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Original Article

Variation in Soil Organic Carbon and Total Nitrogen Content in Different Agroforestry Practices of Moshi Rural District, Northern Tanzania

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ABSTRACT

The variation and amount of carbon and nitrogen sequestered in agroforestry systems depends on the type of agroforestry practices, its condition and its characteristics. This study aimed to examine variations in Soil Organic Carbon (SOC) and Total Nitrogen (TN) with soil depth across Agroforestry Practices. A total of 105 plots (quadrants) measuring 10 m x 10 m were established along transects in three villages (35 quadrats in each village) in Moshi rural district, northern Tanzania. Soil samples were collected at three points along the diagonal of the quadrat using a soil auger. Soil sampling cylinders with a diameter of 6 cm and a height of 4.5 cm were used to collect volumetric soil samples for the estimation of bulk density. Soil organic carbon and total nitrogen were determined by Walkley and Black wet oxidation and Micro-Kjeldahl methods and expressed in tCha-1 and percentage (%), respectively. Variations in SOC and TN in different AFPs were determined by ANOVA in R software. The ratios between SOC and N in different AFPs were determined by regression analysis and subjected to ANOVA for a multiple-means comparison test. Variation in SOC and TN in the different AFPs was determined by ANOVA in R software. The amount and vertical distribution of SOC and TN across soil depths among Agroforestry Practices differed significantly ($P<0.05$). Coffee Intercropped Agroforestry Practice had significantly higher SOC at 0-20 cm depth compared to other AFPs ($P < 0.05$). However, TN in Coffee Intercropping Agroforestry Practices (CIAP) differed significantly with only Boundary Planting Agroforestry Practice (BAP) ($P < 0.05$). The amount of SOC and TN in CIAP differed significantly ($P<0.05$) with BAP and MAP at 20-40 cm. Soil Organic Carbon (SOC) was positively related to Total Nitrogen (TN) in the 0 – 20 cm and 20 – 40 cm depths ($P=0.049$, $r = 0.26$ and $P=0.0003$, $r=0.42$) respectively and was significant. The current study confirms that integrating coffee into agroforestry practices has a direct positive contribution to SOC and TN. Management practices in agroforestry systems should thus aim to encourage the maintenance of coffee in farmlands to ensure a stable amount of organic carbon and nitrogen in the soil.

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INTRODUCTION

Soil organic carbon (SOC) and total nitrogen (TN) are important indicators of soil quality (Smith *et al*., 2013), soil fertility (Gebrewahid *et al*., 2019), and sustainable land use management (Ge *et al*., 2013). They are also major components of global climate change largely through the role soils can play as a source or sink for carbon (C) and nitrogen (N) (Wang *et al*., 2016; Minasny *et al*., 2017). One of the most promising ways to build up SOC and TN in agricultural soils is agroforestry (Griscom *et al*., 2017; Bossio *et al*., 2020; Chapman *et al*., 2020; Pellerin *et al*., 2020). Agroforestry practices have a higher potential to sequester atmospheric CO_2 than single-crop croplands, pastures, or natural grasslands (Lorenz, & Lal, 2014). The art of combining woody perennials (trees and/or shrubs) with annual crops (maize, beans, sorghum, millet, etc.) and/or animals (cattle, goats, sheep, pigs, etc.) in the same piece of land can enhance to climate change adaptation and mitigation (Hunde, 2015; Gebrewahid *et al*., 2018).

The variation and amount of C and N sequestered in AFS depends on the type of agroforestry practice (AFP) (Negash, 2013; De Beenhouwer *et al*., 2016; Chatterjee *et al*., 2019), its structure, characteristics, and function influenced by environmental factors and management practices (Oelbermann *et al*., 2006; Saha *et al*., 2009). Also, the soil C and N stocks from different depths in tropical agroforestry may be governed by soil type and properties (Pan *et al*., 2013; Hobley *et al*., 2015). Several studies have found that agroforestry soils in the tropics contain more carbon and nitrogen than field crops or pastures in developing countries (Verchot *et al*., 2007; Nair, 2012). However, the amount of SOC and TN declines with depth from the surface layer (0-20 cm) towards the bottom layers and its amount differs from one AFP to another due to different land use and agroforestry management practices (Gao *et al*., 2017). Shaded coffee agroforestry systems integrated with tall trees have been reported to enhance high soil C and N sequestrations due to higher plant diversity (Monroe *et al*., 2016). Litter falls and massive roots in the coffee agroforestry system have an influence on SOC and TN availability (Oelbermann, & Voroney, 2007).

Despite studies showing the potential of agroforestry in sequestering carbon and nitrogen (Pandey, 2002; Lorenz, & Lal, 2014), their quantitative estimates in different AFPs are scarce (Pellerin *et al*., 2013; Upson, & Burgess, 2013). Most studies concern tropical regions where agroforestry is a more widespread agricultural practice (Albrecht, & Kandji, 2003; Somarriba *et al*., 2013), but studies which estimate variation and amount of SOC and TN in different agroforestry practices in Tanzania are rare. This may be due to resource constraints and the complexity of agroforestry practices (Tumwebaze *et al*., 2012). This study intended to fill this existing gap by estimating the vertical variation, amount, and ratios of soil organic carbon and total nitrogen in different AFPs of the Moshi rural

