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Crop Harvesting-Related Soil Loss in Tanzania's Usambara Mountains: The Case of Carrot, Onion, and Potato

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Soil losses from root, tuber, and bulb harvesting are among the many soil erosion processes that pose a danger to sustainable agriculture, although they are not well studied, especially in tropical regions. Thus, a study on acrisols and fluvisols in Tanzania's Western Usambara Mountains was carried out in two communities with dissimilar agro-ecological circumstances. Investigating the mass of nutrients and soil lost as well as the variables affecting variations in soil loss due to crop harvesting (SLCH) for potatoes (Solanum tuberosum L.), onions (Allium cepa L.), and carrots (Daucus carrota) under minimal input agriculture was the goal. Soil losses from root, tuber, and bulb harvesting are among the many soil erosion processes that pose a danger to sustainable agriculture, although they are not well studied, especially in tropical regions. Thus, a study on acrisols and fluvisols in Tanzania's Western Usambara Mountains was carried out in two communities with dissimilar agro-ecological circumstances. Investigating the mass of nutrients and soil lost as well as the variables affecting variations in soil loss due to crop harvesting (SLCH) for potatoes (Solanum tuberosum L.), onions (Allium cepa L.), and carrots (Daucus carrota) under minimal input agriculture was the goal. Soil losses from root, tuber, and bulb harvesting are among the many soil erosion processes that pose a danger to sustainable agriculture, although they are not well studied, especially in tropical regions. Thus, a study on acrisols and fluvisols in Tanzania's Western Usambara Mountains was carried out in two communities with dissimilar agro-ecological circumstances. Investigating the mass of nutrients and soil lost as well as the variables affecting variations in soil loss due to crop harvesting (SLCH) for potatoes (Solanum tuberosum L.), onions (Allium cepa L.), and carrots (Daucus carrota) under minimal input agriculture was the goal. Soil losses from root, tuber, and bulb harvesting are among the many soil erosion processes that pose a danger to sustainable agriculture, although they are not well studied, especially in tropical regions. Thus, a study on acrisols and fluvisols in Tanzania's Western Usambara Mountains was carried out in two communities with dissimilar agro-ecological circumstances. Investigating the mass of nutrients and soil lost as well as the variables affecting variations in soil loss due to crop harvesting (SLCH) for potatoes (Solanum tuberosum L.), onions (Allium cepa L.), and carrots (Daucus carrota) under minimal input agriculture was the goal. Soil losses from root, tuber, and bulb harvesting are among the many soil erosion processes that pose a danger to sustainable agriculture, although they are not well studied, especially in tropical regions. Thus, a study on acrisols and fluvisols in Tanzania's Western Usambara Mountains was carried out in two communities with dissimilar agro-ecological circumstances. Investigating the mass of nutrients and soil lost as well as the variables affecting variations in soil loss due to crop harvesting (SLCH) for potatoes (Solanum tuberosum L.), onions (Allium cepa L.), and carrots (Daucus carrota) under minimal input agriculture was the goal.

Key words: Soil erosion; Soil texture; Soil water content; Bulk density.

INTRODUCTION

Due to a lack of sufficient data and a connection between particular soil erosion processes and the appropriate management measures, efforts to halt soil erosion in Sub-Saharan nations, including Tanzania, have advanced very slowly [1]. The majority of these initiatives concentrate on soil erosion caused by water and tillage, while ignoring the substantial soil masses that are removed from arable land when root, tuber, and bulb crops like cassava (Manihot esculenta), onion (Allium cepa L.), potato (Solanum tuberosum L.), and carrot (Daucus carrota) are harvested [2]. Soil loss due to crop harvesting (SLCH) is the term used to describe soil that adheres to the harvested crops and is exported from the field but is rarely brought back to the field [3,4].

Only one study by [4] in Uganda was carried out under low input agriculture, whereas other investigations on SLCH have been carried out under highly automated agriculture [5]. [4] examined SLCH for sweet potatoes (Ipomoea batatas) and cassava (Mannihot esculenta). The findings indicated significant soil losses for cassava (3.4 Mg/ha/yr).

In two contrasting agro-ecological settings in the Usambara Mountains, Tanzania, on Acrisols and Fluvisols, the current study examined the extent of soil and nutrient losses resulting from the harvesting of potatoes (Solanum tuberosum L.), carrots (Daucus carrota), and onions (Allium cepa L.) under traditional low-input agriculture.

