East African Journal of Forestry and Agroforestry, Volume 7, Issue 1, 2024
Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

East African Journal of Forestry & Agroforestry
eajfa.eanso.org
Volume 7, Issue 1, 2024
Print ISSN: 2707-4315 | Online ISSN: 2707-4323
Title DOI: https://doi.org/10.37284/2707-4323

EANSO
EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

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

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Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

Date Published:

10 November 2024

Keywords:

Soil Moisture Contents, Vertical and Spatial Variations, Infiltration, Agroforestry Practice.

ABSTRACT

Agroforestry has been widely practiced in the northern highlands of Tanzania because of its prominent effects in reducing soil losses, maintaining soil moisture contents (SMCs), and improving land-use efficiency and farmer's livelihood. We tested the hypothesis that variations of soil moisture contents in 0-20 cm and 20-40 cm depths from various agroforestry Practices differ significantly in intensified small-scale agroforestry systems. The relationship between SMCs and soil organic carbon was also evaluated. Soil samples were collected from 10 x 10 m2 plot in three points along the diagonal of the quadrat using soil auger. SMCs were determined by gravimetric method and expressed as SMC%. SOC was determined by Walkley and Black method and expressed as SOC %. The variation in SMCs% among the different agroforestry Practices were statistically determined by ANOVA in R software while the correlation between SMCs and SOC were statistically determined by Pearson product-moment analysis. Variation of SMCs was statistically insignificant ($p>0.05$) among surveyed sites. SMCs increased significantly ($p<0.05$) with increasing soil depth from 0-40 cm depth in all agroforestry Practices except in the mixed intercropping agroforestry practice (MAP). At 0-20 cm and 20-40 cm, SMCs differed significantly among agroforestry Practices ($P = 0.071$) and ($P = 0.003$), respectively. Coffee Intercropping Agroforestry Practice (CIAP) had higher ($P<0.05$) SMCs at 0-20 cm depth compared to BAP and MWPAP. But, at 20-40 cm depth, soil moisture contents in CIAP differed significantly ($P<0.05$) with SMCs all AFPs. SMCs showed a positively significant ($P<0.05$) relationship with SOC within 0-20 cm and 20-40 cm depths. The current study confirms that different agroforestry practices have different influence on the amount and vertical distribution of soil moisture. Therefore, management practices in agroforestry systems should aim to encourage the use of practices which ensure a stable amount of moisture contents in the soil.

APA CITATION

Saria, G., Munishi, P. & Kashaigili, J. (2024). Variation in Soil Moisture Content and Soil Organic Carbon in Different Agroforestry Practices in Moshi Rural District, Northern Tanzania. *East African Journal of Forestry and Agroforestry*, *7*(1), 403-422. https://doi.org/10.37284/eajfa.7.1.2402

CHICAGO CITATION

Saria, Godlisten, Pantaleo Munishi and Japhet Kashaigili. 2024. "Variation in Soil Moisture Content and Soil Organic Carbon in Different Agroforestry Practices in Moshi Rural District, Northern Tanzania" *East African Journal of Forestry and Agroforestry* 7 (1), 403-422. https://doi.org/10.37284/eajfa.7.1.2402.

HARVARD CITATION
Saria, G., Munishi, P. & Kashaigili, J. (2024), "Variation in Soil Moisture Content and Soil Organic Carbon in Different Agroforestry Practices in Moshi Rural District, Northern Tanzania", *East African Journal of Forestry and Agroforestry*, 7(1), pp. 403-422. doi: 10.37284/eajfa.7.1.2402.

IEEE CITATION
G., Saria, P., Munishi & J., Kashaigili "Variation in Soil Moisture Content and Soil Organic Carbon in Different Agroforestry Practices in Moshi Rural District, Northern Tanzania", *EAJFA*, vol. 7, no. 1, pp. 403-422, Nov. 2024.

MLA CITATION
Saria, Godlisten, Pantaleo Munishi & Japhet Kashaigili. "Variation in Soil Moisture Content and Soil Organic Carbon in Different Agroforestry Practices in Moshi Rural District, Northern Tanzania". *East African Journal of Forestry and Agroforestry*, Vol. 7, no. 1, Nov. 2024, pp. 403-422, doi:10.37284/eajfa.7.1.2402

INTRODUCTION

Agroforestry system is the land use system where by trees are integrated with annual crops and/or domestic animals within the same piece of land (Zhu *et al*., 2018). The system offers sequence of useful ecosystem services for farmer`s livelihood improvement and conservational biodiversity (Tscharntke *et al*., 2011; Bucheli & Bokelmann, 2017). Ecosystem services recognized on-farms are food, soil fertility, water infiltrations, and fuel wood (De Stefano & Jacobson, 2018). It also recognizes off-farms which are water conservations, carbon storage, and biodiversity (plant richness and evenness) (Steenwerth *et al*., 2014 and Zhu *et al*., 2018). Tree canopy in agroforestry system (AFS) provides shade which can influence microclimate nearby crops plant (Lin, 2007), prevent water loss against evaporation and can maintain greater soil moisture in the system (Lin, 2007; Lin, 2010; Zhu *et al*., 2019).

Vertical distribution of soil water content (SWC) can greatly affect soil water movement (Xing *et al*., 2012), thereby greatly affecting the biomass production and water use efficiency of plants under water stress (Li *et al*., 2011). Research by Li *et al*. (2010) showed that the SWC was increased with the increasing depth in the three types of sandy land. Lin *et al*. (2010) also studied the change of SWC in the vertical soil profile under three different types of plant barriers. The change of SWC was different at different depths. However, amount of water capacity in deep soils is affected with deep rooted plants which is directly increased with root depth (Leung *et al*., 2015). But, soils under the beneath of the trees has ability to hold higher soil moisture content due to soil aggregate and more preferential flow (Pérès *et al*., 2013; Wu *et al*., 2016; Gould *et al*., 2016; Hasselquist *et al*., 2018). Previous studies compared and analyzed the changes in the SWC among different land use and vegetation types across the entire vertical soil profile. Few studies involved the soil moisture vertical distribution under different agroforestry technologies. Therefore, this study aims to fill this existing gap to evaluate the amount of SMC in spatial and vertical soil profile under different AFPs.

Moreover, in AFS, plant cover (tree/shrub cover) conserve soil moisture content against the evaporation from the soil surface (Bayala *et al*., 2015; Milcu *et al*., 2016; Ilstedt *et al*., 2016; Hasselquist *et al*., 2018). Again, the differences in rainfall interception, infiltration, and evapotranspiration related to agro-ecosystem type can lead to soil moisture variations within the same land scape (Lange *et al*., 2014; Milcu *et al*., 2016). Some research has indicated that, different plant species can lead into variation of soil moisture contents due to the variation of rainfall-runoff responses and root system patterns (Yang *et al*., 2014; Rey *et al*., 2017; Padovan *et al*., 2018). Many have studied soil moisture variability for evaluating the factors controlling soil moisture, determining their significance in the ecosystem processes and predicting soil moisture on a large scale (Ba´rdossy & Lehmann, 1998; Qiu *et al*., 2001; Qiu *et al*., 2003). But little attention is paid to the influences of agroforestry practices on soil moisture contents. In some related studies, it was considered that the trees can improve soil moisture holistic conditions in intercropping systems (Meng *et al.*, 2004; Hirota *et al*., 2004) while other studies reported opposite

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

results (Jose *et al*., 2000; Lott *et al*., 2000; Miller & Pallardy, 2001).

Furthermore, frequent farming to the intensified land and changing of practices might result for SOM decline by reducing soil aggregate stability used to hold soil moisture content (Li *et al*., 2008). Such as in latest years, the complex coffee agroforestry system has been observed to mimics a dense multi-story canopy forest with a nicely functions as a watershed (Alemu, 2015). But in a decades ago, the thick coffee agroforestry systems have declined due to land use changes which affects most of the coffee producing areas (Eakin *et al*., 2006). In the study area, coffee production has declined thus caused land use transformations whereby some of small-scale coffee growers have uprooted their coffee and trees by replaced with a new valuable crop (Aide & Grau, 2004). Land use transformation had affected the plant diversity and intensity (Philpott *et al*., 2008).

Tillage practices deprives soil's capacity to hold water, deteriorates structure stability and compactness, nutrient supply, and storage (Lal & Shukla, 2004; Marcela, 2009). An input of particular interest thought to have an interaction on SOC potential is soil moisture content (SMC). The area with large amount of OC contents, its soil tends to increase size, number and continuity of pore spaces which increases the ability to transmit and hold water (Strudley *et al*., 2008; Benegas *et al*., 2014). Researches had confirmed the existence of relationship between SMC and SOC (Azlan *et al*., 2012; Parajuli & Duffy, 2013; Kerr & Ochsner, 2020; Kome *et al*., 2021), and indicated that the higher SOC increase SMCs in the soil (Hugar & Soraganvi, 2014). Since there is the direct relationship between SOC with SMC, the variation of SOC within the land use system might also cause the variations of the soil moisture content (Kar *et al*., 2020).

