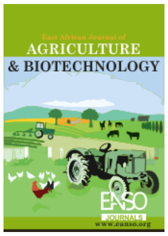

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Original Article

The Influence of Intensive Agriculture on Soil Properties and Nutrient Availability in Kauwi and Zombe Wards of Kitui County, Kenya

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ABSTRACT

Soils perform various functions for the purpose of supporting agroecosystems. Numerous agroecosystem support functions rely on the properties of soils. Inappropriate agricultural techniques and land usage have led to a global 12.5% drop in soil health during the previous few decades. Inappropriate cultivation, nutrient mining, and overuse of inorganic chemical treatments are some of the activities that may have degraded soil quality. A study on the influence of intensive agriculture on soil properties and nutrient availability under different cropping systems and locations was done in the years 2018 and 2019 in Kauwi and Zombe Wards of Kitui County, Kenya. Four commonly occurring cropping systems, namely, vegetable, cereal, fruit, and agroforestry, were selected in the two locations. Uncultivated land in the area was considered as control. In total, there were five treatments, which were replicated five times in each of the locations. During the typical long (March, April, May) and short (October, November, December) rainfall seasons, composite soil samples were randomly taken from the cropping systems. Analysis of the results revealed that the influence of cropping systems on locational variation of soil quality parameters varied significantly ($p<0.05$). Further, the interaction between cropping strategies and locations significantly influenced soil pH and soil organic carbon. In Zombe, the vegetable cropping system registered the lowest soil pH and electrical conductivity values. Similarly, Soil Organic Carbon, Nitrogen, Phosphorus, and Potassium mean values under the vegetable farming system were higher in Zombe compared to Kauwi ward, probably due to the heavy application of fertilisers. Based on the results from the study, farmers in the area should be sensitised to embrace sustainable agricultural practices that promote moderate application of fertilisers to maintain healthy soils.

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INTRODUCTION

Soils perform many functions to support agroecosystems. Numerous agroecosystem support functions rely on the properties of soils. They provide a structure for plant growth, a reservoir for a wide variety of nutrients necessary for the survival of plants, and a filter that regulates air quality via interactions with the atmosphere (Pierzynski et al., 2005). Soils also provide a medium for storing and purifying water as it percolates through and a location where biological life is engaged in decomposing and recycling plant and animal products (Wolf & Snyder, 2003). Many of these soil characteristics have been undermined by methods that have failed to account for their interdependence (Oldeman, 1992).

For subsequent generations to enjoy the same level of agricultural output and environmental quality that we have currently, the soil quality needs to be preserved and even improved. Losses in output resulting from declining soil quality may frequently be compensated for and covered by increased technology and inputs used in today's agricultural production systems. However, the National Research Council (1993) discovered that economic sustainability was reduced when agricultural inputs were increased, and environmental quality was placed at greater risk.

Inappropriate agricultural techniques and land usage have led to a global 12.5% drop in soil health during the previous few decades (Arshad & Martin, 2002). Inappropriate cultivation, nutrient mining, and overuse of inorganic chemical treatments may have degraded soil quality (Xiubin et al., 2002). The rising worldwide need for food is a major contributor to these harmful activities. As of this estimate, the world's population average annual growth rate was 1.1% between 2015 and 2020 (Gu et al., 2021). According to the United Nations, the global population will grow from the current 7 billion people to 9.3 billion in 2050 and 10.1 billion in 2100 (Lee, 2011). To meet the requirements of growing inhabitants, farmers have turned to unsustainable methods including monoculture, excessive use of pesticides and fertilisers, and increased agricultural intensification (Tillman et al., 2012). Farmers have turned to unsustainable methods, including monoculture, excessive use of pesticides and fertilisers, and increased agricultural intensification to meet the requirements of growing inhabitants.

