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Original Article

Soil Chemical and Physical Properties in Taungya and Non-Taungya Plots at Sao Hill Forest Plantation, Tanzania

Godfrey A. Nyakunga[1], Salim M. S. Maliondo[1] & Shaban. A. O. Chamshama[1]*

[1] Sokoine University of Agriculture, P. O. Box 3010, Morogoro, Tanzania.
[*] Author for Correspondence Email: nyakungagodfreya@gmail.com

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ABSTRACT

This study compared soil physical and chemical properties in Taungya and Non-Taungya plots at Sao Hill Forest plantation, Tanzania. Soil samples were collected from 0-20cm depth in February and May Using a zigzag pattern to ensure representative coverage. Physical properties (bulk density, porosity, Soil moisture content, soil texture) and chemical properties (soil pH electrical conductivity, total nitrogen and available phosphorous) were analyzed using standard laboratory methods. Results showed significant differences between the two management practices. In February Non-Taungya plots had higher bulk density(1.33±0.151/cm3) compared to Taungya plots (1.16±0.107 g/cm3; p<0.001), while Taungya plots showed higher porosity (56.12%±4.06p<0.001). May sampling also revealed differences with non-Taungya plots maintaining higher bulk density (1.32±0.15 g/cm3) compared to Taungya plots (1.08±0.09 g/cm3); p<0.001). Soil texture analysis showed no significant differences in sand content between treatments. However, silt content was significantly higher in Taungya plots (13.27 ± 3.849%) compared to non-Taungya plots (10.69 ± 3.23%; p=0.007), while clay percentage did not differ significantly. Soil chemical properties, non-Taungya plots had higher pH (4.67±0.47) compared to Taungya plots (4.3±0.22; p<0.001) while electrical conductivity (0.04±0.04 dS/m) compared to Taungya plots (0.01±0.01 dS/m; p<0.001). Taungya plots showed higher total nitrogen (0.04±0.01%; p<0.0031) compared to non-Taungya plots (0.035±0.01%). In addition May available phosphorous in Taungya plots was (3.95±0.55 mg/kg; p<0.001) compared to non-Taungya plots (1.97±0.32 mg/kg). These results suggest that Taungya practices significantly influence soil properties, potentially impacting soil quality and forest productivity. The study provides valuable awareness for sustainable forest management and highlights the need for long-term monitoring of soil properties under different management systems in plantation forests.

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INTRODUCTION

Forest plantations play an important role in meeting global wood demand, mitigating climate change, and restoring degraded lands (Freer-Smith *et al*., 2019). Nevertheless, the establishment and management of these plantations can significantly impact soil properties, which are fundamental to forest productivity and ecosystem health (Bose *et al*., 2023). One management approach that has increased attention for its potential to enhance both social and ecological outcomes is the taungya system.

The taungya system is an agroforestry practice that allows farmers to cultivate crops between rows of young tree seedlings during the early years of plantation establishment (Edberg *et al*., 2022). This practice, originating in Burma (Myanmar) in the 19th has been adopted in various tropical and subtropical regions worldwide. Some scholars argue that taungya can improve plantation success rates, provide additional income for local communities, and potentially enhance soil fertility through agricultural inputs and management (Adovor, 2021).

Nevertheless, the impact of taungya practices on soil properties in forest plantations remains a subject of debate. However, some studies propose that intercropping can improve soil organic matter content and nutrient availability (Hombegowda *et al*., 2022), others have raised concerns about potential soil degradation due to intensive cultivation and increased erosion risk *(*Sahoo *et al*., 2022). These contradictory findings highlight the need for site-specific investigations to understand the effects of taungya on soil characteristics in different environments. Soil chemical properties such as pH and nutrient concentrations, are critical factors influencing tree growth and overall forest health (Jamil *et al*., 2016). Similarly, soil physical properties including bulk density, soil texture and water holding capacity play important roles in root development, water availability and nutrient uptake (Criscione & Fields, 2023). Understanding how taungya practices affect these soil traits is important for developing sustainable forest management strategies and enhancing the benefits of agroforestry systems.