It is necessary to understand the amount of soil water contents under different agroforestry technologies. This not only lays the foundation for the effective use of water resources in AFSs, but also plays an important role in the evaluation of land productivity. Therefore, the objective of this chapter is to analyse the effects of agroforestry practices on soil moisture contents. In particular, it focuses on the following aspects: (i) to analyse the side effect on the amount of soil moisture contents, (ii) to quantify the amount and vertical variation of soil moisture near surface and sub-surface layers in AFPs, (iii) to characterize the spatial variability of SMC near surface and sub-surface layers under different AFPs, (iv) to determine the effects of coffee farming on the amount of SMC in different AFPs, and (v) to evaluate the relationship between soil organic carbon and soil moisture contents.

MATERIALS AND METHODS

Description of the Study Area

Moshi Rural District is within the Kilimanjaro region at the northern part of Tanzania, it lies between latitude $2^0 30'$ to 50^0 South and longitude 37^0 to 38^0 East (*Figure 1*). It covers the total area of about 1,713 Km^2. Three belts with different altitude are recognized in the study area, 0 m to 900 m, 900 m to 1200 m and 1200 m to 1800 m altitudes for lowland, middle lands, and highland respectively (Misana *et al*., 2012). The altitude between 1000 m and 1800 m is highly populated whereby the population densities found to be between 500-1000 peoples per km^2 (Hemp, 2006). Some place in the district, population densities appeared to be higher than those found in urban population densities (Soini, 2006). Populations increase and land fragmentation has been a big blow to the coffee economy, little of the land available still are subdivided to be given to each son causing land shortage for coffee and other cash crop cultivations (Mhando & Mbeyale, 2010).

Land scarcity and soil erosion due to tree and coffee uprooting is the among the challenge in the study area (URT, 1998). Valuable crops and or animal keeping replaced coffee plant (Maghimbi, 2007). Two seasons of rainy recognized, April-May and September- November for major and minor rainfall respectively, two dry seasons are also experienced, December – January and July-August for major and minor dry seasons respectively. Altitude determines the extent of

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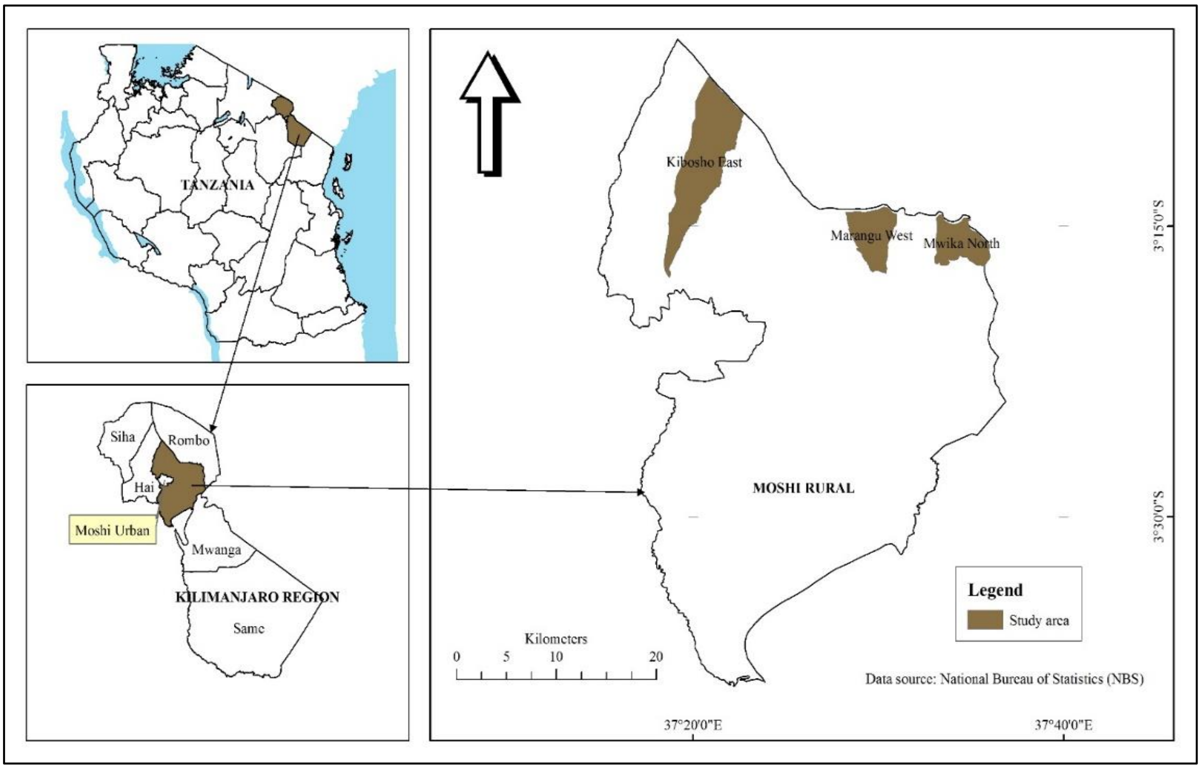
rainfall, it ranges from 4000 – 900 mm, 1000 – 1200 mm, and 1200 – 2000 mm for lowland, middle land, and highland belts respectively (Zongolo et al., 2000). Temperatures varies with altitude level, 40 °C and about 15^0 – 30 ^{0}C for lowland and highland belts respectively (URT, 2002). Mean annual temperature in the region varies between 10 and 21°C. The crop farming, keeping for domestic animals and small business are the main social economic activities in the study area, because of land scarcity, zero grazing are the main technique used in animal keeping (FAO, 2012). Banana are the main staple food although various crops, such as yams, beans, and maize, are also cultivated (Mhando & Mbeyale, 2010). The soil around is alluvial or colluvial volcanic ash which are easily susceptible to erosion (Ikegami, 1994).

Figure 1: A map of Moshi Rural District showing the selected study areas



Sampling Strategy

The study was conducted in Moshi rural district located in northern part of Kilimanjaro region. A purposive technique was used in choosing the study area whereby the three wards and villages were selected. The villages included Samanga, Kiruweni, and Singa from Marangu East, Mwika South, and Kibosho East wards, respectively. The main criterion used in selecting the study villages were the range of the altitude (1000 m to 1800 m), land use intensifications, higher populations densities 500 to 1000 people per Km^2, growing coffee plant within the study area and higher land scarcity. Within each village, five agroforestry practices were identified for soil samples collection table 1. These were; Coffee Intercroping 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; Nahed-Toral *et al*., 2013; Thangata and 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

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

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 and 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 aI*., 1986)

Multiple Wood Perennial Practice (MWPAP)

All wood perennials that are grown and scattered haphazardly on the farm with the intention of providing 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 and 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 and Ågren, 2007), offer 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 and Nigussie, 2018).

Table 1: Characteristics of Surveyed Agroforestry Practices

Agroforestry Practices	Brief description (arrangement of components)	Major groups of components	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 cattles (*Bos taurus*), fodder plants, *Annona reticulata, Citrus limona, Citrus sinensis, Mangifera indica.*
Coffee Intercroping Agroforestry Practice (CIAP)	-Coffee is the dominant plant species. -Banana 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 wind breaks -Protect crops for wildlife, domestic animals and human interference.	-Trees -Shrubs -Crops	*Artocarpusheterophyllus, Erythrina abyssinica, Tectona grandis, Macaranga capensis, Makaranga kilimandscharica, Albizia gummifera Albizia schimperiana*

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Agroforestry Practices	Brief description (arrangement of components)	Major groups of components	Common species in each agroforestry practice
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*

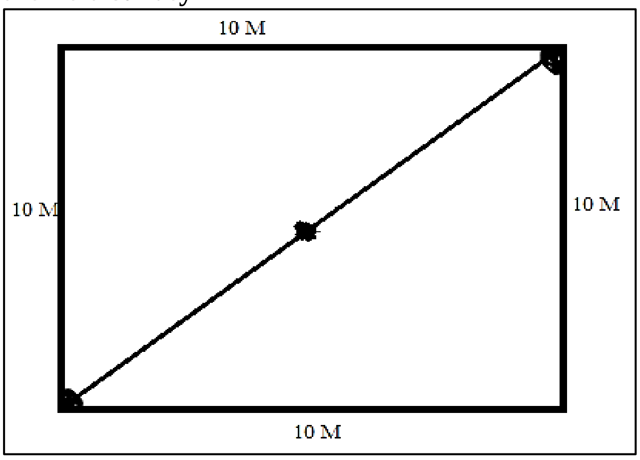
Mixed Intercropping Agroforestry Practice (MAP)

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 fulfill the requirement of food where the land resource is a limiting factor (Undie *et al*., 2012).

