	0.2±0.05	0.063
Average Phosphorus (ppm)	29.54±20.50	21.75±10.63	18.46±9.22	0.555
Calcium (cmole/Kg)	5±1.58	7±3.51	5.3±2.21	0.521
Magnesium (cmoles/Kg)	1.71±0.71	2.5±0.90	1.64±1.21	0.414
Potassium (cmoles/Kg)	0.79±0.23	3.43±2.93	0.62±1.14	0.455
Sodium (cmoles/Kg)	0.1±0.02	0.89±0.78	0.11±0.02	0.408
Percent Sand	63.5±1.50	52.75±3.09	56.25±1.55	0.019
Percent Clay	20.5±1.32	29.75±3.90	30.25±2.95	0.074
Percent Silt	16±1.08	17.5±0.87	13.5±2.36	0.248

Sub soil physical properties

Analysis of Variance of subsoil physical and chemical properties revealed that no sub soil physical property varied significantly among the treatment and Control sites, while among the sub soil chemical properties only percentage nitrogen and average phosphorus showed significant variations at 95% confidence level among the two treatment sites and Control (Table 3). Specifically, percentage Nitrogen was highest in the Control site and lowest under Young Shea tree site, while average phosphorus was highest under young Shea site and lowest under the Mature Shea site.

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Table 3: Variation of sub soil properties in the treatment sites

Soil properties in sub soil composite	Treatment (Mean ± SD)			P value
	Mature Shea	Young Shea	Control garden	
pH	5.75±0.10	5.95±0.32	6.03±0.16	0.656
Organic matter	2.39±0.22	3.49±0.72	2.86±0.32	0.304
Nitrogen (%)	**0.17±0.01**	**0.12±0.01**	**0.19±0.01**	**0.003**
Average Phosphorus (ppm)	**8.07±2.62**	**28.78±0.98**	**18.11±4.52**	**0.003**
Calcium (cmole/Kg)	5.63±1.09	4.20±0.70	5.93±1.49	0.543
Magnesium (cmoles/Kg)	1.34±0.59	1.63±0.54	1.84±0.34	0.780
Potassium (cmoles/Kg)	0.81±0.07	1.01±0.28	0.61±0.12	0.340
Sodium (cmoles/Kg)	0.09±0.01	0.07±0.03	0.08±0.01	0.844
Percent Sand	63.0±3.70	60.00±0.82	54.0±1.15	0.057
Percent Clay	23.50±2.06	22.75±1.89	29.0±2.35	0.126
Percent Silt	13.5±2.63	17.25±1.11	17±1.22	0.257

Relationship between maize and soybean yields with soil physical and chemical properties

Percentage Organic Matter in top soil had a significant positive correlation with maize yield in season two (II). In the sub-soil, the proportion of sand had a significant (*p<0.05*) negative correlation with maize and soybean yields in both planting seasons, while the proportion of clay had a significant (*p<0.05*) positive correlation with maize and soybean yields in both seasons (Table 4). All the other soil properties showed no significant correlation with yield.

Table 4: Correlation between crop yield and soil components

Crop	Parameter	Percentage Organic Matter in Top Soil	Percentage Sand in Sub-soil composite	Percentage of clay in sub-soil composite
Maize Yield	R	-0.573	**-0.676**	**0.637**
Season I	p-value	0.052	0.016	0.026
Soya Bean Yield	R	-0.456	**-0.669**	**0.705**
Season I	p-value	0.136	0.017	0.011
Maize Yield	R	**-0.608**	**-0.665**	**0.633**
Season II	p-value	0.036	0.018	0.027
Soya Bean Yield	R	-0.519	**-0.680**	**0.671**
Season II	p-value	0.084	0.015	0.017

r=pearson correlation coefficient; Figures in bold are significant at 5% level of significance

A yield decline index was constructed to compare the yield difference between maize and soybean (Table 5). The index was constructed by taking the yield from the control experiment as the base and comparing it with the yield from each of the two treatments (Ogwok et al 2019).

$$\text{Yield decline Index} = \left(\frac{\text{Mean yield under shea}}{\text{Mean yield under contro}}\right) * 100$$

Table 5: Comparison maize and soybean yield from the control with the treatments

Comparison	Yield decline Index (%)			
	Season one		Season two	
	Maize	Soybean	Maize	Soybean
Mature Shea /Control Treatments	23.1548	41.7235	25.4183	39.0404
Young Shea/Control Treatments	36.6053	46.3346	33.9325	43.1694