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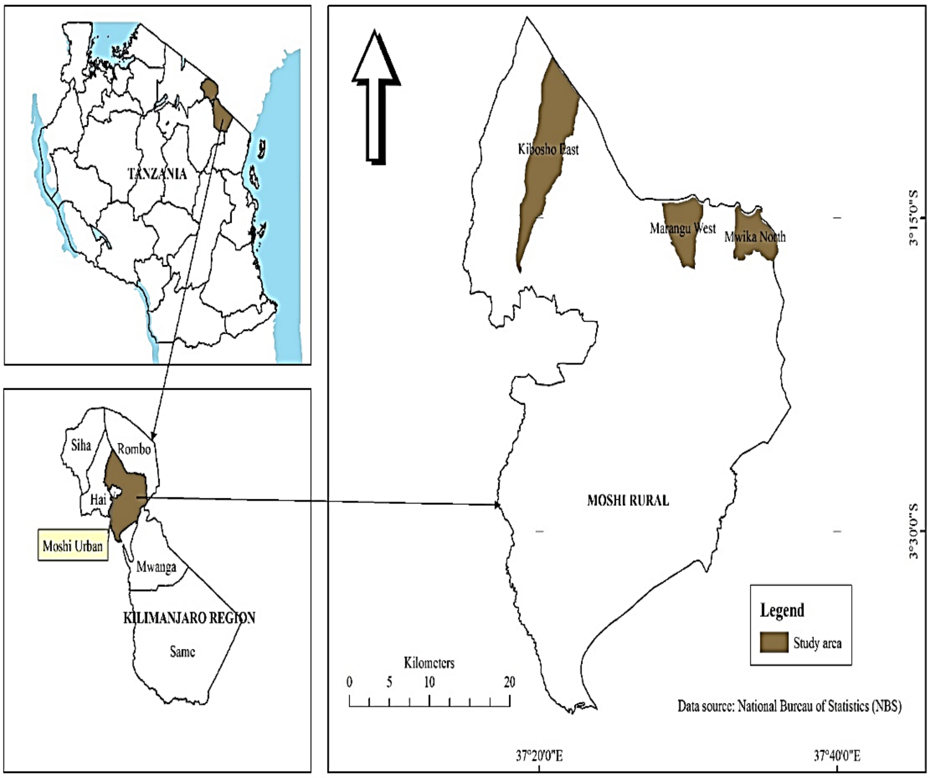
district in northern Tanzania. Therefore, these findings are essential because they will be required throughout these periods of climate change to determine which appropriate agroforestry practice is to be prioritized to produce more ecosystem services for climate change adaptation. Additionally, politicians and decision-makers will use these study findings to develop locally specific-policy solutions.

MATERIALS AND METHODS

Description of the Study Area

Moshi Rural District is within the Kilimanjaro region in the northern part of Tanzania, it lies between latitude 2^0 30' to 5^0 South and longitude 37^0 to 38^0 East (Figure 1). The district consists of three belts with different ranges of altitudes which are lowlands 900 m, middle lands 900 – 1200 m, and highlands 1200 -1800 m (Misana *et al*., 2012) and cover a total area of about 1,713 km^2. The population densities range between 500 - 1000 people per km^2 and are found within 1000 and 1800 m altitudes (Hemp, 2006). Land scarcity, land degradation due to tree cutting, and soil erosion were the main challenges faced by the district (URT, 1998), some parts of the district observed trees and coffee uprooted and replaced with valuable crops or domestic animals (Maghimbi, 2007). Rainy is of two seasons, major rain occurred between April – May and minor between September-November. Two dry seasons were experienced in the study area, major dry occurred between December-January and minor July-August. Range of altitude determines the amount of rainfall, 400-900 mm, 1000-12000 mm, and 1200-2000 mm for rainfall in lowland, midland, and highland belts respectively (Zongolo *et al*., 2000). Temperature varies with the range of altitudes and is cold and hot during the rainy and dry seasons respectively, temperatures in lowland areas are about 40^0C while in higher altitudes areas temperature ranges from about 15^0 - 30^0C (URT, 2002). The main social economic activities in the study area are crop farming, animal keeping, and small business, zero grazing being the main method of animal keeping due to land scarcity (FAO, 2012). The soil around is alluvial or colluvial volcanic soil, the textures vary between clay loams, silt loam coarse sand which is easily susceptible to erosion (Ikegami, 1994).

Figure 1: A Map of Moshi Rural District Showing the Selected Study Areas



METHODOLOGY

Sampling Strategy

The study was conducted in the Moshi rural district located in Kilimanjaro region, Tanzania. Three villages namely Samanga, Kiruweni, and Singa from Marangu East, Mwika South, and Kibosho East were selected based on the level of different agroforestry practices. Within each village, five agroforestry practices were identified (Table 1). These were; Coffee Agroforestry Practice (CIAP), Boundary Planting Agroforestry Practice (BAP), Mixed Intercropping Agroforestry Practice (MAP), Multiple Woody Perennial Practice (MWPAP), and Agrosilvopastoral Practice (ASP) (Mukundente *et al*., 2019; Basamba *et al*., 2016, Toral *et al*., 2013; Thangata, & Alavalapati, 2003). The description of each agroforestry practice is given below.

Agrosilvopastoral Practice (ASP)

Agroforestry practice in which animals and mixed crops plus trees/shrubs are cultivated on the same piece of land simultaneously. In ASP, crops are the main dominant rather than livestock production. The crop residuals and fodders from trees/shrubs are the main principal sources of feed for animals that are fed either inside or outside the hut. The farmer benefits greatly from this type of practice since it offers organic fertilizer for his crops as well as protein meals from the animals (Fernandes *et al*., 1986).