Soil Samples Collection

Two transects were established across each villageand make a total of six transects. 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). A total of 35 plots were sampled in each village making a total of 105. To avoid bias, soil samples were collected from three points along the diagonal of the quadrant, two points from each corner and one point at the center of the diagonal (Wu *et al*., 2010; Ding *et al*., 2017) (Figure 4.2). The soil auger was used to drill soil samples at two soil depth layers; 0-20 cm and 20-40 cm (Tan, 2005). Soil samples from each depth were mixed to get a composite sample (Tan, 2005). From each composite sample, a small subsample was taken at nearest grams and carefully sealed in aluminum foil in order to prevent water evaporation or moisture gain prior to analysis. The soil samples were labelled, placed in plastic bags and transported to the laboratory for analyses.

Figure 2: A quadrant indicating the plot size and soil samples collection points diagonally during the field survey



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Analysis of Soil Moisture Contents

One of the commonest methods of soil moisture content determination is by using the oven-dry method in the laboratory. The soil samples were assessed by means of gravimetric method which is the simplest and most widely used in soil moisture determination (Sharma *et al*., 2018). The soil samples were pre-weighed and placed in the oven and dried at a temperature between 105^oC and 110^oC till the constant weight was achieved and later cooled in desiccators. It takes a minimum of 24 hours to arrive at the soil moisture measurement (Shukla *et al*., 2014). The dry soil samples were then weighed to determine the dry weight and the soil moisture contents were determined as a percentage of the moist soil weight as; $SMC\ (\%) = (W2 - W3\ )/W3 - W1\ )\ x100$ where: MC% = Moisture Content percentage, W_1 = Weight of container (g), W_2 = Weight of moist soil + container (g) and W_3 = Weight of dried soil + container (g).

Analysis of Soil Organic Carbon

In the laboratory, the soil samples were air and oven dried (60^oC to 70^oC for 18 hours). Roots and organic debris were removed, grounded, and sieved through a 2 mm mesh sieve (Wills et al., 2007). The samples were milled to fine powder and sieved at > 2 mm mesh size. The Walkley–Black method was used since is the most common, rapid, and widely used procedure (Nelson & Somners, 1996). The Walkley and Black wet oxidation method was used to determine the organic content which were expressed in percentage (%) whereby the oxidizable matter in the soil is oxidized by 1 N $K_2Cr_2O_7$ solution. The following formula was used: SOC (%)= (meq. $K_2Cr_2O_7$ – meq. $FeSO_4$) × 0.003 × 100 × f × mcf, Where, mcf= moisture correction factor, f= correction factor of the organic carbon not oxidized by the treatment (normally approximately 1.3). The soil organic carbon was established by computing the amount of SOC per unit weight of soil using the laboratory results.

Analysis of variance (ANOVA) in R software was employed to test the degree of variations of SMC in three villages, two soil depths (0-20 cm and 20-40 cm) and in agroforestry technologies. Tukey's Honest Significance Difference (HSD) test was used when the mean separation showed statistically significant differences ($p<0.05$). The relationships between SMC and SOC among the agroforestry practices were determined by Pearson product-moment correlation in R software (R Development Core Team 2020) and recognize for the existence of any significant differences at $p<0.05$.

RESULTS

Site Effect on the Amount of Soil Moisture Contents

The total average of soil moisture content in 0-20 cm soil depth in all sites was found to be 19.58% and 21.16% in 20-40 cm soil depth (*Table 2*). The average soil moisture content in soil samples from 0-40 cm depth was 20.37%. Variation of soil moisture was statistically insignificant (*$p>0.05$*) among surveyed sites in 0-20 cm (F = 1.924, DF = 2, $p = 0.154$), and 20-40 cm (F = 1.992, df = 2, $p = 0.144$) (*Table 2*)

Table 2: Amount of soil moisture contents in surveyed sites

Site	0-20 cm	p-value	20-40 cm	p-value	Total average % SMC
Kiruweni	21.07		22.38		21.73
Samanga	18.91		20.95		19.93
Singa	18.75		20.14		19.45
Total average	19.58	**0.144^{NS}**	21.16	**0.154^{NS}**	20.37

****** Significant at p < 0.001, ** Significant at p < 0.01, * Significant at p < 0.05 and NS = Not Significant.***

Amount and Vertical Variation of Soil Moisture in AFPs

Generally, soil moisture contents increased with increasing soil depth from 0-40 cm depth (*Table 3*). This increase was found to be significant at p

< 0.01 (*Table 2*). SMCs was found to increase significantly (p<0.05) (*Table 4*) with increasing soil depth from 0-40 cm depth in all agroforestry practices except in the MAP (*Table 4*).

Table 3: Amount and vertical variation of soil moisture contents from 0-40 cm depth

Soil depth (cm)	Soil moisture content (%)	p-value
0-20	19.4	
20-40	21.1	0.003**

****** *Significant at p < 0.001, ** Significant at p < 0.01, * Significant at p < 0.05 and NS = Not Significant*

Table 4: Mean and p-values of SMCs and their vertical variation among AFPs

	Agroforestry technologies				
Soil depth (cm)	**CIAP**	**BAP**	**MAP**	**MWPAP**	**ASP**
0-20	21.7	18.4	19.3	18.5	19.2
20-40	23.4	19.6	20.0	20.4	21.5
p-values	0.007**	0.018*	0.241^{NS}	0.0005***	0.017*

**** Significant at p < 0.001, ** Significant at p < 0.01, * Significant at p < 0.05. NS = Not Significant.*
AFPs = Agroforestry Practices, SMC= Soil Moisture Contents, BAP = Boundary Planting Agroforestry Practice, MAP = Mixed Intercropping Agroforestry Practice, MWPAP = Multiple Wood Perennial Agroforestry Practice, ASP = Agrosilvopastoral Practice, CIAP = Coffee Intercropping *Agroforestry Practice*

Spatial Variation of SMC Near Surface and Sub-Surface Layers Under Different AFPs

Figure 3 (a) shows the difference in soil moisture contents within 0-20 cm depth under the five agroforestry practices (AFPs). The SMCs of the surface layer (0–20 cm) in ASP, MWPAP, CIAP, BAP and MAP were 19.16%, 18.46%, 21.7%, 18.36%, and 19.27%, respectively. At this depth (0-20 cm) ANOVA indicated insignificant difference (p>0.05) in soil moisture contents among agroforestry practices (F = 2.233, df = 4, P = 0.071) (*Table 5*). The spatial increase followed an order of practices as BAP< MWPAP< ASP< MAP< CIAP (*Table 5*). At the depth of 20-40 cm, the SMC under the five AFPs were 21.52%, 20.44%, 23.42%, 19.61%, and 20.00% for ASP, MWPAP, CIAP, BAP and MAP, respectively (*Figure 3* (b)). SMCs within 20-40 cm differed significantly among agroforestry practices (F = 4.936, df = 4, P = 0.003) (*Table 5*). The spatial increase at 20-40 cm followed an order of Practices as BAP< MAP< MWPAP< ASP< CIAP which is different to a trend at 0-20 cm. Compared with the surface layer (0–20 cm), the difference of SMCs at the depth of 20-40 cm between AFPs was significant (*p*< 0.01).

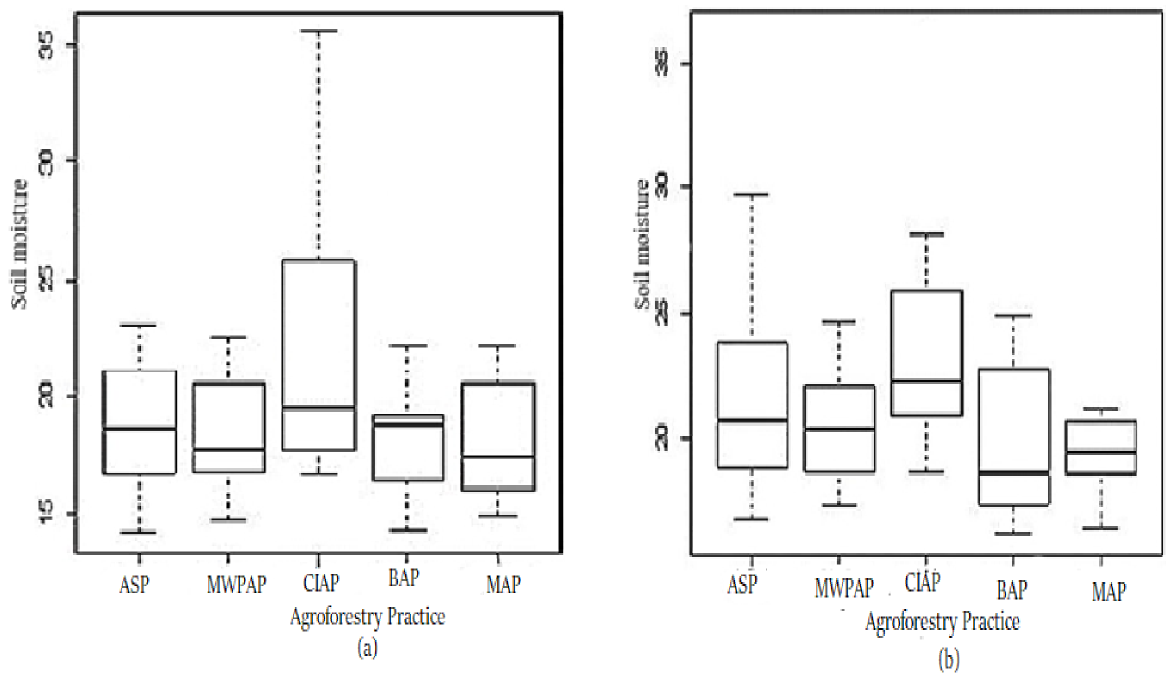
Table 5: ANOVA with significance levels showing the amount of SMCs between AFPs