Farmers in Kitui County's Kauwi and Zombe/Mwitika wards use exclusive cultivation techniques, each with a distinct effect on crop production and the county's overall agricultural sector. Farmers' practices for managing soil have a direct impact on soil quality; thus, it is important to analyse and evaluate how different cropping systems affect soil quality. A decrease in soil quality brought on by the commercialisation of agriculture and intense soil management may be the cause of the decrease in crop yields seen in both areas.

Intensified cultivation practices, the emergence of high-yielding crop varieties, and the greater use of agricultural inputs like herbicides, synthetic fertilisers, irrigation, and automation have all led to a rise in crop output during the past several decades. However, these have led to unintended consequences, including increased soil erosion, reduced soil fertility, quality, and biodiversity, increased groundwater pollution, lake eutrophication, and a rise in greenhouse gases (Matson et al., 1997). Therefore, this study aimed to assess the influence of intensive agriculture on the locational variation of soil quality in Kauwi and Zombe wards of Kitui County.

MATERIALS AND METHODS

Study Area

The research was conducted in two areas of Kitui County: The Kauwi ward (Kauwi hamlet) and the Zombe/Mwitika ward (Thua River basin). Farmers in the Kauwi ward of Kitui County still rely on ploughs and other traditional agricultural equipment, which is characterised by a lack of technological advancement and commercialisation. Natural manures are often used, and examples include compost, cow dung, and farm waste. On the other hand, farmers in the Zombe/Mwitika ward in the Thua River valley have chosen intensive agriculture, a strategy that involves much labour and capital to maximise crop production.

The elevation of Kitui County ranges from 400 to 1,839 meters above sea level, with the highest points being in Kitui Central and Mutito hills. The average annual rainfall in the county is 881 millimetres (34.7 inches) (climate data.org), making for a hot and dry environment. Most of the County is considered to have an arid climate Luvai et al. (2014), one of two climate types in the area. Highs average between 15 and 40 degrees Celsius (59- and 104 degrees Fahrenheit) year-round. Typically, September/October through January/February are the warmest months of the year. The average annual high is about 26 degrees Celsius, while the average annual low is around 14 degrees Celsius, with a wide range in between.

The soils have a high moisture-storing capacity and poor nutrient availability; they are well-drained, moderately deep to very deep, dark reddish brown to dark yellowish brown, friable to hard, and sandy clay to clay. Loamy sand to sandy loam makes up the topsoil in most areas (Koreeny, 2023).

The population density of Kitui County is anticipated to rise to 39 people per square kilometre from its 2009 level of 33 people per square kilometre, according to the Kenya National Population and Housing Census 2019 (Statistics 2019). Kitui West has a total population of 113,497 people with a population density of 170 persons/Km^{2,} while Kitui East has a population of 136,708 people with a population density of 27 persons/Km^2. Hilly topography and several valleys where agriculture grows well support a high population density in the county, and these factors all contribute to the county’s overall pattern of population distribution.

Cropping Systems and Experimental Details

The study followed a descriptive research design since there was no manipulation of the variables. Four cropping systems, i.e., vegetable, cereal, fruit, and agroforestry, were purposefully selected in both the Kauwi and Zombe wards of Kitui County. Uncultivated land was selected as control. Composite soil samples were randomly collected from the cropping systems during conventionally long (March, April, May) and short (October, November, December) rain seasons. The selected systems constituted the treatments and were replicated five times in the farmers’ fields.

Treatment Combination

Five cropping systems were studied in two rain seasons, making the treatment combination ten.

5*2= 10

Replications = 5

Soil Samples and Sampling Procedure

Each farming system had surface soil samples obtained for laboratory examination from a depth of 0 to 15 centimetres throughout the long and short rain seasons. Composite soil samples were selected from each farming method to ensure their inclusion. For the various cropping systems, soil samples were taken during the long rain season March–May) and the short rain season (October–December) for analysis of selected soil indicators. Bulk density, organic carbon, total Nitrogen, Phosphorus, Potassium, electrical conductivity, and pH were also measured in the soil using the standard core method (Singh 1980), rapid titration method (Walkley & Black, 1934), alkaline potassium permanganate (Subbaiah & Asija, 1949), Olsen's method (Olsen, 1954), Ammonium acetate (Merwin and Peech 1951) and 1:2.5 soil: water suspension method (Sims& Jackson, 1971) consecutively. Soil organic carbon stock was computed by multiplying soil carbon content (%) with bulk density and the volume fraction of coarse fragments and expressed as $MgCha^1$ by the formula. The soil analysis was conducted in the KARLO laboratory in Muguga, Kenya.