Coffee Intercropping Agroforestry Practice (CIAP)

It is a traditional and complex agroforestry practice, where coffee is associated with various food crops, including trees for sharing in different stories (Urgessa, & Fekadu, 2021). Plants with different heights (trees, food, and cash crops) are well combined in the same piece of land simultaneously. Solar energy can be used effectively while bananas and other tall trees provide shade for coffee plants. In this practice, the involvement of coffee crops could enhance adequate moisture and a mild climate keeping (Fernandes *et al*., 1986).

Multiple Wood Perennial Practice (MWPAP)

All wood perennials that are grown and scattered haphazardly on the farm provide more than one important contribution to the production or service functions (food, fodder, fuel, lumber, shelter, shade, and land sustainability) of the land use system in which they are planted (Mamo, & Asfaw, 2017). Commonly composed of multipurpose trees/shrubs and other fruit trees. The practice offers shade and mulch for soil erosion control, regulates soil moisture and temperature, improves soil nutrition and provides habitat for biodiversity (Asfaw, & Ågren, 2007), offers eaten food (Guyassa *et al*., 2014) and carbon sequestration (Gebrewahid *et al*., 2019).

Boundary planting Agroforestry Practice (BAP)

The practice is recommended for clarifying property and land use boundaries, consisting of a single line of widely spaced trees/shrubs. Spacing between tree/shrub rows is wider allowing crops to be grown between the tree/shrub rows. The spacing between trees varies from 2 to 10 m depending on the species and their intended uses (Basamba *et al*., 2016; Tafere, & Nigussie, 2018).

Mixed Intercropping Agroforestry Practice (MAP)

In this practice, trees/shrubs are dispersed irregularly and do not require a systematic arrangement. They are randomly mixed with several crops grown on the same unit of land during the same cropping season (Chirwa *et al*., 2003; Von Cossel *et al*., 2019). Mixed intercropping is commonly observed to fulfil the requirement of food where the land resource is a limiting factor (Undie *et al*., 2012).

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Table 1: Characteristics of Surveyed Agroforestry Practices

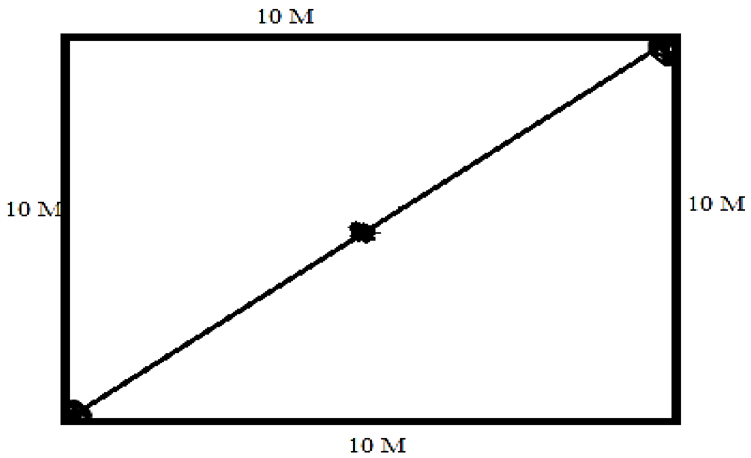
Agroforestry Practices	Brief description (arrangement of components)	Major groups of component	Common species in each agroforestry practice
Agrosilvopastoral Practice (ASP)	-Livestock, various crops and trees/shrubs are managed on the same piece of land. -Crops are the main dominant plants. -Crop residuals, trees/shrubs fodder are used as livestock feed. -It offers organic fertilizer.	-Trees -Shrubs -Livestock -Crops	*Musa* spp, *Phaseolus vulgaris*, Goat (*Capra aegagrus hircus*), Domestic chicken (*Gallus gallus domesticus*), Domestic cattle (*Bos taurus*), fodder plants, *Annona reticulata, Citrus limona, Citrus sinensis, Mangifera indica.*
Coffee Intercropping Agroforestry Practice (CIAP)	-Coffee is the dominant plant species. -Bananas and tall trees provide shade. -Plants are irregularly and randomly arranged.	-Coffee -Trees -Shrubs -Crops	*Coffea arabica,Artocarpusheterophyllus, Erythrina abyssinica, Grevillea robusta, Mangifera indica, Tectona grandis*
Boundary planting Agroforestry Practice (BAP)	-A single line of widely spaced trees/ shrubs. -Farm demarcation and windbreaks -Protect crops from wildlife, domestic animals and human interference.	-Trees -Shrubs -Crops	*Artocarpusheterophyllus, Erythrina abyssinica, Tectona grandis, Macaranga capensis, Makaranga kilimandscharica, Albizia gummifera Albizia schimperiana*
Multiples Wood Perennial Practice (MWPAP)	-Multipurpose trees/shrubs are dominant -Woody perennial species grown and scattered haphazardly on the farm -Provide more than one production (food, fodder, fuel, timber, shelter, shade)	-Trees -Shrubs	*Leucaena leucocephala, Syzygium cumini, Syzygium guineense, Annona reticulata, Citrus limona, Citrus sinensis, Mangifera indica, Tamarindus indica*
Mixed Intercropping Agroforestry Practice (MAP)	-Trees/shrubs are dispersed irregularly (do not require systematic arrangement) -Randomly mixed with several crops to fulfil the requirement of food where land is scarce.	-Trees -Shrubs - Crops	*Zea mays, Phaseolus vulgaris, Annona reticulata, Citrus limona, Citrus sinensis, Mangifera indica, Manihot esculenta*