Soil depth	Agroforestry practice	SMC (%)	F-value	p-value	Significance codes
0-20	ASP	19.16			
	MWPAP	18.46			
	CIAP	21.70			
	BAP	18.36			
	MAP	19.27			
	Overall mean	19.39	2.233	0.071	NS
20-40	ASP	21.52			
	MWPAP	20.44			
	CIAP	23.42			
	BAP	19.61			
	MAP	20.00			
	Overall mean	21.10	4.402	0.003	**

** p < 0.05, **p < 0.01, ***p < 0.001.*
AFPs = Agroforestry Practices, BAP = Boundary Planting Agroforestry Practice, MAP = Mixed Intercropping Agroforestry Practice, MWPAP = Multiple Wood Perennial Agroforestry Practice, ASP = Agrosilvopastoral Practice, CIAP = Coffee Intercropping *Agroforestry Practice*

East African Journal of Forestry and Agroforestry, Volume 7, Issue 1, 2024
Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

Figure 3: Box plots of the amount of soil moisture among agroforestry Practices at 0-20 cm (a) and 20-40 cm (b) depths at N = 21



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

Effects of coffee farming on the amount of SMC in different AFPs.

Coffee farming agroforestry Practice had relatively higher SMCs at 0-20 cm and 20-40 cm depths compared to other AFPs (*Table 5*). The amount of soil moisture contents in CIAP differed significantly only with those in BAP and MWPAP (*P = 0.039* and *0.019*), respectively at 0-20 cm depth. At 20-40 cm depth, soil moisture contents in CIAP differed significantly with those in BAP, MAP, MWPAP, and ASP (*P = 0.002, 0.0007, 0.001* and *0.040*), respectively (*Table 6*).

Table 6: Mean values of SMCs obtained by comparing CIAP with other AFPs in the agroforestry system of Kilimanjaro, Tanzania

Soil depth (cm)	Agroforestry technologies				
	CIAP	**BAP**	**MAP**	**MWPAP**	**ASP**
0-20	21.7	18.4*	19.3^{NS}	18.5*	19.2^{NS}
20-40	23.4	19.6**	20.0***	20.4**	21.5*

**** Significant at p < 0.001, ** Significant at p < 0.01, * Significant at p < 0.05 and NS Not Significant.*
AFPs = Agroforestry Practices, BAP = Boundary Planting Agroforestry Practice, MAP = Mixed Intercropping Agroforestry Practice, MWPAP = Multiple Wood Perennial Agroforestry Practice, ASP = Agrosilvopastoral Practice, CIAP = Coffee Intercropping *Agroforestry Practice*

Relationship between Soil Organic Carbon and Soil Moisture Contents

Pearson product-moment correlation analysis indicated that soil moisture contents within 0-20 cm and 20-40 cm depths was positively related to SOC (*Figure 4* (a) and (b), respectively). This relationship was found to be significant within 0-20 cm and 20-40 cm depths at *P* = 0.017, *r* = 0.23 and *P* = 0.0009, = 0.32, respectively (*Table 7*) meaning that soil moisture increases as the amount of SOC in the soil increases.

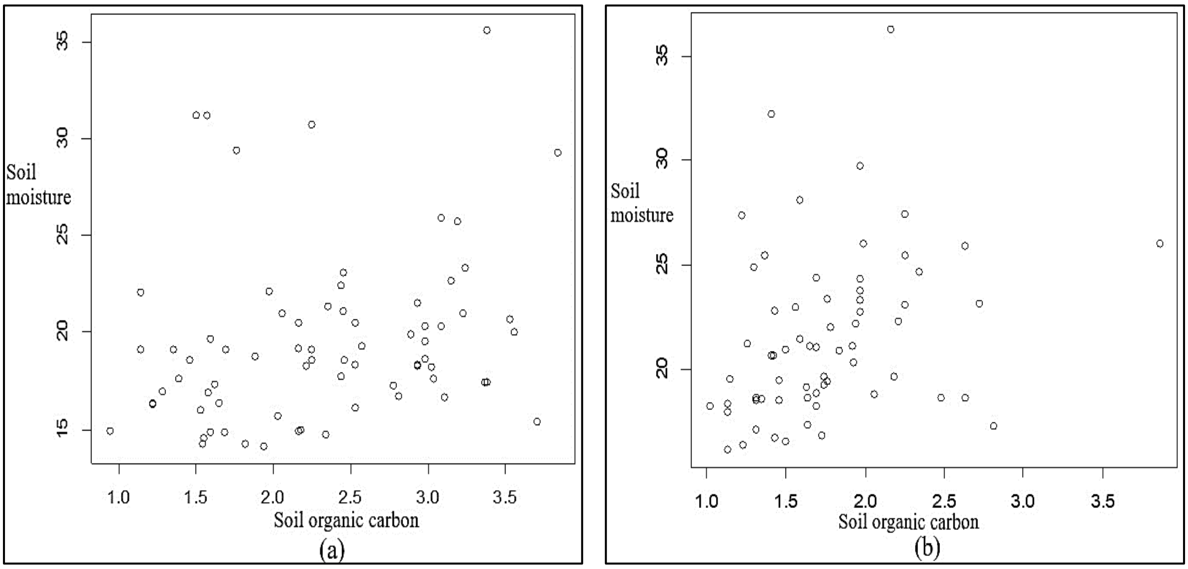
Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

Table 7: Pearson product-moment correlation coefficients (r) with significance levels between SMCs and SOC

Parameters	Soil depth(cm)	R-values	*P*-values	Significance codes
SMC*SOC	0-20	0.23	0.017	*
	20-40	0.32	0.0009	***

SMC = Soil Moisture Content, SOC = Soil Organic Carbon, NS = Not Significant,
$* p < 0.05$, $**p < 0.01$, $***p < 0.001$

Figure 4: Scatter plots of the correlation between SMC and SOC within 0-20 cm (a) and 20-40 cm (b) depths at N = 105



DISCUSSION

Site Effect on the Amount of Soil Moisture Contents

These values are close to the value reported by Azlan *et al*., 2012 who found an average soil moisture content of 19.92 % at three sampling sites in Kelantan, Malaysia. He reported insignificant different in the soil moisture in the study sites. Pezzopane *et al*., (2015) found similar fluctuation of values of moisture storage in the soil among the sampling sites in a silvopastoral system in south-eastern Brazil. The similar amount of SMC in this study may be due to similar soil type, climate condition, and land use of the study sites. But many studies have reported variability of soil moisture which results from differences in topography, soils, vegetation (Grayson & Western, 1998; Gomez-Plaza *et al*., 2000), and land uses (Fu *et al*., 2000). Difference in land uses produce a change in the soil properties and evapotranspiration which increase soil moisture variability across the landscape (Wang *et al*., 2001). It is therefore assumed that the agroforestry practices occurring across the surveyed sites in this study are likely to be the same leading into similar amount of SMC.