This study aims to contribute the growing body of knowledge on the impact of taungya practices in forest plantations by examining soil chemical and physical properties in taungya and non-taunga plots. Specifically, this study aims ;(1) to determine soil chemical characteristics in plantations with and without taungya practices. (2) to assess soil physical characteristics under the two practices. By comparing these soil properties between taungya and non-taungya plots, this study will deliver a valuable understanding of the potential benefits and drawbacks of applying taungya systems in forest plantations. The results of this study have important implications for forest managers, policymakers and

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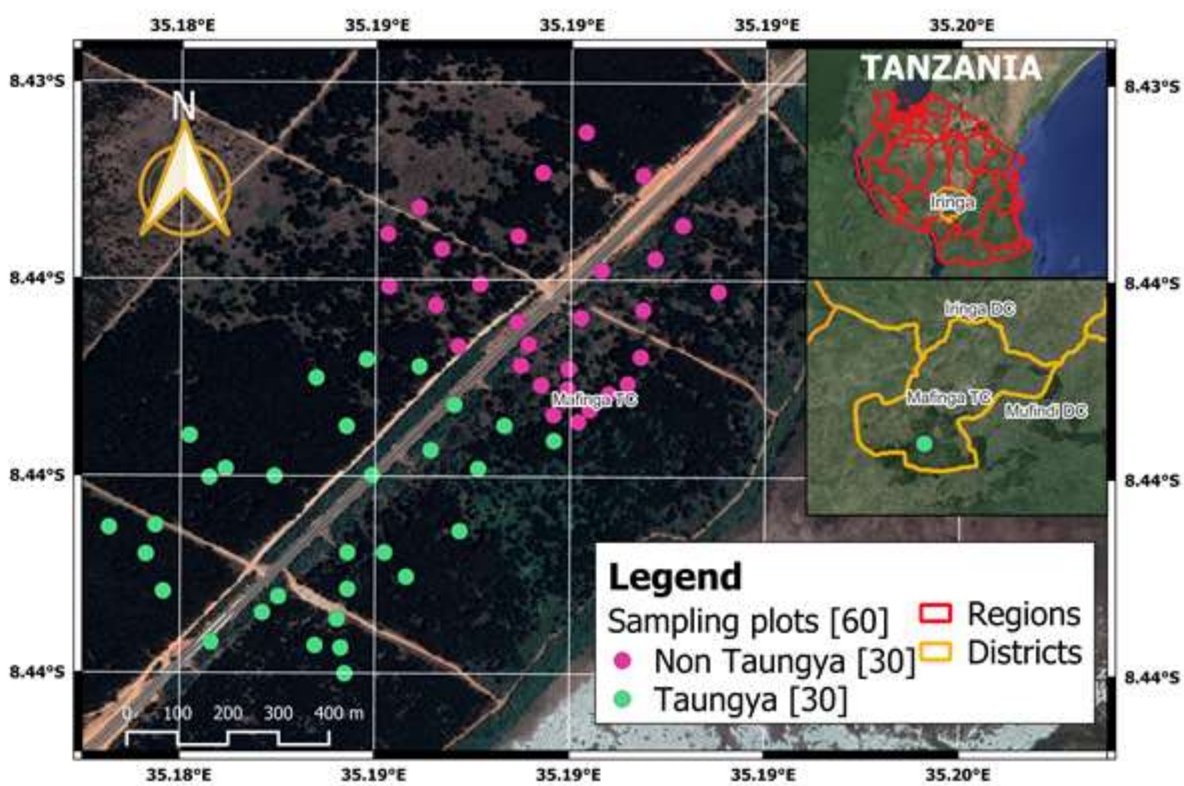
academics working to develop sustainable agroforestry practices that balance wood production, soil conservation, and community. Also, this study will contribute to more informed decision-making in forest plantation management and help maximize the use of agroforestry systems in the environment.