Soil Samples Collection

Two transects were established across each study village. Plots (quadrants) of 10 m x 10 m (100 m^2) were established in each agroforestry practice at an interval of 100 m (Soto-Pinto *et al*., 2002; Fonte *et al*., 2010; Parihaar *et al*., 2015; Mganga *et al*., 2016). To avoid bias, soil samples were collected from three points along the diagonal of the plot, two points, one from each corner and one point at the centre of the diagonal (plot centre) (Ding *et al*., 2017), giving a total of three positions per sampling plot (Figure 2). A soil auger was used to drill soil samples at the top-surface layer (0-20 cm) and sub-surface layer (20-40 cm) (Tan, 2005). Soil samples from each depth were mixed to get a composite sample (Munishi *et al*., 2004).

From each composite sample, a portion of 300 grams was taken and carefully sealed in aluminium foil. Soil sampling cylinders with a diameter of 6 cm and height of 4.5 cm were used to collect volumetric soil samples for the estimation of bulk density. The soil samples were labelled, placed in plastic bags, and transported to the laboratory for analysis.

Figure 2: A Quadrant Indicating the Plot Size and Soil Samples Collection Points



Analysis of Soil Organic Carbon and Total Nitrogen

In the laboratory, the soil samples were air and oven-dried (60ºC to 70ºC for 18 hours). This is the standard temperature for SOC and total nitrogen analysis. The 105ºC to 110ºC is usually used only when you are doing soil moisture analysis. Roots and organic debris were removed, and the soil was ground to a fine powder and sieved through a 2 mm sieve (Wills *et al.*, 2007). The Walkley and Black wet oxidation method was used to determine the organic content in which the organic matter in the soil is oxidized by 1 N $K_2Cr_2O_7$ solution. The Walkley–Black method was used since is the most common, rapid, and widely used procedure, and it requires less equipment (Nelson, & Sommers, 1996). The amount of SOC in tonnes per hectare was obtained by: SOC (t C ha^{-1}) = BD (g/cm^3) × OC (%) × depth (cm) × 10 000 m²/100; Where, BD = bulk density, OC = organic carbon. Total N content was determined using the Micro-Kjeldahl method (Mulvaney, 1996) while the amount of TN in tonnes per hectare was obtained by: TN (t N ha^{-1}) = BD (g/cm^3) × TN (%) × depth (cm) × 10 000 m²/100; Where, BD = bulk density, TN = total nitrogen. The difference in SOC and TN among the different agroforestry practices was determined by ANOVA in R software (R Development Core Team, 2020). The SOC and TN ratios across the different depths and agroforestry practices were subjected to ANOVA for multiple means comparison.

RESULTS

Vertical Variation of Soil Organic Carbon and Total Nitrogen in Top-Surface and Sub-Surface Layers in Different AFPs

Soil organic carbon and total nitrogen contents decreased significantly with increasing soil depth from the top surface (0-20 cm) to the sub-surface (20-40 cm) for the entire dataset (all AFPs). In contrast, there was a gradual increase in the bulk density with an increase in soil depth in all AFPs (Table 2). The average SOC in 40 cm soil depth of all AFPs was found to be 2.11% with much SOC contents in CIAP. The amount of TN contents (1.68%) stored in the 20-40 cm soil depth was around half of that in the 0-20 cm soil depth (3.15%) for all AFPs (Table 2). The average total nitrogen in 40 cm soil depth of all AFPs was found to be 0.49% with much TN contents in CIAP. The average bulk density in the 0-20 cm was found to be 0.92 gram per cubic centimetre (g/cm^3) and 1.12g/cm^3 in the 20-40 cm depth for the entire dataset. The average bulk density in 40 cm soil depth of all AFPs was found to be 1.02g/cm^3 with much bulk density in CIAP (Table 2).

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Table 1: Average BD (g/cm^3), SOC (%), and TN (%) at various depths and AFPs

AFPs	Bulk density (g/cm^3)			Soil organic carbon (%)			Total nitrogen (%)		
	Soil depth (cm)			Soil depth (cm)			Soil depth (cm)		
	0-20	20-40	Total average	0-20	20-40	Total average	0-20	20-40	Total average
CIAP	0.97	1.14	1.06	3.15	1.96	2.56	0.81	0.37	0.59
BAP	0.94	1.08	1.01	1.95	1.61	1.78	0.56	0.28	0.42
MAP	0.90	1.09	1.00	1.82	1.49	1.66	0.67	0.29	0.48
MWPAP	0.84	1.16	1.01	2.51	1.87	2.19	0.53	0.38	0.46
ASP	0.95	1.11	1.03	2.78	1.97	2.38	0.59	0.36	0.48

Source: Authors

Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=Multiple Wood Perennial Agroforestry Practice, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice,

However, there was a significant vertical decrease in the amount of SOC stocks in CIAP and ASP from 0-20 cm to 20-40 cm depths. In contrast, the vertical variation in the amount of TN stocks from 0-20 cm to 20-40 cm depths showed a significant decrease in all AFPs except in MWPAP (Table 3).

Table 2: Mean and *P*-values of SOC (t Cha^{-1}) and TN (t Nha^{-1}) and their Vertical Variation among AFPs in the Top-surface and Sub-surface layers.

