Original Research Article

Effects of Agricultural Land Use Practices on Soil Organic Carbon Stocks, Total Nitrogen and Available Phosphorous in Smallholder Farms in Embu County, Kenya

ABSTRACT

A study was conducted to determine soil organic carbon stocks (SOCs), total nitrogen (TN) and available phosphorous (AP) changes in agricultural land use practices with a focus on maize and coffee based agricultural systems along Kapingazi river catchment in Embu County. Demarcation was done into four agro-ecological zones (AEZ) following the river downstream; Lower Highland Zone 1 LH1; Upper Midland Zone 1, UM1; Upper Midland Zone 2, UM2; Upper Midland Zone 3, UM3. Soil samples were obtained from two depths of 0-25 cm and 25-50 cm across slope positions. The soil organic carbon stocks were high in LH1 at 58.38 kg/m^2 whereas UM3 had least amount at 29.48 kg/m^2. The total nitrogen was higher in LH1 at 0.27% while least at UM3 with 0.07%. The LH1 had higher mean amount of available phosphorous at 19.44 ppm and least at UM3. The coffee agricultural system had more available phosphorous in LH1 at 23.75 ppm whereas maize had more in UM1, UM2 and UM3. The soil organic carbon stocks, available phosphorous and total nitrogen decreased across the AEZ. The Farm Foot Slope sampling point had high soil organic carbon stocks with the lowest amounts in the Farm Summit sampling point at both depths. The concentration of total nitrogen in coffee was high in all slope positions, whereas, available phosphorous was higher in maize. Therefore, it is concluded that topography and agriculture land use and management practices influence soil nutrient status.

Keywords: Agricultural Land Use Practices, Agro-Ecological Zones, Soil Organic Carbon Stocks, Soil Nutrients, Smallholder Farmers.

INTRODUCTION

In view of land degradation, climate change and biodiversity loss, soils have become one of the most vulnerable resources in the world (Food Agriculture Organisation [FAO], 2017). Agricultural land use changes have become an increasing focus of research because of its significance in affecting soil fertility and related properties, such as soil bulk density, soil organic carbon (SOC), total nitrogen (TN), available phosphorus (P), and ultimately the value of ecosystem services (Feng *et al.,* 2010). For example, deforestation for agricultural development or extension is a common land-use problem that may cause a series of changes in the ecological environment and soil carbon stock in planting systems (Wang *et al.,* 2022). Agricultural land use has been reported to show a greater reduction in total organic carbon and total nitrogen stocks (Andrade *et al.,* 2020) and the SOC is a common indicator of soil fertility (Livsey *et al.,* 2020). Zhu *et al.* (2021) reported that natural vegetation soil exhibited the highest SOC and N storage, and grasslands had the highest SOC sequestration rate and N sequestration potential. A decline in soil organic carbon stocks, total nitrogen and available phosphorous creates an array of negative effects on land productivity such as loss of soil quality, decline in crop productivity and sustainability of the agricultural systems in river catchments. The type of land use system is an important factor that controls soil organic matter levels since it affects the amount and quality of litter input, the litter decomposition rates and the processes of organic matter stabilization in soils (International Union for Conservation of Nature and Natural Resources [IUCN], 2018). The continent of Africa is one of the current hotspots of land use and land cover changes and degradation, this has an effect on soil organic carbon stocks, available phosphorous and total nitrogen dynamics including changes along the vertical soil profile (Don *et al.,* 2011).

Smallholder farmers represent 80% of all farms in the Africa continent (Livingston *et al.,* 2011). Productivity of crops per unit of land is low in Africa. Over the last several decades, crop harvest and erosion has led to depleted nitrogen in the soils and declining grain yields (Hickman *et al.,* 2011). Inappropriate agricultural land use practices alters soil-plant nitrogen and phosphorous uptake resulting to erosion of nitrogen and phosphorous based compounds to waterways causing eutrophication (Galloway *et al.,* 2008). A marginal reduction in soil organic carbon content in the order of one per cent can have a significant negative impact on soil natural capital and ecosystems services (Brady *et al.,* 2015). Agriculture is the mainstay of the Kenyan economy directly contributing 23.9% of the country's Gross Domestic Product (GDP) growth in 2012 (Kenya National Bureau of Statistics [KNBS], 2014) and another 25% indirectly. The sector accounts for 65% of Kenya's total exports and provides more than 70% of informal employment in the rural areas (Kenya National Bureau of Statistics [KNBS], 2014). In addition, the sector provides food security and livelihood to over 80% of the Kenyan population. Therefore, the agricultural sector is not only the driver of Kenya's economy but also the means of livelihood for the majority of population (Kenya National Bureau of Statistics [KNBS], 2014). Over the years, population pressure and lack of growth in other economic sectors in Kenya has increased pressure on land resources, resulting in declining soil fertility, productivity and general environmental degradation (Mati, 2005).