MATERIALS AND METHODS

Site description

The study is located in Sao Hill Forest Plantation in SW highlands of Tanzania located between 8^0 18' S to 8^0 33 S and 35 ^{0} 06 E and 35 ^{0} 20 E with an altitude of 1,700 m to 2,000 m above sea level in Mufindi District. The plantation is about 25 km from Mafinga town. The climate of the area is generally cool with one notably dry season starting from July to November. There is only one rainy season which starts from November to April with a 750 mm to 1050 mm average annual rainfall. The temperature ranges from 15^0C to 26^0C in the year with an average of 20^0C. The area has deep soil with poor drainage at lower elevation and acidic pH ranging from 4.4 to 5.4. The study was conducted in division II in Sao Hill forest plantation into two different management systems i.e., with taungya system and without taungya system. All sites are dominated by *Pinus patula* in the third rotation age. The site with taungya system was done by farmers before the onset of the experiment for soil sampling on the taungya system and non- taungya system.

Figure 1: Map showing study area (SaO Hill Forest Plantation, IringaTanzania)



The effect of Taungya and non-Taungya plots on soil properties in the Sao Hill Forest plantation was examined in this study. In the Taungya system, *Pinus patula* seedlings were intercropped with maize, beans, and sunflower, while the non-Taungya plots involved *P. patula* seedlings with natural grass cover.

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Soil sampling

Composite soil samples were collected from two management practices (Taungya and Non-Taungya plots) at one soil depth (0-20cm). Both practices were situated on the same slopes and topography to minimize confusing factors. A total of 120 soil samples were collected with 60 samples from taungya and 60 from non-Taungya plots in two phases February and May respectively, whereby each type consisted of 30 soil samples.

Sampling points were established based on the heterogeneity of land units using a zigzag pattern to ensure representative coverage of the area. At each of thirty (30) sampling points per management practice, both undisturbed and disturbed soil samples were taken in both types.

Undisturbed soil samples were collected using a core sampler for bulk density determination. Disturbed soil samples were obtained using an auger for the analysis of selected chemical and physical properties.

During the collection of soil samples, dead plants, gravel materials, areas near trees, and compost pits were excluded. This precaution was taken to minimize variation differences, which may arise due to mixing of soil organic matter through cultivation and other related factors.

One kilogram of soil samples from each sampling point was collected and packed in plastic bags. The composite soil samples were then air-dried ground and sieved through a 2mm sieve for the analysis of chemical and physical properties. For soil organic carbon (SOC) and total nitrogen (N) analysis, samples were further grounded to pass through a 0.5mm sieve.

Soil physical and chemical properties analysis

Soil texture was analyzed using the hydrometer method, which involves several processes to accurately determine the distribution of sand, silt and clay particles in a soil sample.

The process started with the destruction of organic matter (OM) using hydrogen peroxide (H_2O_2). Following the soil particles were isolated and dispersed using a combination of Sodium carbonate (Na_2CO_3) and sodium hexametaphosphate ($NaPO_3$) in distilled water chemicals helps to break soil aggregates and allow for more accurate measurement of individual particle sizes. The formation of foam in the soil solution was prevented by adding amyl alcohol so as not to interfere with hydrometer readings. The soil suspension was then thoroughly mixed and allowed to settle. The reading from the hydrometer was taken at specific time intervals, typically at 40 seconds and 2 hours. Temperature corrections were applied to the hydrometer readings. After hydrometer readings calculations were performed to determine the percentages of sand, silt and clay in the sample. The percentages were used to classify the soil textural class using the USDA soil textural triangle classification system.

The soil bulk density (BD) was measured from undisturbed soil samples collected using a core sampler. The core samples were dried in an oven at 105^0C to constant weight. After drying, the mass of the soil was measured. The bulk density was calculated by dividing the mass of the dry soil by the volume of the soil core.

The total porosity of soil samples was estimated from the values of bulk density (BD) and particle density (PD). A standard particle density of 2.65g/cm^3 was used in determining the Porosity. The total porosity (TP) was the calculated using the following formula; TP (%) = (1-Bulk density/ particles density) *(100).