Q1=ECiDiEi(1-Gi)

Statistical Analysis

Data was analysed after the experiments, and critical examination was done for easy interpretation. To evaluate the influence of cropping systems on spatial variation of soil quality, an analysis of variance (ANOVA) was carried out to determine the statistical differences amongst the mean values of the different soil quality parameters. The statistical tests were conducted using OPSTAT statistical software, and means were compared at a critical difference of $p < 0.05$.

RESULTS

Locational-Wise Variation in the Status of pH, Electrical Conductivity, and Soil Organic Carbon in Soils under Different Cropping Systems

Results presented in *Table 1* indicated that the cropping system-wise trend of soil organic carbon in the soil was; vegetable-based (2.53%) > orchard based (1.50%) > cereal-based (1.44%) > agroforestry based (1.18%) > uncultivated-land (0.90%) in Zombe while the trend in Kauwi was; vegetable-based (1.26%) > agroforestry based (1.21%) > cereal-based (1.05%), > orchard (0.97%) > uncultivated land (0.48%).

The soil pH ranged from 2.73 in vegetable-based cropping systems to 6.45 in uncultivated land in Zombe ward. It followed the ascending order: vegetable (2.73) < cereal-based (4.42) < orchard-based (5.32) < agroforestry-based (6.08) < uncultivated land (6.45) under the different cropping systems, while in Kauwi ward, the soil pH followed the ascending order; vegetable-based (5.16) < orchard based (6.77) < cereal-based (6.87) < agroforestry based (7.32) < and uncultivated land (7.71). The interaction between cropping systems and locations was found to have a significant influence on soil pH in the region.

The Electrical Conductivity in soil followed the descending order: vegetable-based (347.75 dSm^{-1}), > orchard based (315.25 dSm^{-1}), >agroforestry based (284.71 dSm^{-1}) > cereal-based (267.88 dSm^{-1}), and > uncultivated land (206.68 dSm^{-1}) in Zombe ward while in Kauwi ward it followed the following descending order; vegetable-based (326.15 dSm^{-1}) > orchard based (304.58 dSm^{-1}) > cereal-based (258.18 dSm^{-1}) > agroforestry based (249.11 dSm^{-1}) and > uncultivated land (194.47 dSm^{-1}) across the cropping systems. The results also revealed that Electrical Conductivity (E.C.) was lowest under control, followed by cereal and agroforestry cropping systems in both Kauwi and Zombe wards.

The highest E.C. was observed under vegetable-based and orchard-based cropping systems.

Locational-Wise Variation in the Status of Soil NPK under Different Cropping Systems

Scrutiny of the results in *Table 2* revealed that cropping systems significantly influenced soil nutrients in both Zombe and Kauwi wards. Total nitrogen ranged from 0.79 kg ha^{-1} to 0.23 kg ha^{-1} and 0.32 kg ha^{-1} to 0.16 kg ha^{-1} in both Zombe and Kauwi wards, respectively. It followed the trend; vegetable-based (0.79 kg ha^{-1}) > orchard based (0.56 kg ha^{-1}) > cereal-based (0.44 kg ha^{-1}) > agroforestry based (0.36 kg ha^{-1}) > uncultivated land (0.23 kg ha^{-1}) and cereal-based (0.32 kg ha^{-1}) > agroforestry based (0.30 kg ha^{-1}) > orchard based (0.298 kg ha^{-1}) > vegetable based (0.25 kg ha^{-1}) > uncultivated land (0.16 kg ha^{-1}) in Zombe and Kauwi wards respectively. The overall soil nitrogen levels were substantially greater in the Zombe wards and lower in the Kauwi wards. Total nitrogen was greatest in the vegetable-based farming system (0.79 kg ha-1) in Zombe ward and was statistically at par with the cereal-based (0.32 kg ha-1) cropping system in Kauwi. The lowest rates were recorded in Zombe and Kauwi's uncultivated areas, at 0.23 and 0.16 kilos per hectare per year, respectively. The results of the study revealed that the interaction between cropping systems and locations had a positive significance on soil Nitrogen.