Population pressure in the Eastern highlands of Kenya has increased demand on food production forcing smallholder farmers to practice poor methods of farming such as limited crop rotation (Micheni *et al.,* 2002). The different agricultural land uses in Embu County include cultivation of upper zones with tea. At the lower altitude gradient coffee is grown as a cash crop. This zone is immediately followed by an area where maize, beans, horticultural crops are grown. In all the zones the crops receive different types and quantities of agricultural inputs like fertilizers and manure at different times (Kimenju *et al.,* 2009). Studies have been done on how soil organic carbon, total nitrogen and available phosphorous are affected by land use change in Africa and Kenya (Abdollahi *et al.,* 2014) but the effects of agricultural land use and spatial variation in soil organic carbon stocks, total nitrogen and available phosphorous in smallholder farms in localised Counties in Kenya has not been well documented. Change in land-use management practices such as cultivation of steep slopes, overgrazing, and no or limited fallow periods, and slope position affects the quality of soils (Assefa *et al.,* 2020). Developing land management scenarios that potentially sequester carbon and reduce greenhouse gasses emission on a sustainable basis necessitates quantifying the current carbon stock under different land uses (Toru & Kibret, 2019). This study examined the effects of agricultural land use and spatial variation on soil organic carbon, total nitrogen and available phosphorous in smallholder farms in Embu County of Kenya. The focus was on coffee and maize based agricultural systems located along different agro ecological zones in the Kapingazi river catchment of the Embu County. Entails

Comment [A1]: ?????

MATERIALS AND METHODS

Study Site

The study was conducted in the Kapingazi River Catchment which has an area of 61.23 square kilometre and is part of the larger Upper Tana River catchment. It drains into river Rupingazi at the lower parts of Embu town. It is located in Embu County, Kenya in the Central Highlands on longitudes 0^0.00'N and 38^0.00'E. The catchment illustrates a typical agro-ecological profile of the County. The catchment is 27 km long and is situated at altitudes of between 1230 m to 2100 m above sea level (Mount Kenya East Pilot Project [MKEPP], 2009). The smallholder farmers in the study area used fertilizer in both cropping systems of maize and coffee. The use of fertilizer in the maize crop was undertaken twice in the duration of the maize crop in the farms, which is during the planting season and after weeding. There was increased use of DAP fertilizer in the maize crop whereas in coffee there was high usage of a mixture of NPK and CAN fertilizers. The use of fertilizer in the coffee crop was three times a year by most of the smallholder farmers. The study established that most coffee crops in the farms were of more than ten years whereas maize was of approximately seven weeks.

Comment [A2]: Check, you cannot say longitude 0° … N ; the North is referred to a latitude. Always better to present the extreme coordinates of the site, between x and y lat N and x and Y long E…

Comment [A3]: If possible, if the agricultural calendar is the same, give approximately the date (months) when fertilizers were use

Comment [A4]: Please give the full name of the fertilizers category before abbreviating afterwards

Comment [A5]: Idem ! When ??