The pH of the soil was measured in water (H_2O) suspension using a 1:2.5 soil –to-liquid ratio). The pH was measured using a calibrated pH meter equipped with a glass electrode. The pH meter was calibrated using standard buffer solutions before measurement to ensure accuracy. Electrical conductivity (EC) of soil was determined by using a conductivity meter with a 1:5 soil-to-water ratio.

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The Walkley and Black method was used to determine soil organic carbon. Soil samples were oxidized with potassium dichromate ($K_2Cr_2O_7$) in a concentrated sulfuric acid solution. The excess dichromate was then titrated with ferrous ammonium sulfate using a diphenylamine indicator. The soil nitrogen content was determined using the Kjeldahl method, involving synthesizing samples in concentrated H_2SO_4 with a catalyst. The digest was then distilled with NaOH, capturing released ammonia in boric acid. Lastly, the ammonia was measured by titration with standardized 0.1N H_2SO_4, allowing the calculation of total nitrogen content. Available phosphorus was extracted from soil using a double acid solution (0.05N HCl in 0.025N H_2SO_4). The extract was treated with reagents to produce a blue color, whose intensity was measured by a spectrophotometer to determine phosphorus concentration.

Statistical Analysis

Soil properties in both Taungya and non-Taungya systems were analyzed using IBM SPSS Statistics (version 27.0.1.0). A total of 120 soil samples were collected, with 60 samples for each treatment, evenly distributed through the February and May sampling periods. The analyzed soil properties included; Bulk density, Soil Moisture content, soil texture, pH, Porosity, Total Nitrogen, Soil organic Carbon, available phosphorus, Electrical conductivity.

Descriptive statistics were calculated for each soil property, treatment, and sampling period. Soil properties were compared between Taungya and non-Taungya plots for each sampling period using independent samples t-tests, with a significance level at $\alpha = 0.05$. This method allowed for an effective comparison of soil properties between systems and an examination of seasonal variations.

RESULTS

Soil Physical Properties

Soil samples were collected in February and May to assess the impact of Taungya and Non-Taungya practices on various soil properties**.** The soil properties between Taungya and Non-Taungya practices were compared using independent samples t-tests. Significant differences were found between Non-Taungya and Taungya treatments for all measured soil properties according to the independent samples t-test (Table 1).

Bulk density was higher in non-Taungya plots with a mean of 1.33±0.15g/cm^3 compared to Taungya plots with a mean of (1.16 ± 0.11g/cm^3; t= 4.952, p<0.001), while porosity showed an opposite trend in Taungya plots and the mean was 56.12±4.05%; t = -4.952, p < 0.001). Moisture content was measured in Taungya plots, the mean moisture content was 25.27 ± 5.89% while in non-Taungya plots, the mean moisture content was 26.39 ± 3.16%. The results indicated that there was a slight difference in mean moisture content between the two management practices, this difference is not statistically significant at the predictable significance level p<0.05.

Soil sampling in May revealed more pronounced differences. Bulk density remained higher in non-Taungya plots (1.32± 0.15g/cm^3) than Taungya plots (1.08 ± 0.09g/cm^3; t = 7.564, p < 0.001). Moisture content in non-Taungya plots was significantly higher (26.31 ± 3.55%) compared to Taungya plots (16.52 ± 3.84%, t=10.257, p<.001). Soil Porosity remained lower in non-Taungya plots (50.2520 ± 5.50%) than Taungya plot (59.3270 ± 3.59%, t=-7.564 <.001).

Sand content was similar between the two management practices, with Taungya plots containing (52.75 ± 2.49%) sand and non-Taungya plots (51.47 ± 4.80 %) sand. Silt content was notably lower than sand and clay in both plot types. Taungya plots contained 11.81 ± 3.18% silt, while non-Taungya plots had (10.69 ± 3.23%) silt. Clay content showed variation between the two management practices.

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Non-Taungya plots exhibited a higher clay percentage (37.84 ± 6.18%) compared to Taungya plots (35.44 ± 2.72%).