Data obtained showed that available phosphorus in Zombe was significantly higher across the cropping systems than in the Kauwi ward. It followed the descending order: vegetable-based (267.53 kg ha^{-1}) >orchard-based (224.69 kg ha^{-1}) > agroforestry-based (201.29 kg ha^{-1}) > cereal-based (183.03 kg ha^{-1}) >uncultivated land (139.67 kg ha^{-1}) and orchard based (209.75 kg ha^{-1}) > uncultivated land (153.15 kg ha^{-1}) > cereal-based (134.44 kg ha^{-1}) > vegetable based (93.64 kg ha^{-1}) and > agroforestry (83.27 kg ha^{-1}) in Zombe and Kauwi wards respectively. It was observed that the mean of available phosphorus was highest under the vegetable-based cropping system in Zombe, while under the orchard-based cropping system, it was at par as in Kauwi ward. Similarly, the results showed that the interaction between cropping systems and locations positively impacted available soil phosphorus.

Available potassium was higher in the Zombe ward across all the cropping systems compared to the Kauwi ward. It followed the order; vegetable-based (570.79 kg ha^{-1}) > orchard based (440.94 kg ha^{-1}) > agroforestry based (429.37 kg ha^{-1}) > cereal-based (343.67 kg ha^{-1}) > uncultivated land (275.51 kg ha^{-1}) in Zombe ward and agroforestry based (303.26 kg ha^{-1}) > cereal-based (303.01 kg ha^{-1}) > vegetable based (271.63 kg ha^{-1}) > orchard vegetable (261.81 kg ha^{-1}) > uncultivated land (212.19 kg ha^{-1}) in Kauwi ward. Irrespective of cropping systems, the maximum soil available potassium of 570.79 kg ha^{-1} was recorded in the Zombe ward and the minimum in the Kauwi ward (212.19 kg ha^{-1}). The results revealed that the interaction between cropping systems and locations positively impacted available soil potassium

Table 1: Locational-wise variation in Status of P.H., electrical conductivity, and soil organic carbon in soils under different cropping systems in the study area

Cropping System	Soil quality parameter								
	pH			EC (dSm^{-1}) micro siemen			Soil Organic Carbon (Units %)		
	Zombe	Kauwi	Mean	Zombe	Kauwi	Mean	Zombe	Kauwi	Mean
Vegetable-based	2.73	5.16	3.94	347.75	326.15	336.95	2.53	1.26	1.89
Cereal based	4.42	6.87	5.64	267.88	258.18	263.03	1.44	1.05	1.25
Agroforestry based	6.08	7.32	6.90	284.71	249.11	266.91	1.18	1.21	1.19
Orchard based	5.32	6.77	6.05	315.25	304.58	309.915	1.50	0.97	1.23
Uncultivated land	6.45	7.71	6.89	206.68	194.47	200.58	0.90	0.48	0.69
Mean	5.0	6.77		284.454	266.498		1.51	0.99	
CD $^{0.05}$									
Cropping systems	0.00			0.00			0.00		
Locations	0.00			0.00			0.00		
Cropping systems X Locations	0.002			NS			0.002		

Table 2: Locational-wise variation in the Status of nitrogen, phosphorus, and potassium in soils under different cropping systems in Kitui County