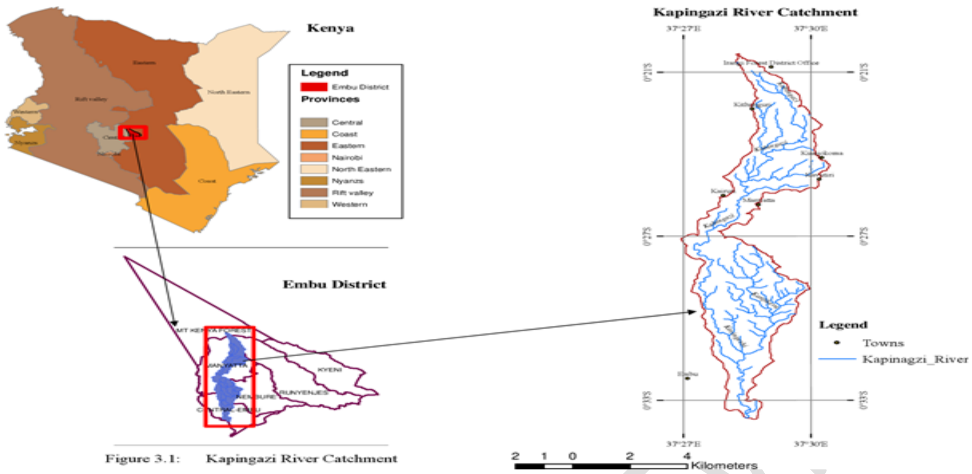
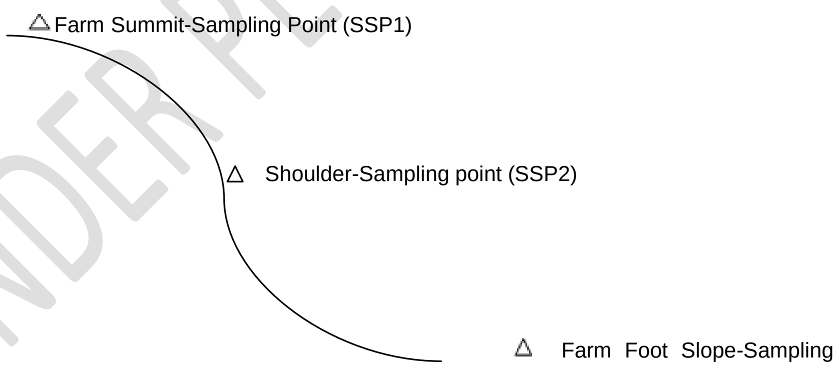


Figure 1: Map showing the location of Kapingazi River Catchment
(Source: Water Resources Management Authority [WRMA], 2009)

Soil sample collection

A total of seventy-two (72) soil samples were collected for each of the two agricultural based systems making a grand total of one hundred and forty-four (144) soil samples. Three soil samples were collected across the landscape position in the two depths of 0-25 cm and 25-50 cm. The landscape positions identified were the Farm Summit - Sampling point (SSP1), Shoulder - Sampling point (SSP2) and the Farm Foot Slope- Sampling point (TSSP) [Figure 2]. The soil samples were appropriately labelled, placed in *khaki* carrier bags and transported to the Kenya Agricultural and Livestock Research Organization (KALRO) laboratory in Embu for analysis.

Comment [A6]: It will be better to display the sampling points on the map, or you can make a table (annex?) showing the coordinates of the 36 x2 sampling points



point (TSSP)

Figure 2: Landscape outline of soil sampling points in the slope positions

Soil analysis

Total nitrogen (TN) was analysed by the micro-Kjeldahl procedure (Institute of Soil Science Chinese Academy of Sciences (ISSCAS], 1978), available phosphorous by the Olsen and Sommers method due to the acidic nature of soil in the study area. The Soil organic carbon (SOC) was analysed using the Walkey and Black method (Nelson & Sommers, 1982). Computation of soil organic carbon was done through the following method.

*SOC = BD * d * %C ………………………………………………….. Equation (1)*

Where, SOC = Soil Organic Carbon [kg/m^2]; BD = Bulk Density [g cm^{-3}]; d = Depth of the Soil Sample [cm];
% C = Carbon Concentration [%]

Statistical analysis

The nominal data obtained from the questionnaire were analysed using cross tabulation in Statistical Packages for Social Science (SPSS) where descriptive statistics (measure of location and dispersion) were obtained. An analysis of variance (ANOVA) was used to analyse data on SOCs, AP and TN obtained from coffee and maize based agricultural land use practices at the two depths. Analysis of variance (ANOVA) was further used to evaluate any significant differences in distribution of soil organic carbon across the coffee and maize based agricultural land use practices. The significantly different means were separated using the Tukey test at α=0.05.

RESULTS AND DISCUSSION

Quantification of the Spatial Distribution in SOC Stocks, TN and AP Contents in Coffee and Maize Based Agricultural Systems along the Kapingazi River Catchment

The findings of this study indicated that the coffee-based agricultural system had the highest concentration of soil organic carbon stocks as compared to the maize-based agricultural systems (Figure 3-a). The results show that soil organic carbon stocks were higher upstream at LH1 and decreased downstream towards UM3 in both agricultural based systems. Similar studies have established that areas of high altitude have large quantities of soil organic carbon stocks (Biazin *et al.,* 2018).