AFPs	SOC (t Cha^{-1})			TN (t Nha^{-1})		
	0 - 20 cm	20 - 40 cm	*p*-value	0 - 20 cm	20 - 40 cm	*p*-value
CIAP	66.1	41.6	0.000	16.5	8.8	0.001
BAP	29.9	32.0	0.271	10.8	5.4	0.003
MAP	32.4	31.9	0.429	11.1	6.4	0.000
MWPAP	42.7	44.7	0.354	8.6	7.7	0.062
ASP	54.5	43.5	0.003	10.8	7.8	0.034

Source: Authors

Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=Multiple Wood Perennial Agroforestry Practice, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice.

Moreover, the ANOVA results of multiple comparisons (Table 4) indicated that the mean SOC in the top-surface layer differed significantly between all AFPs except BAP and MAP while only CIAP showed a significant difference in the amount of TN stock with all AFPs. However, the ANOVA results of multiple comparisons for the amount of SOC and TN stocks in 20 - 40 cm depth indicated that ASP, MWPAP, and CIAP differed significantly from BAP and MAP (Table 4).

Table 3: The ANOVA Results of Multiple Comparisons for the Mean SOC and TN in the Top-surface and Sub-surface Layers of Five AFPs

Soil depth (cm)	AFPs	SOC (t Cha^{-1})	TN (t Nha^{-1})
0 – 20	ASP	54.5^{a}	10.8^{a}
	MWPAP	42.7^{b}	8.6^{a}
	CIAP	66.1^{c}	16.5^{b}
	BAP	30.0^{d}	10.8^{a}
	MAP	32.4^{d}	11.1^{a}
20 – 40	ASP	43.5^{a}	7.8^{a}
	MWPAP	44.7^{a}	7.7^{a}
	CIAP	41.6^{a}	8.8^{a}
	BAP	32.0^{b}	5.4^{b}
	MAP	31.9^{b}	6.4^{b}

Source: Authors

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Values in each column with the same letters are not significantly ($P < 0.05$) different across AFPs. Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=Multiple Wood Perennial, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice.

Variation of SOC and TN in Top-Surface and Sub-Surface Layers Across AFPs

The ANOVA results indicated that the SOC and TN stocks across all AFPs are statistically different (P< 0.001) in both 0-20 cm and 20-40 cm depths (Table 5), indicating that varied levels of AFPs are associated with varying SOC and TN levels.

Table 4: Variation of Mean SOC and TN Top-surface and Sub-surface Layers across All AFPs

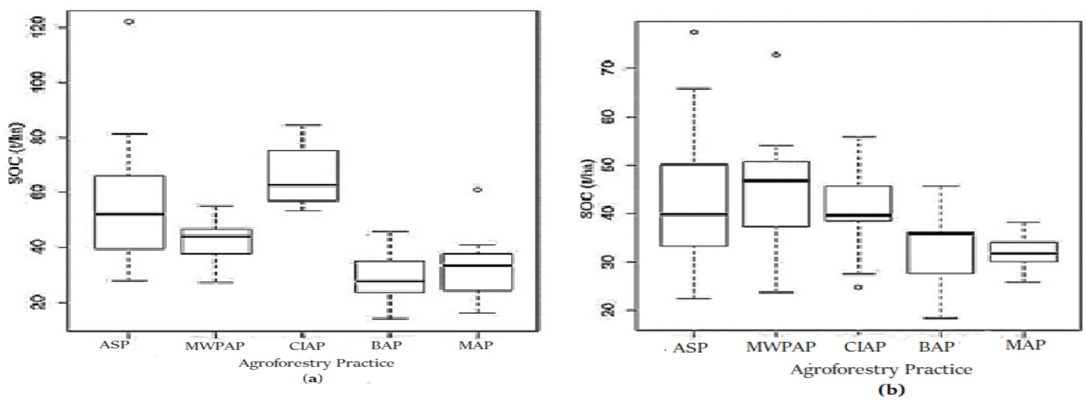
Depth	Soil Organic Carbon (t C ha^{-1})					
	CIAP	**BAP**	**MAP**	**MWPAP**	**ASP**	**P - values**
0-20	66.1	29.92	32.43	42.66	54.52	0.0000
20-40	41.55	31.98	31.91	44.68	43.45	0.0000
	Total Nitrogen (t N ha^{-1})					
0-20	16.5	10.8	11.1	8.6	10.8	0.0018
20-40	8.8	5.4	6.4	7.7	7.8	0.0013

Source: Authors

Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=Multiple Wood Perennial Agroforestry Practice, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice.

However, Figure 3 (a) shows the difference in the amount of SOC stocks within the 0-20 cm depth in all agroforestry practices. The SOC at the 0-20 cm depth was highest in the Coffee Agroforestry Practice while in Figure 3 (b) SOC was highest in the Multiple Wood Perennial Practice (Table 5). Moreover, Figures 4 (a) and (b) show that at 0-20 cm and 20-40 cm depths, the amount of TN stocks was highest in the Coffee Agroforestry Practice (Table 3). Furthermore, the amount of SOC stocks in the Coffee Agroforestry Practice differed significantly from all other AFPs ($P < 0.05$) only at 0-20 cm soil depth.