2. MATERIALS AND METHODS

2.1 Study Area

Migambo and Majulai villages, Western Usambara Mountains, Lushoto District, Tanzania (Fig. 1), between coordinates 38°15' E to 38° 24' E and 4° 34' S to 4° 48' S, with an altitude range of 1400-1600 m.a.s.l., were the study's main locations. With daily air temperatures between 12 and 17°C and an average of 1000 mm of precipitation per year, Migambo is a humid cold climate [6]. Majulai has a mean annual precipitation of 700 mm and a dry, moderate climate with daily air temperatures between 16 and 21°C [6]. More than 102 people per km2 are supported by the Usambara Mountains [7]. The study area's predominant soil types were primarily fluvisols in valley bottoms and acrisols on slopes.

Cropland on slopes and valley bottoms, as well as settlements on depressions, ridge peaks, and slopes, are the primary land uses. In valleys (Table 1), vegetables such carrots, onions, tomatoes, cabbages, and peas are grown as the only crops and are either rain-fed or irrigated traditionally. Rain-fed mixed farming is used to cultivate beans, maize, potatoes, and fruits like bananas, pears, avocados, plums, and peaches on ridge slopes (Table 1). In valleys, potatoes are also produced either as a stand-alone crop or in combination with maize. While beans are grown during the lengthy rainy season, maize is mostly grown during the short rainy season. Some vegetable crops, like cabbages, tomatoes, and sweet peppers, are also grown during the off-season by traditional irrigation in a few areas with water sources. However, potatoes, carrots, onions, cabbages, tomatoes, and sweet peppers are typically grown twice a year during both the long rain season (masika) and the short rain season (vuli). Carrots and onions are easily uprooted by manual tugging, whereas potatoes are harvested with a hand hoe. The lush cropland is under a lot of strain since crops grown in the Usambara Mountains are sold in local markets as well as shipped to large cities in the nearby plains, including as Dar es Salaam, Tanga, Arusha, Morogoro, Mombasa, Nairobi, and Southern Sudan.

2.2 Data Collection

18 farms per crop type were chosen from each community. Harvesting was place in a randomly chosen 1 m2 plot quadrant at each farm. Crop samples were taken from 54 quadrants in each community, for a total of 108 quadrants throughout the two villages. Roots, bulbs, and tubers were cleaned with clean water to get rid of clinging soil particles. Following the wash water's evaporation at 75–80°C and an overnight oven-drying process at 105°C, the total dry soil mass was calculated [4]. Kopeck's core rings were used to gather one undisturbed topsoil sample (100 cm3) from each sampling quadrant in order to determine the bulk density and soil moisture parameters (using pressure plate methods and oven drying at 105°C). For the purpose of analyzing soil fertility, composite topsoil samples were taken from ten subsamples that were randomly selected at a depth of 0 to 30 cm from the farmers' plots. Land usage, slope grade, and altitude were noted at every sampling location. Soil loss due to crop harvesting was calculated as SLCH per unit of Where; Mds is the mass of oven-dry soil (kg), Mrf is the mass of rock fragments (kg) = 0, Mcrop is the net crop mass (kg).

SLCHcrop (Mg/ha/harvest) = SLCHspec x Mcy (2) Where, Mcy (Mg/ha/harvest) is the crop yield.

Nutrient loss (kg/ha/harvest)= Nutrient Content (g/kg soil) x SLCHcrop(MG/ha/harvest) (3)

The nutrient content is expressed on oven-dry soil.

2.3 Soil Analysis

Soil analysis was done following the laboratory manual of [8]. Organic carbon (OC) was measured using the dichromate oxidation method; total nitrogen (N) by Kjeldahl method; available phosphorus (P), exchangeable calcium (Ca^{2+}) and exchangeable magnesium (Mg^{2+}) by atomic absorption spectrophotometer, exchangeable sodium (Na+) and exchangeable

net fresh crop mass i.e. mass-specific SLCH

(SLCHspec) and SLCH on an area-unit basis i.e. (K+) by Flame photometer; pH was crop-specific SLCH (SLCHcrop) as defined by [3].

determined by normal laboratory pH meter; bulk density by gravimetric method and soil texture by the hydrometer method.