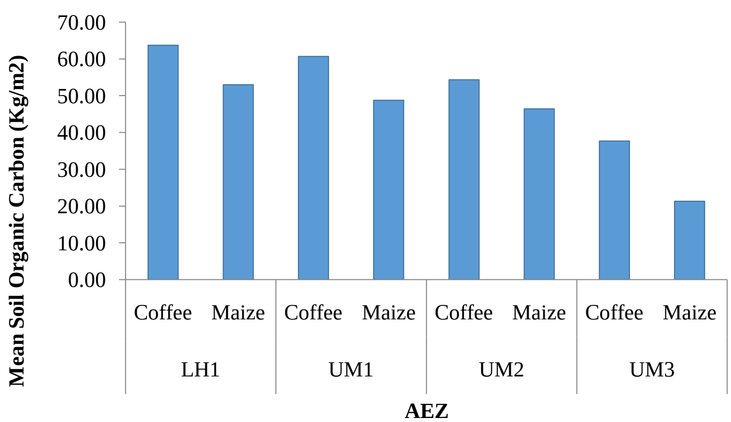


Figure 3-a: Comparison of the spatial distribution of soil organic carbon stocks in the agricultural systems. This title lacks precision, explain the meaning of abbreviations. AEZ, UM1…….

The results showed that coffee based agricultural system had the highest concentration of total nitrogen compared to the maize based system. Total nitrogen was higher in LH1 and reduced towards UM3 in both agricultural systems (Figure 3-b). The findings of the study were similar to that of Brevik *et al.* (2016).

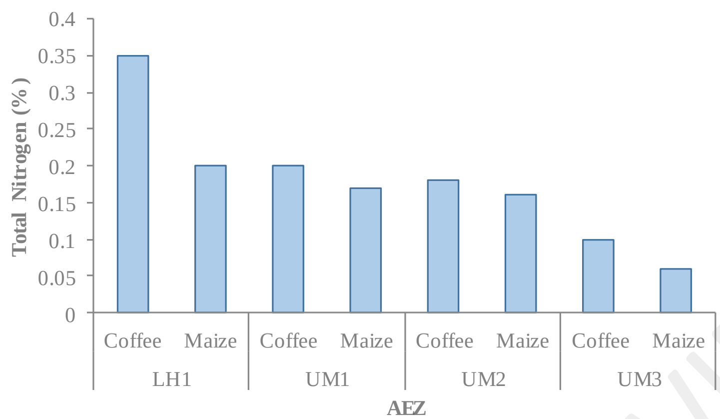


Figure 3-b: Comparison of the spatial distribution of total nitrogen in the agricultural systems *Idem abbreviations !!!*

Formatted: English (U.S.)

The results derived for available phosphorous indicated that the trend did not follow the spatial distribution like that of soil organic carbon stocks and total nitrogen. The agroecological zone LH1 showed the highest concentration of available phosphorous in coffee whereas in agroecological zone UM1 showed the higher concentration of available Phosphorous in maize (Figure 3-c).

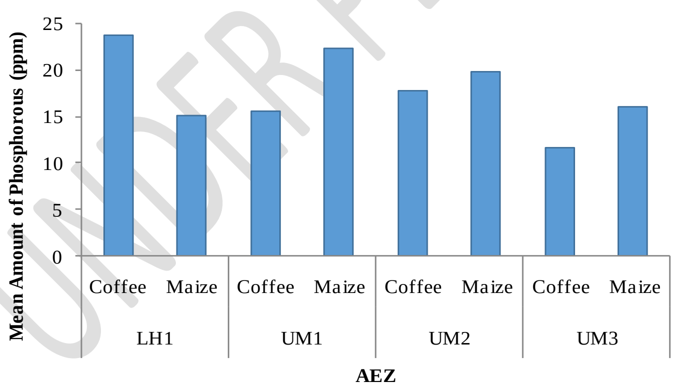


Figure 3-c: Comparison of the spatial distribution of available phosphorous in the agricultural systems *idem precisions !!!!*

The figures are not well organized. You cannot do Figures 3a, 3b, and 3c separately and call them all Figure 3xx. It would be better to make a single figure 3 on which have to see a, b and c

Formatted: English (U.S.)