Amount and Vertical Variation of Soil Moisture in AFPs

The lowest soil moisture content recorded at 0-20 cm in this study could be due to loss of water at the topsoil layer by evaporation and the high rate of soil moisture infiltration to the deeper soil layers. Our results are similar to those reported by several scholars elsewhere on the vertical increase of SMC with soil depth. For example, Livesley *et al*. (2004) reported an increase in soil water content with increasing depth between 20 and 50 cm in the agroforestry systems of the sub-humid highlands in western Kenya. Diongue *et al*. (2021) found that soil moisture at 20-60 cm of the soil layer increased with depth in an agro-silvo-pastoral ecosystem dominated by *Faidherbia*

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

albida in Senegal. Yang *et al*. (2018) also found an increasing trend of SWC from 0 to 200 cm in Horqin Sandy Land, northern China. Soil moisture content under the intercropping land, cropland and fallow land was found to increase with depth (Fu *et al*., 2003). Wang *et al*. (2014) and Toro-Guerrero *et al*. (2018) reported that SWC increases with increasing soil depth in a Small Catchment on the Hilly-Gully Loess Plateau and in a Mediterranean Mountainous Region of Baja California, Mexico, respectively. In contrast, Liu *et al*., (2021) found a significant decreasing trend of soil moisture content with increasing soil depth in the Black Soil Regions of China. The above results reveal reciprocal advantages of agroforestry system for improving moisture contents in the soil (Kiepe, 1995). In contrast, Wang *et al*., (2014) found a decreasing trend of soil water content in woodlands of Small Catchment on the Hilly-Gully Loess Plateau. This divergence may be due to ecosystem processes which occur differently in natural forest and agroforestry systems. A better valuation of soil moisture vertical variations in agroforestry systems, considering soil physical properties is very crucial.

Also, research by Li *et al*., (2010) showed that the SWC increased with increasing depth in the 0 to 40 cm soil layer in the three types of sandy land. Lin (2010) studied the change of SWC in the vertical soil profile under three different types of plant barriers and found that SWC was different at different depths from 10 to 20, 20 to 60, 60 to 80 and 80 to 100 cm. Niu *et al*, (2015) found an increase of soil moisture in vertical variation under different land uses in Horqin Sandy Land. But this study found that SMCs at 0-20 cm depth did not differ with 20-40 cm in the MAP different with what obtained in other agroforestry technologies. These results show that different AFPs have different amount and vertical variation of the SMCs. Cheng *et al*., (2013) concluded that, SWC in different vegetation is affected by rainfall and evaporation. Therefore, understanding the vertical distribution of SMC can help with water management in agroforestry systems of northern highlands of Tanzania.

Spatial Variation of SMC Near Surface and Sub-Surface Layers Under Different AFPs

One possible explanation for insignificant difference of SMCs within 0-20 cm depth is that the AFPs had similar soil physical properties. Fu *et al*. (2003) found that the differences in soil physical properties such as particle distribution and bulk density may contribute to the difference in soil moisture contents in different vegetation's. Wang *et al*. (2009) suggested that, similar leaf coverage, plant height, and similar root depth may lead into the same SMC in different AFPs. The possible reason being the same water consumption patterns by plants which may occur in different AFPs. However, the remarkable heterogeneity of SMCs under AFPs at 20-40 cm depth is water absorption by different roots from varieties of tree species grown. Rainfall, infiltration to the inner layers and the difference in distribution of roots may also contribute to this difference. Wang et al. (2009) found that most of the roots of trees in AFPs are distributed at the depths of 0-40 cm and the heterogeneity of plant root densities in this layer cause soil moisture variability within the agro-ecosystem (Wang *et al*., 2013). Therefore, various vegetation types have vital impacts on soil moisture heterogeneity by affecting the infiltration rate, surface runoff intensity, soil evaporation intensity, and soil physical and chemical properties, combined with vegetation transpiration, root distribution, and hydraulic redistribution (Venkatesh *et al*., 2011; Yang *et al*., 2010).

Effects of Coffee Farming on the Amount of SMC in Different AFPs

These results suggest the difference in water consumption between coffee species and other agroforestry tree species. Muñoz-Villers *et al*. (2020) reported that amount of soil water between shade trees and coffee plants was attributed by different in water usage. In Nicaragua, Padovan *et al*. (2015) compared the root distribution, soil moisture, transpiration, and leaf water potential patterns in a sun-grown coffee system and an agroforestry of coffee planted with two timber trees (deciduous *Tabebuia rosea* and evergreen

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

Simarouba glauca). Their findings showed that coffee roots were more abundant than tree roots and mainly concentrated in the shallow soil layers. But most roots of both tree species were observed in deeper layers, suggesting a clear niche differentiation with coffee. Greater soil water uptake from trees in different soil profiles provides clear evidence of high SMCs in CIAP. A study by Padovan *et al*., (2018) found that shade tree species are able to tap water from deeper soil layers than coffee species, suggesting that trees are deep rooted and able to explore larger soil volumes, causing large water consumption compared with coffee. However, Guo *et al*. (2020) suggested that the slow decomposition of leaves of other agroforestry trees have beneficial effects on long term soil moisture maintenance compared to coffee shrubs. Furthermore, Ekqvist (2015) found that agroforestry coffee systems increased sequestration of carbon above-and below ground as well as favour soil moisture contents, when compared to monoculture systems. Therefore, the above findings conclude that different plant species have different water consumption which affects SMCs stored in the soil.

Relationship Between Soil Organic Carbon and Soil Moisture Contents

Our results are consistent with many studies elsewhere who found a positive correlation between SMCs and SOC under different vegetation cover and land use types. For example, Azlan *et al*. (2012) found a positive and significant correlation of SMCs with SOM at different land use in Kelantan, Malaysia. Kerr and Ochsner (2020) reported positive correlations between soil moisture and SOC at 0-20, 20-40, 40-60 cm depths. Wang *et al*. (2002) observed high degrees of a positive and significant correlations between SMCs and SOC. According to Franzluebbers (2002) and Parajuli and Duffy (2013), soil organic carbon was known to influence SWC in agricultural fields. A recent study by Kome *et al*. (2021) found a positive and significant relationship between water holding capacity (WHC) and SOC and suggested that increase in SOM increases the soil's ability to retain water. Fantappiè *et al*. (2010) showed that estimated soil moisture was a key predictor of SOC variations across Italy and they were more strongly related. Similarly, a global study by Hursh *et al*. (2017) reported a strong correlation between soil moisture and SOC and indicated that soil moisture was a dominant predictor of soil respiration within certain biomes at the global scale. Therefore, soil moisture and soil organic carbon relationship clearly permits increased research attention in different ecosystems.

CONCLUSIONS AND RECOMMENDATION

The amount of SMC among surveyed sites was the same may be due to similar soil type, climate condition and land use. The vertical increase of SMCs with depth from 0-40 cm in agroforestry practices suggests the importance of agroforestry in maintenance of soil water. However, the difference of SMCs at 0-20 cm and 20-40 cm in various agroforestry Practices indicates the ability of the soil to store water under different soil management. Coffee farming agroforestry Practice had higher SMCs compared with the other AFPs at 20-40 cm depth may be due to different in rooting systems of coffee plant and other trees species. SMCs showed a positively significant relationship with SOC within 0-20 cm and 20-40 cm depths. Meaning that, SOC has a positive contribution to the amount of water stored in the soil. The current study confirms that different agroforestry practices have different influence in the amount and vertical distribution of soil moisture. Estimating soil moisture in different agroforestry practices is very crucial as it has an impact on water management in the soil. Therefore, management practices in agroforestry systems should aim to encourage the use of practices which ensure stable amount of moisture contents in the soil.

ACKNOWLEDGEMENTS

This study was funded by the University of Dodoma (UDOM) as a scholarship awarded to the corresponding author as support to peruse Ph.D. studies at the Sokoine University of Agriculture. We are grateful to the Village leaders, Mr. Paulo Lazaro Ngowi (Singa village), Mr. Kifai Mlay

(Samanga Village) and Mr. Jackson Machamu (Kiruweni village) for allowing us to carry out this research in their villages. Thanks go to George B. Bulenga, Elvis Maole and Stanley Fredrick for assisting in soil sampling and Mr. Louis Mdoe, Mr. Amuru Suleiman and Pascalina Mtangi for assisting in laboratory analysis of soil samples.

REFERENCES

Aide, T. M. and Grau, H. R. (2004). Globalization, migration, and Latin American ecosystems. *Science* 305: 1915–1916.

Alemu, M. M. (2015). Effect of tree shade on coffee crop production. *Journal of Sustainable Development8*(9): 66.

Asfaw, Z. and Ågren, G.I. (2007). Farmers' local knowledge and topsoil properties of agroforestry practices in Sidama, Southern Ethiopia. *Agroforestry Systems* 71(1): 35-48.

Azlan, A., Aweng, E.R., Ibrahim, C.O. and Noorhaidah, A. (2012). Correlation between Soil Organic Matter, Total Organic Matter and Water Content with Climate and Depths of Soil at Different Land use in Kelantan, Malaysia. J. Appl. Sci. *Environ. Manage* 16 (4): 353-358.

Ba´rdossy, A. and Lehmann, W. (1998). Spatial distribution of soil moisture in a small catchment: Part 1. Geostatistical analysis. *Journal of Hydrology* 206: 1–15.