SLCHspec (kg/kg) = Mds + Mrf Mcrop-----------(1)

2.4 Statistical Analysis

Skewed data were log-normally converted, descriptive statistics were performed, and homogeneity of variances was tested. Minitab 14 software [9] was used to do regression analysis in order to identify the correlations between SLCHspec and bulk density, soil water content, and soil texture. To compare across crops, SLCH variables were subjected to analysis of variance (ANOVA) using Genstat 14 software [10]. To find mean differences, the Least Significant Difference (LSD0.05) was employed.

3. RESULTS AND DISCUSSION

3.1 Characteristics of the Selected Farm Plots in the Studied Villages

Table 1 describes the farms that were sampled and the types of soil that were present at the farms in Majulai and Migambo villages throughout the survey. These include the range of soil texture, SWC, bulk density, and soil types.

3.2 Effect of Soil Water Content, Bulk Density (BD) and Soil Texture on SLCH Variability

3.2.1 Onion

Table 2 shows the SLCH variability for onions in Majulai and Migambo villages with according to SWC, BD, and soil texture. In Majulai, the median SLCHspec for onions was 0.1 kg/kg, with a range of 0.02 to 0.3 kg/kg. In Migambo, the median SLCHspec was 0.5 kg/kg, with a range of 0.2 to 0.6 kg/kg. The mean SLCHspec was 0.4 kg/kg. With an average of 2.8 Mg/ha/harvest and a median of 3.0 Mg/ha/harvest, the SLCHcrop ranged from 1.0 to 4.0 Mg/ha/harvest in Majulai, and between 2.2 and 12.2 Mg/ha/harvest in Migambo, with an average of 5.2 Mg/ha/harvest and a median of 5.1 Mg/ha/harvest. In Majulai, bulk density (BD) had a favorable impact on the SLCHspec for onions at the 5% level (R^2 = 0.53, P =.03), while in Migambo, it had no effect (Table 2). The variability of SLCH for onions in both villages was mostly unaffected by the soil water content (SWC) and texture at harvest. The tiny differences in SWC at harvest, as well as the sand, clay, and silt contents resulting from the slight variations in the landform of the farms evaluated, contribute to the low association between SLCHspec for onions with SWC and soil texture within the villages under study (Table 1). Similar findings were made by [2] and [3], who noted that minor differences in the amounts of sand and clay as well as SWC that were present in the majority of the farms they investigated were the cause of the weak relationships between SWC and SLCH with texture.

After combining the results from the two villages, the SLCH variability for onions is shown in Table 3. The following differences in onion SLCHspec were noted in relation to SWC, bulk density, and soil texture. In contrast to sand, silt, clay, and BD, which had modest relationships with SLCHspec for onions, soil water content at harvest had a positive impact on SLCHspec (R^2 = 0.39, P =.006) (Table 3). Similarly, SWC showed a strong (P <.001) correlation with SLCHspec when the factors were submitted to multiple regressions, and the sum of the factors could account for almost 79% of the differences in SLCHspec for onions (Table 3). The difference in soil moisture contents between the two villages—Migambo, which has a humid environment, had a higher soil moisture content than Majulai, which has a dry climate—explains the positive association between SWC and SLCHspec for onions (Table 1). A similar finding was made by [11], who discovered that the depth of rainfall affected the sugar beets' SLCH.

3.2.2 Carrot

Table 2 shows the SLCH variability for carrots in Majulai and Migambo villages with according to SWC, BD, and soil texture. In Migambo, the mean SLCHspec for carrots was 0.4 kg/kg, with a range of 0.2 to 0.8 kg/kg and a median of 0.3 kg/kg, but in Majulai, it was 0.3 kg/kg, with a range of 0.2 to 0.6 kg/kg and a median of 0.3 Mg/ha/harvest. With a mean of 7.0 Mg/ha/harvest and a median of 7.0 Mg/ha/harvest, the SLCHcrop ranged from 4.0 to 13.0 Mg/ha/harvest in Majulai, and from 2.8 to 23.0 Mg/ha/harvest in Migambo, with a mean of 7.1 Mg/ha/harvest and a median of 5.5 Mg/ha/harvest. For carrot, bulk density (R^2 = 0.84, P <.001), SWC (R^2 = 0.71, P =.004), and clay percentage (R^2 = 0.84, P =.001) had a positive impact on SLCHspec, while sand percentage (R^2 = 0.83, P =.001) and silt percentage (R^2 = 0.84, P <.001) had a negative impact in Migambo (Table 3); this was in line with a study by [12,2] that found that SLCHspec was positively correlated with both gravimetric soil moisture content and clay percentage. In contrast, BD, SWC, % clay, and % sand had a negligible impact on SLCH in Majulai, although % silt had a positive impact (R^2 =

0.44, P =.05). The higher SWC in Migambo during harvest than in Majulai village can be used to explain the link between SWC and BD with SLCHspec for carrots in Migambo village.