Same for Figures 4a, 4b and 4c

Contribution of smallholder farms landscape differences on soil organic carbon stocks, total nitrogen and available phosphorous in coffee and maize based agricultural systems

The results indicated that coffee based agricultural system had the highest concentration of soil organic carbon stocks in all slope positions as compared to the maize based agricultural system. this is probably due to the fact that coffee based systems exists as a natural vegetation compared to maize crop land which lasts for a short duration of time. Changes in land use from natural vegetation to cropland have been reported to cause significant reductions in SOC stocks in the long term (Wang *et al.,* 2022). The results showed that soil organic carbon stocks in TSSP was higher than the results obtained in SSP1 and SSP2 (Figure 4-a). Wiaux *et al*. (2014) established that the soil organic carbon stocks of the Farm Foot Slope position were 2.5 times higher than other slope positions. Similar studies by Reza *et al.* (2016) established that steep slopes have lower soil organic carbon stock content than flat land, as they are more vulnerable to erosion, especially when associated with inappropriate management and overuse. The landscape position SSP2 had the lowest mean concentration in both depths of soil organic carbon stocks (Figure 4-a). This could be attributed to erosion in this position. The higher concentration in TSSP could be due to deposition that occurs in this slope position. Similar studies by Amuyou & Kotingo (2015) revealed higher soil organic carbon stocks in bottom slope is probably associated to the effect of cultivation and geomorphologic processes that result in the transportation and deposition of soil materials. Hao *et al.* (2002) established lower concentration of soil organic carbon stocks in the middle slope due to soil erosion. There is more occurrence of soil erosion on the steeper middle slope than upslope hence the latter is likely to have more soil organic carbon amounts than the former.

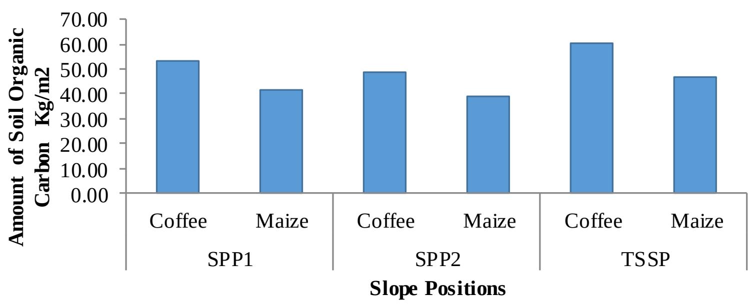


Figure 4-a: Comparison of soil organic carbon stocks in different slope positions of the agricultural based systems

The results indicate that coffee based agricultural system had the highest concentration of total nitrogen in all slope positions as compared to the maize based system (Figure 4-b). Similar studies have established that cultivated soils have significantly lower total nitrogen at all depths when compared to grasslands and forestlands, indicating that continuous cultivation ultimately reduces the total nitrogen contents in the soil (Abera & Belachew, 2011). The results show that total nitrogen in TSSP was higher in coffee whereas in maize SSP1 showed higher concentration of total nitrogen. The landscape position SSP2 had the lowest mean concentration in both depths of total nitrogen (Figure 4-b). This could be attributed to accumulation of SOC at the farm foot slope due to soil erosion in this position which increased the organic matter which is a store of most nutrients. The higher concentration in TSSP could be contributed to deposition that occurs in this slope position. Similar studies have supported these findings that total nitrogen significantly differs with the slope positions (Yimer *et al.,* 2006). The result depicts similar concentrations that were derived in soil organic carbon stocks. The enhanced levels of total nitrogen and soil organic carbon stocks in coffee based agricultural system could be attributed to management practices that minimised soil disturbances and erosion, these increased the soil organic matter which is a primary source of nitrogen in soils. Ma *et al.* (2022) indicated that improved agricultural management plays a vital role in protecting soils from degradation in Eastern Africa and changing practices such as reducing tillage, fertilizer use or cover crops are expected to enhance soil organic carbon (SOC) storage, with climate change mitigation co-benefits, while increasing crop production.