Figure 3: Box Plots for the Amount of SOC among Agroforestry Practices
(a) 0 -20 cm (b) 20 - 40 cm depths (N=21)



Source: Authors

Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=MultipleWood Perennial Agroforestry Practice, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice

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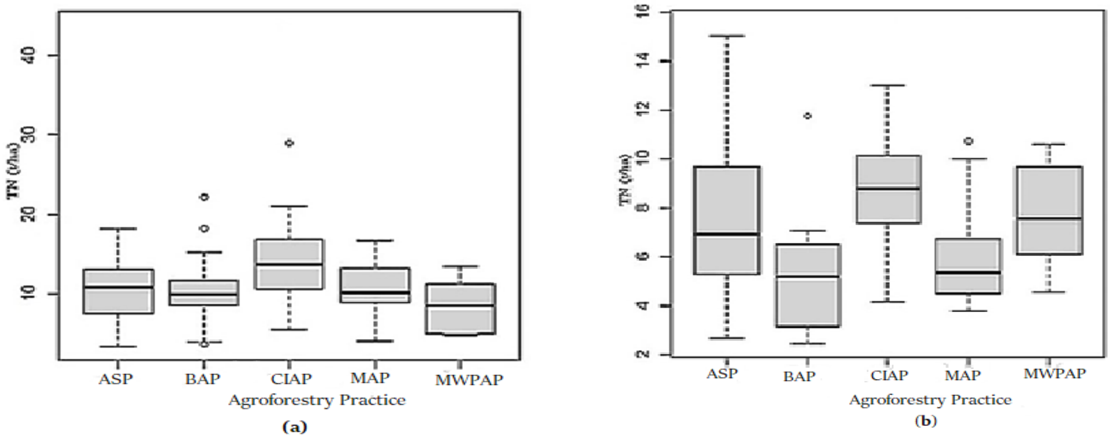
Figure 4: Box Plots of the Amount of TN among Agroforestry Practices (a) 0 - 20 cm (b) 20-40 cm depths (N=21)



Source: Authors

Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=multiple Wood Perennial Agroforestry Practice, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice.

Ratios of Soil Organic Carbon and Total Nitrogen

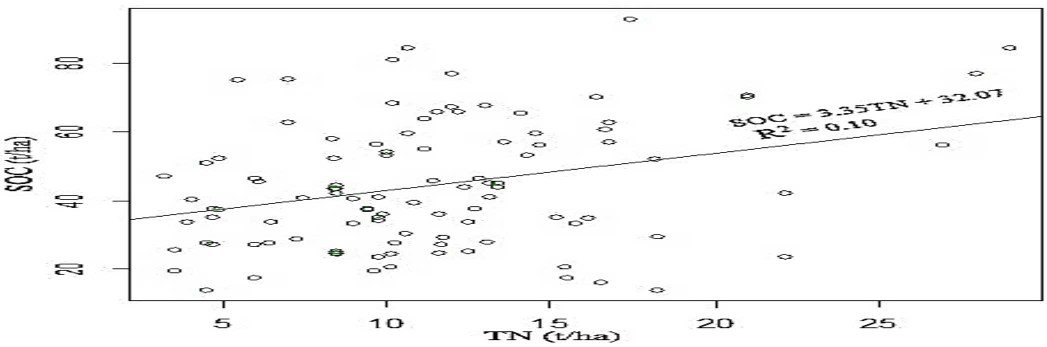
Regression analysis was performed on the SOC and TN data for 0-20 cm and 20-40 cm depths to determine if there was a relationship between the two variables in all AFPs. The results in 0-20 cm depth show a slightly significant (*P*-value = 0.001) positive correlation between SOC and TN (Table 6). This means that the amount of TN stocks increases as the amount of SOC stocks in the soil increases. Figure 5 is a plot of the entire dataset (n = 105) for 0-20 cm depth. This graph illustrates the minimal correlation between the two variables confirmed by the low $R^2 = 0.10$ value. There was no significant correlation between the amount of SOC and TN stocks (Table 6) and (Figure 6) in 20-40 cm depth.

Table 5: Regression Analysis between SOC and TN in Top-surface and Sub-surface Layers for the Entire Dataset

Test parameters	Depth (cm)	DF	R^2	*F*-statistic	*p*-values
TN Vs SOC	0 - 20	103	0.10	11.22	0.001
	20 - 40	103	0.02	2.44	0.122

Source: Authors

Figure 5: Correlation Plot of SOC Stock (t/ha) and TN Stock (t/ha) across all AFPs in 0 - 20 cm Depth (n = 105). Linear Correlation Exists