Basamba, T.A., Mayanja, C., Kiiza, B., Nakileza, B., Matsiko, F., Nyende, P. and Ssekabira, K. (2016). Enhancing adoption of agroforestry in the eastern agro ecological zone of Uganda. *Int. J. Ecol. Sci. Environ. Eng* 3: 20-31.

Bayala, J., Sanou, J., Teklehaimanot, Z., Ouedraogo, S. J., Kalinganire, A., Coe, R. and Van Noordwijk, M. (2015). Advances in knowledge of processes in soil–tree–crop interactions in parkland systems in the West African Sahel: A review. *Agriculture, Ecosystems & Environment*205: 25-35.

Benegas, L., Ilstedt, U., Roupsard, O., Jones, J. and Malmer, A. (2014). Effects of trees on infiltrability and preferential flow in two contrasting agroecosystems in Central America. *Agriculture, ecosystems & environment* 183: 185-196.

Bucheli, V.J.P. and Bokelmann, W. (2017). Agroforestry systems for biodiversity and ecosystem services: the case of the Sibundoy Valley in the Colombian province of Putumayo. *Int J Biodivers Sci Eco Serv Manag* 13:380–397

Cheng, L.P. and Liu, W.Z. (2013). Long term effects of intercropping system on soil water content and dry soil layer in deep loess profile of Loess Tableland in China. *Journal of Integrative Agriculture* 13(6): 1382–1392.

Chirwa, P. W., Black2, C. R., Ong, C. K. and Maghembe, J. A. (2003). Tree and crop productivity in gliricidia/maize/pigeonpea cropping systems in southern Malawi. *Agroforestry Systems*, *59*: 265-277.

De Stefano, A. and Jacobson, M. G. (2018). Soil carbon sequestration in agroforestry systems: a meta-analysis. *Agroforestry systems 92*(2): 285-299.

Ding, J., Chen, L., Ji, C., Hugelius, G., Li, Y., Liu, L., ... and Yang, Y. (2017). Decadal soil carbon accumulation across Tibetan permafrost regions. *Nature Geoscience* 10(6): 420-424.

Diongue, D., Didier Orange, Waly Faye, Olivier Roupsard, Frederic Do, Christophe Jourdan, Christine Stumpp, Awa Niang Fall, and Serigne Faye (2021). Influence of trees and topography on soil water content in semiarid region, the case of an agro-silvo-pastoral ecosystem dominated by Faidherbia albida (Senegal). EGU21-9060, updated on 31 Jul 2021 https://doi.org/ 10.5194/egusphere-egu21-9060 EGU General Assembly 2021.

Donte, S. J., Barrios, E. and Six, J. (2010). Earthworms, soil fertility and aggregate-associated soil organic matter dynamics in the

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

Quesungual agroforestry system. *Geoderma* 155(3-4): 320-328.

Eakin, H., Tucker, C. and Castellanos, E. (2006). Responding to the coffee crisis: a pilot study of farmers' adaptations in Mexico, Guatemala and Honduras. *Geographical Journal*172(2): 156-171

Ekqvist, I. (2015). The influence of agroforestry on soil fertility in coffee cultivations. A review and a field study on smallholding coffee farms in Colombia. Bachelor thesis in biology, Örebro University.

Fantappiè, M., L'Abate, G. and Costantini, E. A. A. (2010). Factors influencing soil organic carbon stock variations in Italy during the last three decades. In Zdruli, P., Pagliai, M., Kapur, S., & Faz Cano, A. (Eds). *Land degradation and desertification: Assessment, mitigation and remediation* 435–465.

FAO. (2012). National Sample Census of Agriculture 2002/2003 Volume Vc: Regional Report: Kilimanjaro region. https://www.fao.org/tempref/AG/Reserved/PPLPF/ftpOUT/GLiPHA/DATA/Queue/Working/tanzania/KILIMANJARO%20REGION%20REPORT.pdf]Site visited on 15/06/ 2018.

Fernandes, E.C., Nair, P.R. (1986). An evaluation of the structure and function of tropical homegardens. *Agricultural systems* 21(4): 279-310.

Franzluebbers, A.J. (2002). Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil Tillage Res* 66: 197–205.

Fu, B., Jun W., Liding, C. and Yang, Q. (2003). The effects of land use on soil moisture variation in the Danangou catchment of the Loess Plateau, China. *Catena* 54:197–213.

Fu, B.J., Chen, L.D., Ma, K.M., Zhou, H.F. and Wang, J. (2000). The relationships between land use and soil conditions in the hilly area of the Loess Plateau in northern Shaanxi, China. *Catena* 36: 69–78.

Gebrewahid, Y., Teka, K., Gebre-Egziabhier, T.B., Tewolde-Berhan, S., Birhane, E., Eyasu, G. and Meresa, E. (2019). Dispersed trees on smallholder farms enhance soil fertility in semi- arid Ethiopia. *Ecological Processes* 8(1): 1-8.

Gómez-Plaza, A., Alvarez-Rogel, J., Albaladejo, J. and Castillo, V. M. (2000). Spatial patterns and temporal stability of soil moisture across a range of scales in a semi-arid environment. *Hydrological Processes 14* (7):1261-1277.

Gould, I. J., Quinton, J. N., Weigelt, A., De Deyn, G. B. and Bardgett, R. D. (2016). Plant diversity and root traits benefit physical properties key to soil function in grasslands. *Ecology letters 19*(9): 1140-1149.

Grayson, R.B. and Western, A.W. (1998). Towards areal estimation of soil water content from point measurements: time and space stability of mean response. *Journal of Hydrology* 207:68–82.

Guo, X, Fu, Q, Hang, Y, Lu, H, Gao, F. and Si, J. (2020). Spatial Variability of Soil Moisture in Relation to Land Use Types and Topographic Features on Hillslopes in the Black Soil (Mollisols) Area of Northeast China. *Sustainability12*:3552.

Guyassa, E., Raj, A.J., Gidey, K. and Tadesse, A. (2014). Domestication of indigenous fruit and fodder trees/shrubs in dryland agroforestry and its implication on food security. *Int J Ecosyst* 4(2): 83-88.

Hasselquist, N. J., Benegas, L., Roupsard, O., Malmer, A. and Ilstedt, U. (2018). Canopy cover effects on local soil water dynamics in a tropical agroforestry system: Evaporation drives soil water isotopic enrichment. *Hydrological processes 32*(8): 994-1004.

Hemp, A. (2006). The banana forests of Kilimanjaro: biodiversity and conservation of the Chagga homegardens. In *Forest Diversity and Management* 133-155.

Hirota, I., Sakuratani, T., Sato, T., Higuchi, H. and Nawata, E. (2004). A split-root apparatus for examining the effects of hydraulic lift by trees on the water status of neighbouring crops. *Agroforestry Systems* 60: 181–187.

Hollis, J.M., Jones, R.J.A. and Palmer, R.C. (1977). The effect of organic matter and particle size on the water retention properties of some soils in the West Midlands of England. *Geoderma* 17: 225 – 238.

Hugar, G. M. and Soraganvi, V. S. (2014). Effect of SOC in the form of amendments on hydraulic properties of arid soils. *International Journal of Civil & Structural Engineering 4*(3): 450-468.

Hursh, A., Ballantyne, A., Cooper, L., Maneta, M., Kimball, J. and Watts, J. (2017). The sensitivity of soil respiration to soil temperature, moisture, and carbon supply at the global scale. *Global Change Biology23*: 2090–2103.

Ikegami, K. (1994). The Traditional Agro-silvopastoral Complex System in the Kilimanjaro Region, and its implications for the Japanese-Assisted Lower Irrigation Project. [https://repository.kulib.kyoto-u.ac.jp › d space › bit stream › ASM_15_189]. Site visited on 17/07/ 2018.

Ilstedt, U., Tobella, A. B., Bazié, H. R., Bayala, J., Verbeeten, E., Nyberg, G. and Sheil, D. (2016). Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics. *Scientific Reports 6*: 21930.

Jose, S., Gillespie, A.R., Seifert, J.R. and Biehle, D.J. (2000). Defining competition vectors in a temperate alley cropping system in the midwestern USA: 2. Competition for water. *Agroforestry Systems* 48: 41–59.

Kar, G., Kumar, A., Panigrahi, S., Dixit, P. R. and Sahoo, H. (2020). Soil Organic Carbon Stock of Some Upland Use System Under Tropical Monsoon Climate and Their Interrelationship with Soil Water Retention. In *Carbon Management in Tropical and Sub-Tropical Terrestrial Systems* 265-280.

Kiepe, P. (1995). No runoff, no soil loss: soil and water conservation in hedgerow barrier systems. Tropical Resource Management Papers. Wageningen Agricultural University, Wageningen, pp. 1 –42.

Kome, G. K., Roger, K.E. and Bernard, P.K.Y. (2021). *Soil Organic Carbon Distribution in a Humid Tropical Plain of Cameroon*: Interrelationships with Soil Properties. Applied and Environmental Soil Science. Volume 2021, Article ID 6052513, 18 pp.