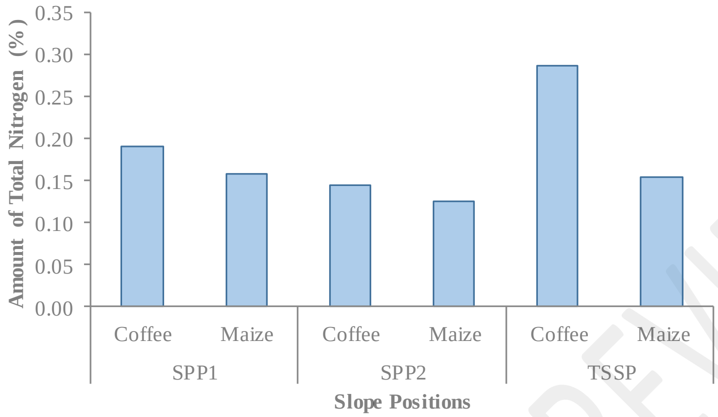


Figure 4-b: Comparison of total nitrogen in different slope positions of the agricultural based systems

The result indicates that maize based agricultural system had the highest concentration of available phosphorous in all slope positions as compared to the coffee based agricultural system (Figure 4-c). The presence of greater available phosphorous concentration in maize based agricultural system might be due to the differential uptake of phosphorus between coffee and maize. Similar results of Amuyou & Kotingo (2015) revealed that soil high in available phosphorous also have high organic matter contents. The results show that available phosphorous in SSP2 was higher in both coffee and maize based agricultural systems (Figure 4-c). In most agricultural land use systems farmers intensify the soil management practices on the shoulder region because of increased activities in this area. It has been reported that agricultural intensity positively correlates with phosphorous content (De Neve *et al.,* 2006), and the mean total phosphorus stocks was observed to increase with increasing management intensity (Livsey *et al.,* 2020). Increase in agricultural land use may result to a soil that is well restored and that has less phosphorus fixation that may explain why there was higher levels of available phosphorus in the shoulder region.

In the "Statistical analysis" section, the authors say they did an analysis of variance and assessed whether the differences were significant.

In the figures and in the text, we do not see it, there is nothing referring to statistical analysis (standard deviations, differences, etc.)

Formatted: English (U.S.)

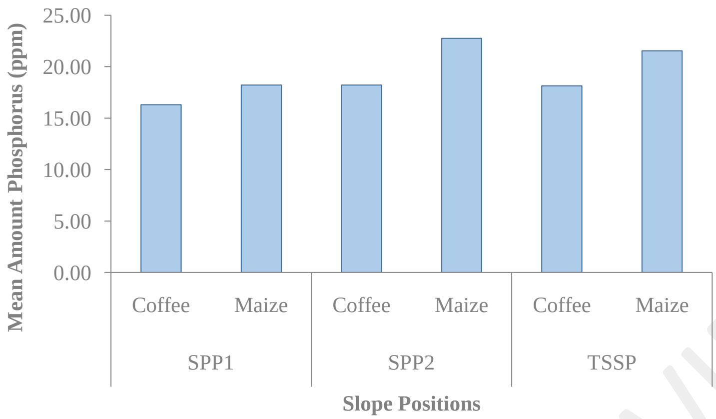


Figure 4-c: Comparison of available phosphorous in different slope positions of the agricultural based system

Conclusion

The study established that soil organic carbon stocks, total nitrogen and available phosphorous significantly varied among agricultural practices, agroecological zones, soil depths and slope positions. In areas such as those on shoulder slopes as shown in this study, greater efforts to increase soil organic carbon stocks, total nitrogen and available phosphorous are required. However, further study of the area is recommended, especially agricultural practices in combination with other topographic features such as altitude and their effects on soil organic carbon stocks, total nitrogen and available phosphorous content. Factors and agricultural practices that increase soil organic carbon stocks, total nitrogen and available phosphorous whilst at the same time enhancing other aspects of the environment such as improved soil fertility, enhanced carbon sequestration, decreased erosion and improved yield of agricultural production should be taken into consideration. There is need to enhance management practices that retain soil organic carbon, total nitrogen and available phosphorous. Such practices are widely advocated by international agreements and conventions, and hence, smallholder farmers can play a role in contributing towards this and benefit from funds associated with the role they play towards this.