Source: Authors

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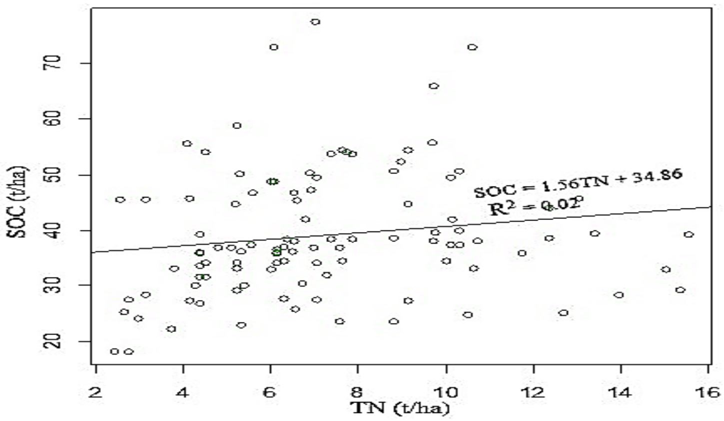
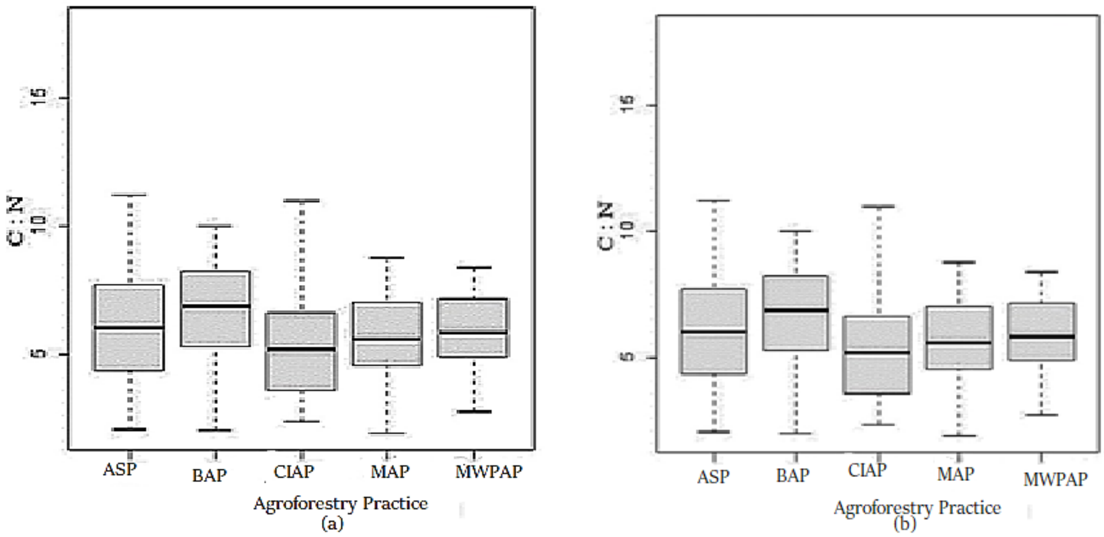
Figure 6: Correlation Plot of SOC Stock (t/ha) and TN Stock (t/ha) across all AFPs in 20 - 40 cm Depth (n = 105)



Source: Authors

However, Figure 7 (a) shows the mean differences in C: N stocks at the 0-20 cm depth in agroforestry practices. The C: N at the 0-20 cm depth was highest in the Agrosilvopastoral Practice while at the 20-40 cm depth, the C: N was highest in the Boundary Planting Agroforestry Practice (Figure 7 (b)). The ANOVA indicated that C: N ratio within 0-20 cm depth differed significantly (DF = 4, F-value = 5.37, *P* = 0.00058) among agroforestry practices but there was no significant difference (DF = 4, F-value = 1.71, *P* = 0.153) in C: N ratio at the 20-40 cm depth.

Figure 7: Box Plots of the Mean Differences in C: N among Agroforestry Practices (a) 0-20 cm (b) 20-40 cm Depths (N=21)



Source: Authors

Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=multiple Wood Perennial Agroforestry Practice, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice.

Moreover, the ANOVA results of multiple comparisons for the mean C: N in the top-surface layer indicated that ASP, MWPAP, and CIAP differed significantly from BAP and MAP (Table 7). However, there was no significant difference in the C: N ratio at the sub-surface layer in all AFPs.

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Table 7: ANOVA Results of Multiple Comparisons for Mean and *P*-values of SOC to TN Ratios in Various AFPs

AFPs	C: N	
	0-20 cm	20-40 cm
CIAP	5.29a	5.35[a]
BAP	3.46b	7.29[a]
MAP	3.18b	5.60[a]
MWPAP	5.56a	6.29[a]
ASP	5.73a	6.55[a]

Source: Authors

Values in each column with the same letters are not significantly (P < 0.05) different across AFTs. Where, BAP=Boundary Planting Agroforestry Practice, MWPAP=Multiple Wood Perennial, ASP=Agrosilvopastoral Practice, CIAP=Coffee Intercropping Agroforestry Practice, MAP=Mixed Intercropping Agroforestry Practice.

DISCUSSION

The average bulk density in 40 cm depths in all AFPs was found to be 1.02 g/cm^3 different from the average value of 1.19 g/cm found by Kafle *et al*. (2020) in Tropical Agroforests of the Churiya Range in Makawanpur, Nepal. The average soil organic carbon in the 40 cm soil depth of the AFPs was found to be 2.11% with much SOC contents in CIAP which is similar to Kafle *et al*. (2020) who found 2.1% SOC in Tropical Agroforests in the Churiya Range of Makawanpur, Nepal. This may be due to different or similar physiographical ranges, climatic conditions, and soil sampling techniques. According to Negash, & Starr (2013), the amount of soil organic carbon and total nitrogen in agroforestry systems differs with regions, agroforestry systems, and soil depths. The amount of TN contents (1.68%) stored in the 20-40 cm soil depth was around half of that in the 0-20 cm soil depth (3.16%) for the entire dataset (Table 2). The higher average total nitrogen percentage in 0-20 cm depth may be caused by the higher organic matter content in 0-20 cm of the agroforestry practices in the study area.

Our results show that vertical variation and the amount of SOC and TN contents in the soil are influenced by agroforestry practices. Pathak, & Reddy (2021) found that SOC and TN varied with land use patterns and that in all land use patterns SOC and TN were highest in the topmost soil horizon (0-10 cm) and then decreased towards deeper horizons (up to 40 cm) in the soil profile. But many studies have demonstrated that SOC and TN decrease with increasing soil depth (Song *et al*., 2016; Pandey, & Bhusal, 2016; Ghimire *et al*., 2018; Kunlanit *et al*., 2019) irrespective of land uses and vegetation types. The above findings agree with the findings of this study for the vertical variation of total nitrogen but deviate from the vertical variation of SOC. Total nitrogen showed a decreasing pattern as soil depth increased in all agroforestry practices. But SOC contents decreased from 0-20 cm to 20-40 cm depths in Coffee Agroforestry Practice, Mixed Intercropping Agroforestry Practice, and Agrosilvopastoral Practice, and increased from 0-20 cm to 20-40 cm depths in Boundary Planting Agroforestry Practice and Multiple Wood Perennial Practice.