Lal, R. and Shukla, M.K. (2004). Principles of Soil Physics. Marcel Dekker, New York, 716 pp

Lange, M., Habekost, M., Eisenhauer, N., Roscher, C., Bessler, H., Engels, C. and Gleixner, G. (2014). Biotic and abiotic properties mediating plant diversity effects on soil microbial communities in an experimental grassland. *PloS one9*(5): e96182.

Leung, A. K., Garg, A., Coo, J. L., Ng, C. W. W. and Hau, B. C. H. (2015). Effects of the roots of Cynodon dactylon and Schefflera heptaphylla on water infiltration rate and soil hydraulic conductivity. *Hydrological processes* 29(15): 3342-3354.

Li, J., Bing, C., Xiaofang, L., Yujuan, Z., Yangjing, C., Bin, J. ... and Ming'an, S. (2008). Effects of deep soil desiccation on artificial forestlands in different vegetation zones on the Loess Plateau of China. *Acta Ecologica Sinica* 28(4): 1429-1445.

Li, J.W., Zuo, H.T., Li, Q.F., Fan, X.F. and Hou, X.C. (2011). Effect of soil water spatial distribution pattern on switch grass during first growing season. *Acta Agrista Sinica* 19: 43–50.

Li, Y.Q., Zhang, T.H., Liu, X.P., Tong, X.Z., Tang, X. and Lian, J. (2010). Change pattern of soil water content in different dunes and

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

grassland in Horqin sandy land. *Bulletin of Soil and Water Conservation* 30(3): 31–35.

Lin, B. B. (2007). Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. *Agricultural and Forest Meteorology 144*(1-2): 85-94.

Lin, B. B. (2010). The role of agroforestry in reducing water loss through soil evaporation and crop transpiration in coffee agroecosystems. *Agricultural and Forest Meteorology 150*(4): 510-518.

Lin, H., Wheeler, D., Bell, J. and Wilding, L. (2005). Assessment of soil spatial variability at multiple scales. *Ecological Modelling 182*(3-4): 271-290.

Liu, X., Tang, Y., Cheng, X., Jia, Z., Li, C., Ma, S., Zhai, L., Zhang, B. and Zhang, J. (2021). Comparison of Changes in Soil Moisture Content Following Rainfall in Different Subtropical Plantations of the Yangtze River Delta Region. *Water13*(7): 1-22.

Livesley, S.J., Gregory, P.J. and Buresh, R.J. (2004). Competition in tree row agroforestry systems. 3. Soil water distribution and dynamics. *Plant and Soil* 264:129–139.

Lott, J.E., Howard, S.B., Ong, C.K. and Black, C.R. (2000). Long-term productivity of a Grevillea robusta-based overstorey agroforestry system in semi-arid Kenya: II. Crop growth and system performance. *Forest Ecology and Management* 139: 187–201.

Maghimbi, S. (2007). Recent changes in crop patterns in the Kilimanjaro region of Tanzania: the decline of coffee and the rise of maize and rice. [https://repository.kulib.kyoto- u.ac.jp/ dspace/bitstr eam/2433/68490/1/ASMS3573.pdf]. Site visited in 4/12/2019.

Marcela, Q. (2009). Effect of Conservation Tillage in Soil Carbon Sequestration and Net Revenues of Potato-Based Rotations in the Colombian Andes. (M.Sc. thesis) University of Florida, USA, pp. 18–30.

Mamo, D. and Asfaw, Z. (2017). Assessment of farmers' management activities on scattered trees on crop fields at Gemechis district, West Hararge Zone, Oromia, Ethiopia. *International Journal of Agriculture* 2(1): 41-57.

Meng, P. and Zhang, J. (2004). Effects of pear-wheat inter-cropping on water and land utilization efficiency. *Forest Research* 17: 167–171.

Meng, L., Xin, Y. and Zhao, Y. S. (2010). Influence of Horqin Sandy Land Plant Sand Barrier on Soil Moisture. In *Advanced Materials Research* 113: 1110-1114

Mganga, K. Z., Razavi, B. S. and Kuzyakov, Y. (2016). Land use affects soil biochemical properties in Mt. Kilimanjaro region. *Catena* 141:22-29.

Mhando, D. G. and Mbeyale, G. (2010). *An Analysis of the Coffee Value Chain in the Kilimanjaro Region, Tanzania*. NCCR North-South. https://www.nccr- northsouth.ch/Upload/Mhando_and_Mbeyale_NCCR_Dialogue_27_2010.pdf.] Site visited on 15/05/2019.

Milcu, A., Eugster, W., Bachmann, D., Guderle, M., Roscher, C., Gockele, A., Landais, D., Ravel, O., Gessler, A., Lange, M., Ebeling, A., Weisser, W.W., Roy, J., Hildebrandt, A. and Buchmann, N. (2016). Plant functional diversity increases grassland productivity-related water vapor fluxes: an Ecotron and modeling approach. *Ecology* 97: 2044-2054.

Miller, A.W. and Pallardy, S.G. (2001). Resource competition across the crop-tree interface in a maize-silver maple temperate alley cropping stand in Missouri. *Agroforestry Systems* 53: 247–259

Misana, S. B., Sokoni, C. and Mbonile, M. J. (2012). Land-use/cover changes and their drivers on the slopes of Mount Kilimanjaro, Tanzania. *Journal of geography and Regional Planning5*(8):151.

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

Mukundente, L., Ndunda, E. and Gathuru, G. (2019). Agroforestry Technologies Adopted by Smallholder Farmers in Southern Province of Rwanda. *East African Journal of Forestry and Agroforestry* 1(1):24-31.

Muñoz-Villers, L. E., Geris, J., Alvarado-Barrientos, M. S., Holwerda, F. and Dawson, T. (2020). Coffee and shade trees show complementary use of soil water in a traditional agroforestry ecosystem. *Hydrology and Earth System Sciences 24*(4): 1649-1668.

Nahed-Toral, J., Sanchez-Muñoz, B., Mena, Y., Ruiz-Rojas, J., Aguilar-Jimenez, R., Castel, J.M. and Delgadillo-Puga, C. (2013). Feasibility of converting agrosilvopastoral systems of dairy cattle to the organic production model in southeastern Mexico. *Journal of Cleaner Production* 43:136-145.

Nelson, D.W. and Sommers, L.E. (1996). Total carbon, organic carbon and organic matter in DL Sparks (Ed), Methods of Soil Analysis, Part 3, Chemical Methods, Soil Science Society of America, Madison WI., pp: 961-1010

Niu, C. Y., Musa, A. and Liu, Y. (2015). Analysis of soil moisture condition under different land uses in the arid region of Horqin sandy land, northern China. *Solid Earth* 6(4): 1157-1167.

Padovan, M. P., Cortez V. J., Navarrete L. F., Navarrete E. D., Deffner A. C., Centeno L. G. (2015). Root distribution and water use in coffee shaded with *Tabebuia rosea* Bertol. and *Simarouba glauca* DC. Compared to full sun coffee in suboptimal environmental conditions. *Agroforestry Systems* 89:857-868.

Padovan, M. P., Cortez V. J., Navarrete L. F., Navarrete E. D., Deffner A. C., Centeno L. G. (2018). Water loss by transpiration and soil evaporation in coffee shaded by *Tabebuia rosea* bertol. and *Simarouba glauca* dc. Compared to unshaded coffee in sub-optimal environmental conditions. *Agricultural and Forest Meteorology*, 248:1-14.

Parajuli, P. B. and Sarah, D. (2013). Evaluation of Soil Organic Carbon and Soil Moisture Content from Agricultural Fields in Mississippi. *Open Journal of Soil Science* 3: 81-90

Parihaar, R. S., Bargali, K. and Bargali, S. S. (2015). Status of an indigenous agroforestry system: a case study in Kumaun Himalaya, India. *Indian Journal of Agricultural Sciences 85*(3): 442-447.

Pérès, G., Cluzeau, D., Menasseri, S., Soussana, J.F., Bessler, H., Engels, C., Habekost, M., Gleixner, G., Weigelt, A., Weisser, W.W., Scheu, S. and Eisenhauer, N. (2013) Mechanisms linking plant community properties to soil aggregate stability in an experimental grassland plant diversity gradient. *Plant and Soil* 373: 285-299.

Pezzopane, J. M., Cristiam, B., Maria, L.F.N., Patrícia, M.S., Pedro, G.C. and Renan, S.P. (2015). Microclimate and soil moisture in a silvopastoral system in southeastern Brazil. Bragantia, *Campinas* 74(1): 110-119.