Soil Chemical Properties

Soil samples collected in May to assess the impact of Taungya and Non-Taungya systems on various soil chemical properties. The independent samples t-test revealed significant differences between Non-Taungya and Taungya treatments for all measured soil properties (Table 1).

Soil pH measured in May was significantly higher in Non-Taungya (4.670 ± 0.47) compared to Taungya (4.26 ± 0.22) treatments ($t(58) = 4.304$, $p < .001$). Electrical conductivity (EC) was significantly higher in Non-Taungya (0.04 ± 0.04 dS/m) than Taungya (0.0100 ± 0.010 dS/m) treatments ($t(58) = 3.789$, $p < .001$).Total nitrogen in the May samples was significantly higher in Taungya (0.04± 0.01%) compared to Non-Taungya (0.035 ± 0.02%) treatments ($t(58) = -2.214$, $p = .031$). Whereas, the available phosphorus levels were higher in non-Taungya plots in February, they were higher in Taungya plots (3.95 ± 0.55 mg/kg) compared to non-Taungya (1.97 ± 0.32 mg/kg) ($t(58) = -3.585$, $p < .001$), in May, as showed in Table 1.

Table 1: soil properties between Non-Taungya and Taungya treatments (February and May samples)

Month	Soil property	Taungya mean±SD	Non-Taungya mean±SD	t-value	p-value
February	Bulk density (g/cm3)	1.1627±0.10745	1.3300±0.15062	4.952	<0.001
	Moisture content (%)	25.2744±5.89594	26.3884±3.15525	0.192	0.365
	Porosity (%)	56.1240±4.05479	49.8119±5.68360	-4.952	<0.001
	Soil Organic Carbon (%)	1.4790±0.57486	1.4080±0.24265	-0.624	0.535
	pH	4.6700±0.46659	4.5243±0.35520	-1.361	0.179
	EC	0.0520±0.07527	0.0153±0.0730	-2.656	0.010
	Total N (%)	0.0699±0.02069	0.0581±0.00828	-2.913	0.005
	Available P (mg/kg)	1.7547±0.033036	1.9835±0.32405	2.708	0.009
	Sand (%)	52.7533±2.49451	51.4667±4.79578	-1.304	0.197
	Total silt (%)	11.8067±3.17858	10.6933±3.23163	-1.345	0.184
	Clay (%)	35.4400±2.71720	37.8400±6.18193	1.947	0.056
May	Bulk density (g/cm3)	1.0778±0.09515	1.3183±0.14584	7.564	<0.001
	Moisture content (%)	16.5214±3.83521	26.3115±3.55252	10.257	<0.001
	Porosity (%)	59.3270±3.59073	50.2520± 5.5034	-7.564	<0.001
	Soil Organic Carbon (%)	1.6563±0.29752	1.3849±0.23040	-3.951	<0.001
	pH	4.2610±0.22343	4.6670±0.46592	4.304	<0.001
	EC	0.0100±0.01083	0.0407±0.04299	3.789	<0.001
	Total N(%)	0.0413±0.0113	0.0348±0.01165	-2.214	.031
	Availbale P(mg/kg)	3.9451±0.54854	1.9674±0.32140	-3.585	<0.001
	Sand (%)	52.9400±4.34103	51.3033±84938	-1.304	0.197
	Total silt (%)	13.2767±3.84866	10.6933±3.23163	-2.816	0.007