References

Abera, Y., & Belachew, T. (2011). Effects of Land Use on Soil Organic Carbon and Nitrogen in Soils of Bale, South Eastern Ethiopia. Tropical and Subtropical Agro-ecosystem, pp: 14, 229-23. DOI: https://www.redalyc.org/articulo.oa?id=93915703022

Abdollahi, L., Schjønning, P., Elmholt, S., & Munkholm, L. J. (2014). The effects of organic matter application and intensive tillage & traffic on soil structure formation & stability. *Soil and Tillage Research*, pp: 136(0), 28–37. DOI: https://doi.org/10.1016/j.still.2013.09.011

Amuyou, U. A., & Kotingo, K. E. (2015). Toposequence analysis of soil properties of an agricultural field in the Obudu Mountain slopes, cross river state-Nigeria. *International Journal of Scientific & Engineering Research.* pp. 8, DOI: *https://www.ijser.org/researchpaper/Assessment-of-Agricultural-Landuse-and-Soil-Chemical-Properties-in-the-Obudu-Mountain-Slope-Southeast-Nigeria.pdf*

Andrade, E.M., Valbrum, W., de Almeida, A.M.M., Rosa, G., & da Silva, A,G.R. (2020). Land-Use Effect on Soil Carbon and Nitrogen Stock in a Seasonally Dry Tropical Forest . Agronomy 2020, 10(2), 158; https://doi.org/10.3390/agronomy10020158

Assefa, F., Elias, E., Soromessa, T., & Ayele, G. T. (2020). Effect of changes in land-use management practices on soil physicochemical properties in Kabe Watershed, Ethiopia. Air Soil Water Res 13: 1178622120939587.
Biazin, B., Kim, D.G., & Mengistu, T. (2018). Soil Organic Carbon and Nitrogen Stocks Following Land Use Changes in a Sub-Humid Climate. pp: 8.70. *Environment and Natural Resource Research.* **DOI:** 10.5539/enrr.v8n1p70
Brady M.V., Hedlund K., Cong R.G., Hemerik L., Hotes S., Machado, S., Mattsson, L., Schulz, E. & Thomsen I.K. (2015). Valuing supporting soil ecosystem services in agriculture: a Natural Capital Approach. Agronomy Journal, pp: 107, 1809-1821. DOI: 10.2134/agronj14.0597
Brevik, E. C., Calzolari, C., Miller, B. A., Pereira, P., Kabala, C., Baumgarten, A., Jordan, A. (2016). Soil mapping, classification, and pedological modelling: History and future directions. Geoderma, pp: 264:256–274. https://doi.org/10.1016/j.geoderma.2015.05.017
De Neve, S.; Van Den Bossche, A.; Sleutel, S.; Hofman, G. (2006). Soil nutrient status of organic farms in flanders: An overview and a comparison with the conventional situation. Biol. Agric. Hortic. pp. 24, 217–235.
Don, A., Schumacher, J., & Freibauer, A. (2011). Impact of tropical land-use change on soil organic carbon stocks – a meta-analysis. Global Change Biology, pp: 17, 1658-1670. DOI: 10.1111/j.1365-2486.2010.02336.x
FAO (Food Agriculture Organisation) (2017). Soil Organic Carbon: the hidden potential. Rome, Italy. http://www.fao.org/documents/card/en/c/ed16dbf7-b777-4d07-8790-798604fd490a/
Feng, X., Fu, B., & Yang, X. (2010). Remote sensing of ecosystem services: An opportunity for spatially explicit assessment. pp: 20(6): 522– 535. DOI: https://doi.org/10.1007/s11769-010-0428-y
Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P. & Sutton, M.A. (2008). Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science, pp: 320: 889-892. DOI: 10.1126/science.1136674
Hao, Y., Lal, R., Owens, L. B., Izaurralde, R. C., Post, W. M., & Hothem, D. L. (2002). Effect of cropland management and slope position on soil organic carbon pool at the North Appalachian Experimental Watersheds. Soil and Tillage Research, pp: 68(2), 133-142. DOI: https://naldc.nal.usda.gov/download/15668/PDF
Hickman, J., Havlikova, M., Kroeze, C., & Palm, C. (2011). Current and future nitrous oxide emissions from African agriculture. Current Opinion in Environmental Sustainability, pp: 3, 370-378. DOI: 10.1016/j.cosust.2011.08.001
IUCN (International Union for Conservation of Nature and Natural Resources) (2018). Soil Biodiversity and Soil Organic Carbon: keeping drylands alive. Gland, Switzerland: IUCN. DOI: https://portals.iucn.org/library/node/47735
ISSCAS (Institute of Soil Sciences, Chinese Academy of Sciences) (1978). Physical and Chemical Analysis Methods of Soils. Shanghai: Shanghai Science Technology Press, pp: 7−15. DOI/; http://english.issas.cas.cn/
Kenya National Bureau of Statistics (KNBS) (2014). Economic survey. DOI: https://www.knbs.or.ke/?s=KNBS+2014
Kimenju, J. W., Karanja, N. K., Mutua, G. K., Rimberia, B. M., & Wachira, P. M. (2009). Nematode community structure as influenced by land use and intensity of Cultivation. Tropical and Subtropical Agro ecosystems, pp: 11(2), 353-360. DOI: https://www.researchgate.net/publication/287492898
Livingston, G., Schonberger, S., & Delaney, S. (2011). SSA: The State of Smallholders in Agriculture. Rome: International Fund for Agricultural Development. DOI: https://docs.igihe.com/IMG/pdf/untitled-3.pdf
Livsey, J., Alavaisha, E., Tumbo, M., Lyon, S.W., Canale, A., Cecotti, M., Lindborg, R, & Manzoni, S. (2020). Soil Carbon, Nitrogen and Phosphorus Contents along a Gradient of Agricultural Intensity in the Kilombero Valley, Tanzania. Land **2020**, 9, 121; DOI: 10.3390/land9040121
Ma, J., Rabin, S. S., Anthoni, P., Bayer, A. D., Nyawira, S. S., Olin, S., ... & Arneth, A. (2022). Assessing the impacts of agricultural managements on soil carbon stocks, nitrogen loss and crop production—a modelling study in Eastern Africa. *Biogeosciences Discussions*, 1-31.
Mati, B. M. (2005). Overview of water and soil nutrient management under smallholder rainfed agriculture in East Africa: Working Paper 105. Colombo, Sri Lanka: International Water Management