Made it easier for dirt to adhere to carrot roots. Similarly, the tendency of moist soil to adhere to roots more than dry soil was cited by [4] as an explanation for the association between SLCHspec and SWC.

After combining the results from the two villages, the SLCH variability for carrot is shown in Table 3. Weak (P =.05) relationships were seen between the variability of carrot SLCHspec and SWC, soil texture, and BD. Multiple regression analysis of the factors revealed that BD had a substantial (P =.01) correlation with carrot SLCHspec, and that the factors taken together could account for almost 79% of the differences in carrot SLCHspec (Table 3). The rough and kinked morphology of carrots is directly related to this; therefore, the higher the bulk density, the more likely it is that the soil will adhere to the carrot roots.

3.2.3 Potato

Tables 2 and 3 show the SLCH variability for potatoes in relation to SWC, BD, and soil texture. In Majulai, the mean SLCHspec for potatoes was 0.1 kg/kg, with a range of 0.05 to 0.14 kg/kg and a median of 0.1 kg/kg; in Migambo, with a range of 0.05 to 0.20 kg/kg and a median of 0.06 kg/kg, the mean SLCHspec was 0.1 kg/kg. With a mean of 1.1 Mg/ha/harvest and a median of 1.1 Mg/ha/harvest, the SLCHcrop varied from 0.7 to 2.0 Mg/ha/harvest in Majulai, and from 0.23 to 1.20 Mg/ha/harvest in Migambo, with a mean of 0.5 Mg/ha/harvest and a median of 0.5 Mg/ha/harvest. Soil texture at harvest time, SWC, and BD had no discernible effects on the potato's SLCHspec (P =.05). Similarly, when the covariates were integrated in multiple regressions, they only explained roughly 24% of the variability in SLCHspec for potatoes and did not substantially (P =.05) connect with SLCHspec (Table 3).

3.3 Crop Variations in SLCH in Majulai and Migambo Villages

Table 4 makes it evident that the SLCHspec and SLCHcrop for carrots were significantly (P =.05) greater than those for potatoes and onions. The same pattern applied to crop yields as well. When taking into account the impact of villages, it is evident that in Majulai village, the SLCHspec and SLCHcrop values per harvest for carrot were considerably (P =.05) higher than those for onion and potato; the similar pattern was observed in Migambo village. However, in Majulai village, the output of onions was considerably (P =.05) higher than that of carrots and potatoes, but in Migambo village, the yield of carrots was higher than that of onion and potato. Because carrots have a larger gross output than potatoes and onions, as well as a rougher, kinked morphology, more soil is projected to adhere to their rougher root skin than to the smoother tubers and bulbs of potatoes. These factors account for the higher values of the SLCH variable for carrots. This finding is corroborated by [4], who found that higher gross output and rough morphology of cassava roots were linked to higher SLCH variables in cassava compared to potatoes. However, the fact that the SLCHspec for potatoes did not substantially correlate with the SLCH factors under study may be due to the smoother morphology of potato tubers as compared to carrot and onion tubers. It is important to remember that the crops under study are often grown twice a year, during the long and short rain seasons.

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3.4 Soil Nutrient Losses Associated with SLCH of the Studied Crops

Table 5 shows soil nutrient losses as a result of crop harvesting. The variations in average crop yield (Table 4) and the intrinsic nutrient status of the topsoil (Table 6) can be used to explain the variations in soil nutrient loss between crops and villages. Generally, nutrient losses were higher in Migambo (humid cold) than in Majulai (dry warm) with the order of magnitude such that OC

> Total N > Ca > Mg > K > Na > P. Carrot harvesting had the highest soil nutrient losses (Table 5) where the OC, N, P, K, Ca, Mg and Na losses were respectively 365, 30, 0.1, 2, 19, 4 and 0.7 kg/ha/harvest in Majulai and 423, 32,