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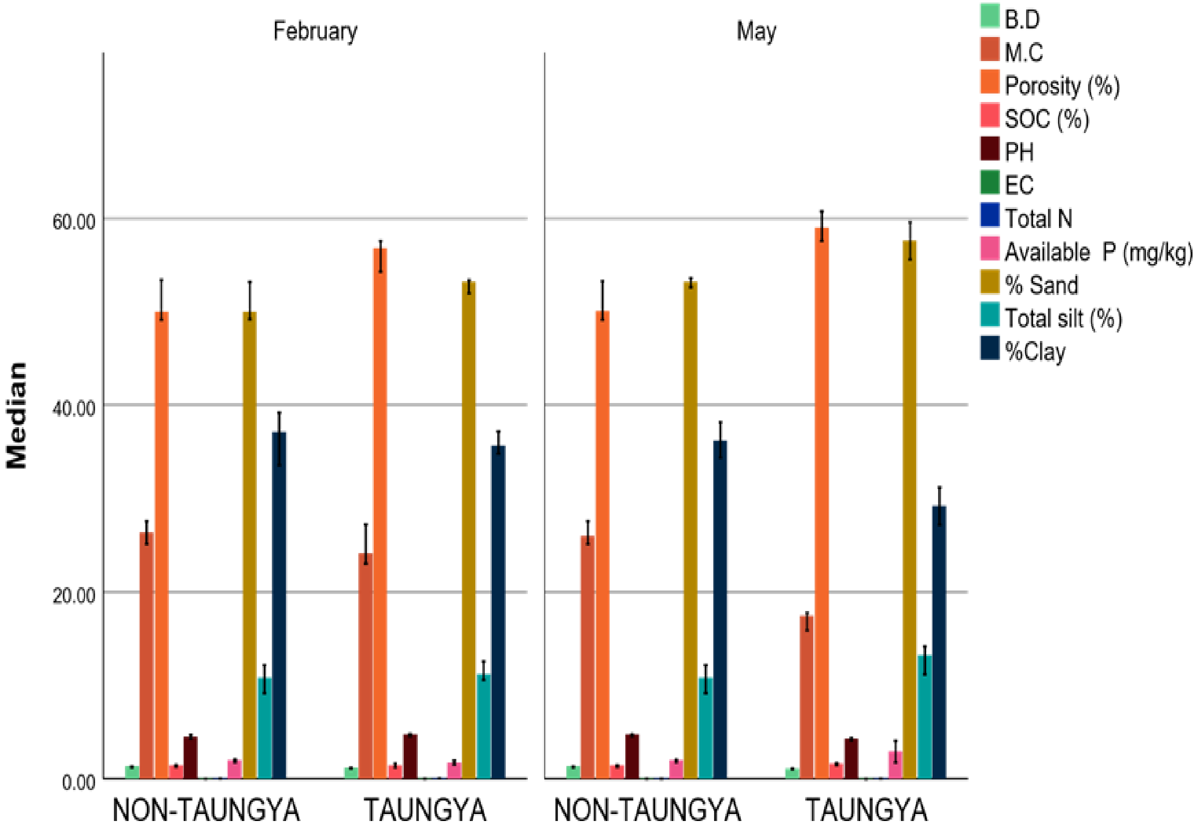
Figure 2; Bar graph of median of soil properties against treatments across time



DISCUSSION

The effect of Taungya and non-Taungya plots on soil properties in the Sao Hill Forest plantation was examined in this study. The results showed differences in both physical and chemical soil properties between the two plots, as defined in Table 1 and showed in Figure 2.

Soil Physical Properties in Taungya and Non-Taungya plots

Taungya plots showed lower bulk density and higher porosity compared to the non-Taungya plots in both February and May, as showed in Table 1 and Figure 2. In May, the bulk density was remarkably lower in the Taungya plots (1.0778 ± 0.09515 g/cm³) compared to the non-Taungya plots (1.3183 ± 0.14584 g/cm³) ($t(58) = 7.564$, $p < .001$). Also, there was a significant difference in soil porosity between the Taungya (59.3270 ± 3.59073%) and non-Taungya (50.2520 ± 5.50349%) treatments ($t(58) = -7.564$, $p < .001$), with the Taungya plots showing higher porosity.

The results showed significantly lower soil bulk density and porosity with taungya in both February and May. The results align with the other studies in agroforestry including the latest study on agroforestry. Ngaba *et al*. (2024) reported a 9% decrease in soil bulk density in agroforestry systems compared to monocultures. Also, a meta-analysis conducted by Udawattam and Gantzer (2022) showed an increase of 8.4% in soil porosity in agroforestry systems relative to traditional agricultural practices. The diverse cropping system is responsible for the enhanced soil physical properties in Taungya plots compared to the simpler *P. patula* and grass in non-Taungya plots, the combination of maize, beans, and sunflower with *P. patula* seedlings likely resulted in a more extensive and diverse root system. According to Fahad *et al*. (2022), the improvements in soil physical properties

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were more significant in multi-crop agroforestry systems compared to monoculture systems, which aligns with the results.