Institute (IWMI). DOI: http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR105.pdf
Micheni, A., Tuwei, P., Mugwe, J. & Kiruiro, E. (2002). Integration of Organic and Inorganic Soil Fertility Improvement Inputs for Improved Crop Yields in Central Highlands of Kenya. (1) 12th ISCO Conference, Beijing.DOI:https://irlibrary.ku.ac.ke/bitstream/handle/123456789/18518/An%20evaluation%20of%20intergrated.....pdf?sequence=1&isAllowed=y
MKEPP (Mount Kenya East Pilot Project (2009). Database. Embu: Miika Mäkelä. Mount Kenya East Pilot Project for Natural Resources Management.
Nelson D. W., & Sommers L. E. (1982). Total carbon, organic carbon, and organic matter. In: Page A L, Miller R H, Keeney D R. Methods of Soil Analysis, Agronomy, part 2. 2nd ed. Madison, WI: ASA and SSSA, pp: 539–577. DOI: https://doi.org/10.2134/agronmonogr9.2.2ed.c29
Reza, A., Eum, J., Jung, S., Choi, Y., Owen, J. S., & Kim, B. (2016). Export of non-point source suspended sediment, nitrogen, and phosphorus from sloping highland agricultural fields in the East Asian monsoon region, Environ. Monit. Assess., pp: 188, 692. DOI: 10.1007/s10661-016-5681-9
Toru, T & Kibret, K. (2019). Carbon stock under major land use/land cover types of Hades sub-watershed, eastern Ethiopia. Carbon Balance Manage 14, 7. https://doi.org/10.1186/s13021-019-0122-z
Wang, B., Wang, G., Myo, S.T.Z., Li, Y., Xu, C., Lin, Z., Qian, Z., & Tang. L. (2022). Deforestation for Agriculture Temporarily Improved Soil Quality and Soil Organic Carbon Stocks. Forests 2022, 13, 228. https://doi.org/10.3390/f13020228.
WRMA (Water Resources Management Authority), (2009). Kapingazi sub-catchment management plan. Embu: Kapingazi WRUA, WRMA and other stakeholders.
Wiaux, F., Cornelis, J. T., Cao, W., Vanclooster, M., & Van, O. K. (2014). Combined effect of geomorphic and pedogenic processes on the distribution of soil organic carbon quality along an eroding hillslope on loess soil. Geoderma pp: 216:36–47. DOI: https://www.academia.edu/33459071
Yimer, F., Ledin, S., & Abdelkadir, A. (2006). Soil organic carbon and total nitrogen stocks as affected by topographic aspect and vegetation in the Bale Mountains, Ethiopia. Geoderma. pp: 135. 335-344. DOI: 10.1016/j.geoderma.2006.01.005
Zhu, G., Shangguan, Z., Hu, X., & Deng, L. (2021). Effects of land use changes on soil organic carbon, nitrogen and their losses in a typical watershed of the Loess Plateau, China. *Ecological Indicators*, *133*, 108443.