0.1, 0.8, 16, 3 and 0.4 kg/ha/harvest in Migambo village. Due to the significant amount of soil and nutrient losses that have been documented, soils will eventually become depleted, which will result in serious nutritional imbalances. According to a research conducted in Migambo village by [6], the overall losses of N, P, and K as a result of interill and rill erosion were approximately 248, 31, and 3 kg/ha/year, respectively. The documented losses in the current study, specifically for OC, Total N, Ca, Mg, and K, are concerning in absolute numbers. Controlling water erosion is much more critical than addressing soil and nutrient losses brought on by water erosion. Crop leftovers are typically left on fields, and some farmers restock their plots with minor amounts of urea and diammonium phosphate (DAP) (10–50 kg/ha), while others use no fertilizer at all.

Harvested crops are typically cleaned in river streams by farmers in the Usambara Mountains before being transported to local markets in Dar es Salaam, Tanga, Arusha, Morogoro, Mombasa, Nairobi, Southern Sudan, and other neighboring towns. Occasionally, harvested crops are kept in farmers' compounds prior to transportation. The majority of SLCH are dumped in these markets and in river streams after crops are cleaned, while some are lost during storage and transportation. This is because some farmers still do not clean their harvested crops, meaning that shortly after harvesting, the crops containing soil particles are packed and transported to the aforementioned markets. As a result, the cropland where the crop was grown rarely receives the soil and nutrients that are lost as a result of these harvesting methods. Cleanup of harvested crops in river streams, however, adds to the sediment load and contaminates the river water, which can have detrimental downstream effects (e.g. floods, siltation in stations and channels).

3.5 Comparing the Soil Losses from Other Soil Erosion Processes with the Soil Losses Seen in the Current Study

It is clear that the observed losses in this study should not be underestimated when contrasted with soil losses caused by other soil erosion processes as interill, rill, and tillage (Table 7). Considering the two cropping cycles in a year, the soil losses observed in this study—5.2 for onions, 7.1 Mg/ha/harvest for carrots, and 1.1 Mg/ha/harvest for potatoes—fall under the moderate erosion severity classes for interill and rill erosion as reported by [13]. When compared to studies by [14] and [12] in Belgium, which reported mean SLCH values of 15.8 Mg/ha/harvest for carrot and 3.2 Mg/ha/harvest for potato, respectively, and [4] in Uganda, which reported an SLCH of 3.4 Mg/ha/harvest for cassava, the current study's SLCH results were comparatively low.

4. CONCLUSIONS AND RECOMMENDATIONS

In the Usambara Mountains, it was discovered that agricultural harvesting caused significant rates of soil and nutrient losses. In order to lower overall soil loss rates, it is necessary to incorporate SLCH into soil erosion assessment and mitigation measures. The variability of SLCH for onions was significantly influenced by the water content of the soil, but BD for carrots was only little affected by it. The SLCH of the crops under study was not significantly impacted by soil texture. Carrot harvesting had the highest SLCH, followed by onion and potato harvesting, which had the lowest. SLCHspec and SLCHcrop rates were greater in Migambo village than Majulai.

By not harvesting crops when the soil is sticky and moist, soil losses from crop harvesting can be minimized. In order to prevent soil and nutrient losses from farm lands and to protect river streams from pollution and sedimentation, farmers should also remove as much of the soil that has become stuck on the harvested crops at their farm plots rather than cleaning them at their homes and river streams, as is customary in the Usambara Mountains. Allowing the roots or tubers to dry in the field for a few days before moving them is a simple method because much of the dirt will fall out and stay in the field when the soil dries.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kimaro DN. Assessment of major forms of soil erosion in the morningside catchments, Uluguru Mountains, Tanzania.

PhD Thesis, Sokoine University of Agriculture. 2003;292.

2. Ruysschaert G, Poesen J, Verstraeten G, Govers G. Soil losses due to crop harvesting of various crop types in contrasting agro-ecological environments. Agriculture, Ecosystems and Environment. 2007;120:153–165.

3. Ruysschaert G, Poesen J, Verstraeten G, Govers G. Soil loss due to crop harvesting: Significance and determining factors. Progress in Physical Geography. 2004;28:467–501.