The soil moisture content in May revealed a significant difference, with non-Taungya treatments having higher moisture (26.3115 ± 3.55252%) compared to Taungya treatments (16.5214 ± 3.83521%) (t (58) = 10.257, p < .001). Recent research supports this apparently conflicting observation. According to Iqbal *et al*. (2020) grass cover in young pine plantations can serve as a "living mulch", thereby reducing soil surface evaporation. This result can explain the higher surface moisture in non-Taungya plot. However, the moisture content on the surface does not always reflect the overall effectiveness of water management. According to Kaushal *et al*., (2021), although agroforestry plots had lower surface soil moisture probably due to higher transpiration by trees, although, they might have maintained higher levels of deep soil moisture given the deeper tree roots offering channels for water percolation, providing better overall water management even though lower surface moisture. In terms of soil texture, both Taungya and non-Taungya plots had similar texture types i.e. Sandy soils suggesting that cultivation did not significantly affect soil particle size distribution.

Soil Chemical Properties in Taungya and Non-Taungya plots

The results of this study revealed that as of May, there was a significant increase in Soil Organic Carbon (SOC) in the Taungya plots (1.6563 ± 0.29752%) compared to the non-Taungya treatment (1.3849 ± 0.23040%) (t (58) = -3.951, p < .001). This result aligns with a comprehensive analysis by Riyadh *et al*. (2018) which showed that agroforestry systems raised SOC by an average of 19% in comparison to traditional agriculture. The improved soil organic carbon (SOC) in Taungya plots can be related with the higher amount of plant material from the different crop system and the minimized disturbance of the soil (Akanwa *et al.*, 2019; Fahad *et al*., 2022). The presence of woody vegetation and trees contributes to the accumulation of organic matter in the soil through leaf litter, root systems and the decomposition processes. Muchane *et al.* (2020)) reported that areas with agroforestry practices can increase SOC content by up to 21% compared to monoculture systems.

The study results further showed that the soil pH was lower in the Taungya area (4.2610 ± 0.22343) compared to the non-Taungya area (4.6670 ± 0.46592) in May (t (58) = 4.304, p < .001). The observations agree with the findings of Tomar *et al*., (2021) that agroforestry can cause a slight reduction in soil pH in certain tropical areas because of the higher decomposition of organic matter. Furthermore, Rolo *et al*. (2023) emphasized that agroforestry systems based on maize tended to have a slightly lower soil pH because of the increased production of organic acids from root exudates and organic matter decomposition.

The significantly higher Total nitrogen in May in the Taungya (Table 1 and Figure 2) might be attributed to the presence of legumes in the Taungya system. N-fixing legumes and shrubs form symbiotic relationships with bacteria to fix atmospheric nitrogen and accumulate it in soil and biomass. According to Lebrazi and Fikri-Benbrahim (2022), legume-based agroforestry systems have the potential to fix up to 100 kg N ha-1 year-1, making them an important contributor to soil nitrogen storage. This result also aligns with Kim and Isaac (2022) who observed that agroforestry systems integrating nitrogen-fixing trees can increase soil nitrogen. Moreover, a meta-analysis by Muchane et al. (2020) demonstrated that agroforestry practices can enhance soil nitrogen by an average of 13% compared to monoculture systems. The observed increase in total nitrogen under Taungya management is particularly significant given its relatively short-term implementation. Moreover, Rosenstock *et al.* (2019) found that the benefits of agroforestry influence nutrient cycling in agricultural fields,

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farms, and surrounding landscapes, both directly and indirectly. They extract nitrogen, and other essential nutrients from deeper layers of the soil, making them available to plants through the decomposition of biomass and root regeneration.