Philpott, S.M., Arendt, W.J., Armbrecht, I., Bichier, P., Diestch, T. V., Gordon, C., and Zolotoff, J. M. (2008). Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees. *Conservation Biology 22*(5): 1093-1105.

Qiu, Y., Fu, B.J., Wang, J. and Chen, L.D. (2001). Soil moisture variation in relation to topography and land use in a hillslope catchment of the Loess Plateau, China. *Journal of Hydrology* 240:243–263.
Qiu, Y., Fu, B.J., Wang, J. and Chen, L.D. (2003). Spatio-temporal prediction of soil moisture content using multiple-linear regression in a small catchment of the Loess Plateau, China. *Catena* 54: 173 – 195.

R Development Core Team. (2020). R version 3.5.2. R Foundation for Statistical Computing, Vienna, Austria.

Rey, A., Oyonarte, C., Morán-López, T., Raimundo, J. and Pegoraro, E. (2017). Changes in soil moisture predict soil carbon losses upon rewetting in a perennial semiarid steppe in SE Spain. *Geoderma*287: 135-146.

Sharma, P. K., Kumar, D., Srivastava, H. S. and Patel, P. (2018). Assessment of different methods for soil moisture estimation: A review. *Journal of Remote Sensing and GIS* 9(1):57-73.

Shukla, A., Panchal, H., Mishra, M., Patel, P. R., Srivastava, H. S., Patel, P. and Shukla, A. K. (2014). Soil moisture estimation using gravimetric technique and FDR probe technique: a comparative analysis. *Am Int J Res Formal, Appl Nat Sci* 8: 89-92.

Soini E. (2006). Livelihood, Land Use and Environment Interactions in the Highlands of East Africa. PhD Thesis, University of Helsinki. https://helda.helsinki.fi/bitstream/handle/10138/21188/liveliho.pdf?sequence=1]. Site visited on 21/05/2019.

Soto-Pinto, L., Perfecto, I. and Caballero-Nieto, J. (2002). Shade over coffee: its effects on berry borer, leaf rust and spontaneous herbs in Chiapas, Mexico. *Agroforestry systems* 55(1): 37-45.

Steenwerth, K. L., Hodson, A. K., Bloom, A. J., Carter, M. R., Cattaneo, A., Chartres, C. J. and Jackson, L. E. (2014). Climate-smart agriculture global research agenda: scientific basis for action. *Agriculture & Food Security* 3(1):1-39.

Strudley, M. W., Green, T. R. and Ascough II, J. C. (2008). Tillage effects on soil hydraulic properties in space and time: State of the science. *Soil and Tillage Research*99(1): 4-48.

Tafere, S. M. and Nigussie, Z. A. (2018). The adoption of introduced agroforestry innovations: determinants of a high adoption rate–a case-study from Ethiopia. *Forests, Trees and Livelihoods* 27(3): 175-194.

Tan, K. H. (2005). *Soil sampling, preparation, and analysis*. CRC press. Second Edition. Univenity of Georgia Greensboro, Georgia, New York. 668pp.

Thangata, P.H. and Alavalapati, J.R. (2003). Agroforestry adoption in southern Malawi: the case of mixed intercropping of *Gliricidia sepium* and maize. *Agricultural systems* 78(1):57-

Toro-Guerrero, D., José, F., Vivoni, E. R., Kretzschmar, T., Bullock Runquist, S. H. and Vázquez-González, R. (2018). Variations in soil water content, infiltration and potential recharge at three sites in a Mediterranean mountainous region of Baja California, Mexico. *Water* 10(12):1844.

Tscharntke, T., Clough, Y., Bhagwat, S. A., Buchori, D., Faust, H., Hertel, D. and Scherber, C. (2011). Multifunctional shade-tree management in tropical agroforestry landscapes–a review. *Journal of Applied Ecology* 48(3): 619-629.

Undie, U. L., Uwah, D. F. and Attoe, E. E. (2012). Effect of intercropping and crop arrangement on yield and productivity of late season maize/soybean mixtures in the humid environment of south southern Nigeria. *Journal of Agricultural Science*, *4*(4): 37-50.

Urgessa Waktola, T. and Fekadu, K. (2021). Adoption of coffee shade agroforestry technology and shade tree management in gobu seyo district, east wollega, oromia. *Advances in Agriculture 2021*.

URT. (1998). *Kilimanjaro Region Socio-Economic Profile*. The planning commission in Dar es Salaam and Kilimanjaro Regional commissioner's office, Government Printers, Dar es Salaam, Tanzania. 238pp.

URT. (2002). *Kilimanjaro Region Socio-Economic Profile*. The planning commission in Dar es Salaam and Kilimanjaro Regional commissioner's office, Government Printers, Dar es Salaam, Tanzania. 237pp.

Venkatesh, B.; Lakshman, N.; Purandara, B.K. and Reddy, V.B. (2011). Analysis of observed soil moisture patterns under different land covers in Western Ghats, India. *J. Hydrol* 397: 281–294.

Von Cossel, M., Wagner, M., Lask, J., Magenau, E., Bauerle, A., Von Cossel, V. and Winkler, B. (2019). Prospects of bioenergy cropping systems for a more social-ecologically sound bioeconomy. *Agronomy*, *9*(10): 605.

Wang, B., Wen, F., Wu, J., Wang, X. and Hu, Y. (2014). Vertical profiles of soil water content as influenced by environmental factors in a small catchment on the hilly-gully Loess Plateau. *PLoS One* 9(10): e109546.

Wang, F., Wang, S.Q., Han, X.Z., Wang, F.X. and Zhang, K.Q. (2009). Soil moisture dynamics of different land-cover types in the Black Soil Regions of China. *Chin. J. Eco-Agric* 17: 256–260.

Wang, H., Hall, C. A., Cornell, J. D. and Hall, M. H. (2002). Spatial dependence and the relationship of soil organic carbon and soil moisture in the Luquillo Experimental Forest, Puerto Rico. *Landscape Ecology*17(8): 671-684.

Wang, J., Fu, B.J., Qiu, Y., Chen, L.D. and Wang, Z. (2001). Geostatistical analysis of soil moisture variability on Danangou catchment of Loess Plateau, China. *Environmental Geology* 41: 113–120.

Wang, Y., Shao, M. A., Liu, Z. and Horton, R. (2013). Regional-scale variation and distribution patterns of soil saturated hydraulic conductivities in surface and subsurface layers in the loessial soils of China. *Journal of Hydrology* 487: 13-23.

Wu, G. L., Liu, Z. H., Zhang, L., Hu, T. M. and Chen, J. M. (2010). Effects of artificial grassland establishment on soil nutrients and carbon properties in a black-soil-type degraded grassland. *Plant and soil*333(1-2): 469-479.

Wu, G. L., Yang, Z., Cui, Z., Liu, Y., Fang, N. F. and Shi, Z. H. (2016). Mixed artificial grasslands with more roots improved mine soil infiltration capacity. *Journal of Hydrology* 535: 54-60.

Xing, G., Zhalkjng, X.M., Fei, X.L. and Wu, Y.X. (2012). Study on soil moisture content under different land use types in Sunjiacha basin. *Agricultural Research in the Arid Areas* 30: 225–229.

Yang, T., Ala, M., Zhang, Y., Wu, J., Wang, A. and Guan D. (2018) Characteristics of soil moisture under different vegetation coverage in Horqin Sandy Land, northern China. *PLoS ONE* 13(6): e0198805.

Yang, D.W., Lei, H.M. and Cong, Z.T. (2010). Overview of the research status in interaction between hydrological processes and vegetation in catchment. *J. Hydraul. Eng* 41:1142–1149.

Yang, L., Wei, W., Chen, L., Chen, W. and Wang, J. (2014). Response of temporal variation of soil moisture to vegetation restoration in semi-arid Loess Plateau, China. *Catena* 115: 123-133.

Yang, T., Ala, M., Zhang, Y., Wu, J., Wang, A. and Guan, D. (2018). Characteristics of soil moisture under different vegetation coverage in Horqin Sandy Land, northern China. *PLoS One* 13(6): e0198805.

Zhu, X., Chen, C., Wu, J., Yang, J., Zhang, W., Zou, X., ... and Jiang, X. (2019). Can intercrops improve soil water infiltrability and preferential flow in rubber-based agroforestry system? *Soil and Tillage Research* 191: 327-339.

Zhu, X., Liu, W., Jiang, X. J., Wang, P. and Li, W. (2018). Effects of land-use changes on runoff and sediment yield: Implications for soil conservation and forest management in

Article DOI: https://doi.org/10.37284/eajfa.7.1.2402

Xishuangbanna, Southwest China. *Land Degradation & Development*29(9): 2962-2974.

Zongolo, S. A., Kiluvia, S. Mghase, G., (2000). Traditional irrigation assessment report, Moshi Rural District 2000. Traditional irrigation and environmental development organization, Moshi, 36 pp.