4. Isabirye M, Ruysschaert G, Van linden L, Poesen J, Magunda MK, Deckers J. Soil losses due to cassava and sweet potato harvesting: A case study from low input traditional agriculture. Soil and Tillage Research. 2007;92:96-103.

5. Poesen J, Verstraeten G, Soenens R, Seynaeve L. Soil losses due to harvesting of chicory roots and sugar beet: an underrated geomorphic process. CATENA. 2001;43:35–47.

6. Msita HB. Insights into indigenous soil and water conservation technologies in Western Usambara Mountains, Tanzania. PhD Thesis KU Leuven Belgium. 2013;198.

7. NBS (National Bureau of Statistics). Ministry of Planning, Economy and Empowerment (MPEE). United Republic of Tanzania 2002 Census. Volume X Dar es Salaam; 2006.

8. Moberg JP. Soil and plant analysis manual. The Royal Veterinary and Agricultural University, Chemistry Department, Copenhagen, Denmark. 2001;133.

9. Minitab. Minitab statistical software for quality improvement. Meet Minitab: Minitab User Guide. Minitab Inc. Pennsylvania State University, USA: 2004;134.

10. Genstat. Introduction to Genstat 14 for Windows. Reading, UK: Statistical Service Centre, University of Reading UK. 2011;41.

11. Ruysschaert G, Poesen J, Verstraeten G, Govers G. Interannual variation of soil losses due to sugar beet harvesting in West Europe. Agriculture, Ecosystem and Environment. 2005;107:317-329.

12. Ruysschaert G, Poesen J, Verstraeten G, Govers G. Soil losses due to mechanized potato harvesting. Soil and Tillage Research. 2006;86:52–72.

13. Turkelboom F, Poesen J, Ohler I, Ongprasert S. Reassessment of tillage erosion rates by manual tillage on steep slopes in Northern Thailand. CATENA. 1999;29:29-44.

14. Van Esch L. Soil losses due to harvesting of carrots (Daucus carota L.). MSc. Thesis, Department of Geography, KU Leuven, Leuven; 2003.

15. Belotserkovsky Y, Larionov A. Removal of soil by harvest of potatoes and root crops. Vestnik Moskovskogo Universiteta Seriia 5. Geografia. 1988;4:49–54.

16. Auerswald K, Gerl G, Kainz M. Influence of cropping system on harvest erosion under potato. Soil & Tillage Research. 2006;89:22–34.

17. Kimaro DN, Poesen J, Msanya BM, Deckers JA. Magnitude of soil erosion on the northern slope of the Uluguru Mountsins, Tanzania: Interrill and rill erosion. CATENA. 2008;75:38-44.

18. Temple PH. Measurements of runoff and soil erosion at an erosion plot scale with particular references to Tanzania. Geografiska Annaler. 1972;54A:203-220.

19. Kimaro DN, Deckers JA, Poesen J, Kilasara M, Msanya BM. Short and medium term assessment of tillage erosion in the Uluguru Mountains, Tanzania. Soil & Tillage Research. 2005;81:97-108.

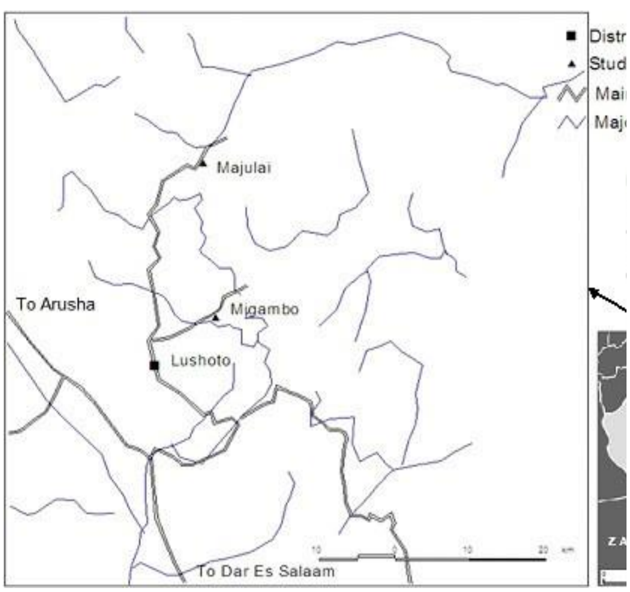

Fig. 1. The location map of Majulai and Migambo villages Lushoto District, Tanzania