This study further showed that In February, the available phosphorus levels were higher in non-Taungya plots, but were higher in Taungya plots (3.9451 ± 0.54854 mg/kg) compared to non-Taungya in May (Table, 1). The increase in available phosphorus observed in Taungya plots from February to May, exceeding the increase in non-Taungya plots, is consistent with recent findings on the effects of nitrogen-fixing plants on soil phosphorus dynamics in tropical systems (Aleixo *et al*., 2020). The increase in phosphorus availability observed in Taungya systems can be attributed to several key mechanisms associated with agroforestry practices.

Enhanced biological activity plays a crucial role in phosphorus dynamics within Taungya systems. The diverse plant community, particularly the presence of nitrogen-fixing trees, stimulates soil biological activity (Gupta *et al*., 2023). Joshi *et al*. (2021) found that increased microbial activity leads to greater mineralization of organic phosphorus, making it more readily available for plant uptake. This process is fundamental to the improvement of phosphorus cycling observed in Taungya agroforestry systems. In addition, root exudates and enzymes produced by nitrogen-fixing trees contribute significantly to phosphorus mobilization. For instance, Sun *et al.* (2024) demonstrated that these trees often release root exudates rich in organic acids and phosphatase enzymes. These compounds have the ability to solubilize and mobilize soil phosphorus, effectively increasing its availability to plants. This biochemical process is a direct result of the tree-crop integration characteristic of Taungya systems.

The integration of trees in Taungya systems also leads to improved soil structure, with cascading effects on nutrient dynamics. For example, Isaac and Borden (2019) observed that increased organic matter input from trees enhances soil structure and promotes better nutrient retention, including phosphorus. This improvement in soil physical properties creates a more favorable environment for nutrient cycling and plant uptake. Finally, pH modification by nitrogen-fixing trees can have a substantial impact on phosphorus availability. Li *et al*. (2022) noted that some of these trees can alter soil pH, which in turn affects phosphorus solubility and availability. This pH modification can make previously unavailable forms of phosphorus more accessible to plants, contributing to the overall increase in phosphorus availability observed in Taungya systems.

This study also shows that the non-Taungya plots had significantly higher soil electrical conductivity than the Taungya plots. Higher electrical conductivity values usually indicate higher concentrations of soluble salts in the soil solution, which may affect nutrient availability and plant growth (Gondek *et al., 2020)*. The difference observed may be due to various factors such as differences in management practices, vegetation cover, and soil composition between the two systems. Current studies on soil electrical conductivity in agroforestry systems, such as Bhardwaj *et al*. (2024) and Verma *et al*. (2023) showed that management practices can have a significant impact on soil properties, including electrical conductivity. These studies suggest that lower electrical conductivity in Taungya plots may be due to better nutrient cycling and improved soil structure due to the integration of crops with trees.

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study compared soil physical and chemical properties between Taungya and Non-Taungya plots. The results showed significant differences in various soil properties between the two management practices.

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Taungya plots showed lower bulk density and higher porosity compared to non-Taungya plots, suggesting improved soil structure and better conditions for root growth and water infiltration. Soil Chemical properties, non-Taungya plots showed higher pH and electrical conductivity. However, Taungya plots demonstrated higher total nitrogen and available phosphorus levels, showing improved nutrient status for plant growth.

These findings suggest that the Taungya system can have positive effects on soil physical and chemical properties, which might lead to improved soil quality and forest productivity. The differences observed between February and May samplings also highlight the importance of considering seasonal variations in soil properties.

RECOMMENDATIONS

Based on the study of soil properties in Taungya systems the following recommendations were proposed to optimize the management and sustainability of these agroforestry practices.

- Long –term monitoring program to observe changes in soil properties under both management systems over long periods,
- Conduct soil sampling at multiple depths to understand the vertical distribution of soil properties and how management practices affect the different soil layers.
- Conduct detailed studies on the mechanisms accounting for the observed differences, such as the role of crop residues, root systems, and microbial activity in Taungya plots. These recommendations are tailored for implementation by government entities responsible forestry and agriculture also Policy making institutions.

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