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DISCUSSION

This study investigated the variation in soil physical and chemical properties under different physiological states of *Vitellaria paradoxa* and the association between soil physical and chemical properties with maize and soybeans yields in Otuke district. With the exception of percentage topsoil sand, percentage subsoil nitrogen and subsoil average phosphorus, the study found that the soil physical and chemical properties were not significantly different under mature, young and Control gardens. Since all experiments were done in the same geographical area with the same climatic conditions and topography, variation in soil physical and chemical properties tends to be location specific. This partly explains why there was no significant variation in most physical and chemical properties of the soil investigated. Our results are consistent with those of Mebrate et al (2022) and Onasanya *et al*. (2009) who reported that areas of land with the same topography normally exhibit similar soil physical and chemical properties especially within the same altitude. We thus attribute any observed differences in maize and soybean status under *V. paradoxa* to other factors and not difference in soil physical and chemical properties. Previous studies (Bwambale and Mourad 2022; Epule *et al.*, 2021) report that soil physical and chemical properties in the study area are in a range for optimal growth of both maize and soybeans.

Results of higher percentage topsoil sand are consistent with those of Moore (2008) that show variations in soil composition for the various tree cover. Specifically, Moore (2008) reported that a higher proportion of sand and a lower proportion of clay composition support the growth of denser, older Shea trees. He also reported that there is a significant variation in the soil chemical compositions of Shea tree sites. Onasanya *et al*., (2009) reported similar results for soil physical and chemical properties in southern Nigeria. According to Kogbe & Adediran (2003), levels of soil chemical properties such as those reported in this study were considered low for optimum maize production. Maize for instance is very sensitive to soils low in Nitrogen, Phosphorus and Potassium.

Nitrogen is required for vegetative growth of plants, while Phosphorus plays a role in photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement and several other processes in plants . Further analysis showed significant differences in means for Young Shea treatment and Mature Shea treatment, and Young Shea treatment and Control treatment, with the Young Shea treatment having significantly lower Nitrogen content than the rest. In the case of Average Phosphorus, there was a significance difference between Young Shea and Mature Shea treatments, with the Young Shea treatment having a significantly higher Average Phosphorus.

Whereas agro-forestry trees are known to improve soil fertility in their localities, (Pinho *et al.*, 2012) observed that the improvement in soil fertility is more pronounced in situation where there is a diversity of tree species. This is contrary to the current study sites where there were only *Vitellaria paradoxa* trees.

With the exception of percentage topsoil organic matter, percentage sub-soil sand and percentage sub-soil clay, we found no significant correlation of soil properties with maize and soybean yields in the study sites. These results seem to suggest that variation in yield is not due to variation in soil physical and chemical properties. However, the variation in the proportion of sand and clay could have a significant effect on yield through their effects on the water holding capacity of the soil. For instance, sand has the least water holding capacity while clay has the highest water holding capacity.

CONCLUSION

In this study, we investigated the variation in soil physical and chemical properties under Mature and Young Shea tree sites with a Control site that had no Shea tree. We also provided a relationship between

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soil physical and chemical properties and maize and soybean yields. We had hypothesized that there would be significant variations in the studied soil physical and chemical properties at the study sites, and that these variations would have a significant association to maize and soybean yields under the treatments. Specifically, we expected to find soils under Mature Shea to be more fertile than soils under Young Shea and Control sites respectively.

Contrary to our expectations on soil physical and chemical properties, we found no significant variations in most soil physical and chemical properties at the study site. In the topsoil, only percent sand showed a significant variation, declining from Mature Shea to the Control site, and finally to the Young Shea site. In the subsoil, only percentage Nitrogen and Average phosphorus varied significantly across treatments. We also found no significant correlation with maize and soybeans yields with most of the soil properties under Mature, Young Shea and Control sites. This was expected since most of the soil properties did not significantly vary across the Mature, Young and Control sites.

Declaration of Conflicting Interests

The authors have no conflicts of interest to declare regarding the publication of this paper.

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Data Availability

All the necessary data for this study is availed within the paper.

Authors' Contributions

All authors confirm their contribution to the paper as follows: study conception and design: Ogwok G and Kizza-Nkambwe S; data collection: Ogwok G; analysis and interpretation of results: Ogwok G, P. O. Alele and Kizza-Nkambwe S; draft manuscript preparation: Ogwok G, Kizza-Nkambwe S, Kasima JS and Mpewo M. All authors agree to the content of the final version of the manuscript.

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