This may be due to a reduction in the quantity and quality of organic inputs added to the soil in different agroforestry practices as well as the nature of organic matter translocation across soil depths. Also, management options in agroforestry practices differ from one another. For example; differences in tillage types and frequencies that mix up the surface and deep soil depending on the AFP may cause variation in the amount of SOC to the topsoil layer. Riezebos, & Loerts (1998) suggested that soil mixing in tillage systems can completely translocate surface SOC to lower depths. However, Lorenz, & Lal (2014) suggested that the adoptions of agroforestry management practices are site-specific which would affect the overall performance of SOC. Understanding the amounts and dynamics of SOC and TN in different agroforestry practices is important for designing sustainable soil management options.

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Our study indicates that various AFPs have an impact on SOC and TN heterogeneity by affecting litter fall and accumulation, surface runoff, and root distribution. This is attributed to the inclusion of different plant species in AFPs which significantly influence the amount of organic carbon and nitrogen in the soil. Coffee Intercropping Agroforestry Practice, Mixed Intercropping Agroforestry Practice, and Agrosilvopastoral Practice revealed higher amounts of SOC and TN in the 0-20 cm and 20-40 cm depths than other AFPs. Mayer *et al*. (2021) reported that hedgerows (boundary tree planting) had the highest SOC sequestration in the topsoil and subsoil, followed by alley cropping systems while silvopastoral systems showed a slight mean of SOC. In contrast, our results found that Boundary Planting Agroforestry Practice and Multiple Wood Perennial Practice had relatively lower SOC and TN. This may be due to the anthropogenic influence (frequent tillage) (Shrestha *et al*., 2004) and soil erosion because the agroforestry trees/shrubs are not well incorporated into the systems. Lowering SOC possibly will result in lowering TN as well if all conditions remain the same. Therefore, management practices in agroforestry practices should also aim to minimize disturbances to ensure the maximum amount of organic carbon in the soil (Negash *et al*., 2022).

Our study found that Coffee Agroforestry Practice had higher SOC and TN at 0-20 cm depth compared to other AFPs. Our findings are similar to Tumwebaze, & Byakagaba (2016) who found that SOC was greater under coffee-based AFs (49.64 –71.17 t C ha^{-1}) than coffee mono-crops (50.987–51.780 t C ha^{-1}) in Uganda. This may be attributed to the continuous input of leaves, foliage, and dead roots by the shade trees and crops in the agroforestry systems than in a single species agroecosystem. Schmitt-Harsh *et al.* (2012) reported that shade trees in coffee intercropping play an important role in facilitating carbon sequestration and soil conservation. However, the extent to which organic material is deposited depends on both species (the crop and shade tree) and the management system involved (Gama-Rodrigues *et al*., 2011). Therefore, this study suggests further studies on integrating coffee shrubs in agroforestry practices to enhance soil carbon and nitrogen.

Furthermore, we found a positive relationship between soil organic carbon and total nitrogen in different agroforestry practices. This indicates the interdependence between soil carbon and nitrogen in ecosystem processes and functions. Our results are similar to Guo *et al*. (2020) who found a significant positive linear relationship between the SOC and TN contents in afforestation and agroforestry systems of eastern China. However, studies by Reich *et al*. (2006) and Liu, & Greaver, (2010) reported that nitrogen plays a crucial role through the interaction with carbon in the ecosystem productivity and carbon sequestration. Kafle (2019) found a positive correlation between SOC and nitrogen in the Kankali community forest in the Chitwan district located in the tropical region of Nepal. Gautam, & Mandal (2013) also reported a positive correlation between SOC and nitrogen in a tropical moist forest in eastern Nepal. Moreover, nitrogen is a significant stimulant of plant growth (Niu *et al*., 2010; Liu *et al*., 2017) and an important limiting element in terrestrial ecosystems (Vitousek, & Howarth, 1991). This indicates that, while quantifying soil nutrients and their interactions in agroforestry, nitrogen should not be ignored. Therefore, rapid estimations of soil N stocks will facilitate assessments of the role of soil in terrestrial ecosystems in terms of N and C cycles.

CONCLUSIONS AND RECOMMENDATION

We can conclude that soil organic carbon and total nitrogen in different AFPs are different in both 0-20cm and 20-40cm depths. This indicates that varied levels of AFPs are associated with varying SOC and TN or different AFPs are linked with substantial differences in SOC and TN. Coffee Agroforestry Practice showed a direct positive contribution to SOC and TN than other AFPs. Soil organic carbon within the 0-20 cm and 20-40 cm soil depths was positively correlated with total nitrogen. Understanding soil organic carbon and

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total nitrogen in different agroforestry practices is very crucial as it has an impact on soil fertility and influences the availability of soil nutrients. Therefore, the study recommends the AFP which should aim to encourage the maintenance of trees in farmlands to ensure the maximum amount of carbon and nitrogen in the soil. Therefore, agroforestry practices of the Moshi rural district in Northern Tanzania have played a role in global climate change mitigation by storing considerable amounts of SOC and TN.

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