Cropping System	Soil quality parameter								
	Nitrogen % (total)			Phosphorus ppM (available)			Potassium ppM (available)		
	Zombe	Kauwi	Mean	Zombe	Kauwi	Mean	Zombe	Kauwi	Mean
Vegetable-based	0.79	0.25	0.52	267.53	93.64	180.585	570.79	271.63	421.21
Cereal based	0.44	0.32	0.38	183.03	134.44	158.733	343.67	303.01	333.34
Agroforestry based	0.36	0.30	0.33	201.29	83.27	142.28	429.37	303.26	366.32
Orchard based	0.56	0.298	0.43	224.69	209.75	217.22	440.94	261.81	351.37
Uncultivated land	0.23	0.16	0.19	139.67	153.15	146.41	275.51	212.19	243.85
Mean	0.48	0.26		203.24	134.85		416.06	270.38	
CD $^{0.05}$									
Cropping systems	0.00			0.00			0.00		
Locations	0.00			0.00			0.00		
Cropping systems X Locations	0.00			0.00			0.00		

Location-wise Variation in the Status of Soil Bulk Density under Different Cropping Systems

Locational variation status showed that soil bulk density ranged from 1.8 to 1.64 Mg m^{-3} in Zombe, while in Kauwi, it ranged from 1.66 to 1.56 Mg m^{-3}. It followed the decreasing order of vegetable-based (1.8 Mg m^{-3}) > cereal-based (1.76 Mg m^{-3}) > agroforestry based (1.72 Mg m^{-3}) > orchard based (1.68 Mg m^{-3}) > uncultivated land (1.64 Mg m^{-3}) and vegetable-based (1.66 Mg m^{-3}) > cereal-based (1.63 Mg m^{-3}) > agroforestry based (1.61 Mg m^{-3}) > orchard based (1.58 Mg m^{-3}) > uncultivated land (1.56 Mg m^{-3}) in Zombe and Kauwi wards, respectively, (*Table 3*). It was discovered that soil bulk density was significantly ($p<0.05$) affected by the interaction between cropping systems and locations.

Table 3: Locational variation in the Status of soil bulk density in soils under different cropping systems in Kitui County

Cropping System	Soil quality parameter		
	Soil Bulk Density (Mg m^{-3})		
	Zombe	Kauwi	Mean
Vegetable-based	1.798	1.66	1.73
Cereal based	1.76	1.63	1.699
Agroforestry based	1.72	1.61	1.67
Orchard based	1.68	1.58	1.63
Uncultivated land	1.64	1.56	1.599
Mean	1.72	1.61	
CD $^{0.05}$			
Cropping systems		0.00	
Locations		0.00	
Cropping systems X Locations		0.009	

DISCUSSION

The current study showed that the interaction between cropping systems and locations was found to have a significant ($p<0.05$) influence on soil organic carbon. The highest soil organic carbon observed in vegetable-based compared to the other cropping systems and uncultivated land in Zombe was maybe due to the regular application of inorganic manure under intensive agriculture in Thua Valley, Zombe ward. Intensive farming aims at increasing the productivity and profitability of a piece of land by high-level inputs of different factors that help with yields, such as capital, labour, fertilisers, insecticides, pesticides, herbicides, and others. High SOC observed in orchard-based and cereal-based compared to agroforestry and uncultivated land may also be ascribed to the high use of inorganic fertiliser under intensive agriculture. Inorganic fertiliser consists of mineral-based nutrients manufactured for immediate application on crops and does not need to decompose over time to supply nutrients to plants. Most inorganic fertilisers contain balanced amounts of Nitrogen, Potassium, and phosphorus to feed plants and foster growth. The results are in accordance with the findings of (Bhavya et al., 2017), who found the highest SOC stocks in the mango orchard in a similar study. The relatively high SOC in vegetable-based cropping systems, as compared to the other cropping systems in Kauwi, can be associated with the application of compost under traditional forms of farming. Litter is a source of soil organic matter, and the more litter that is produced by the plantations, the higher the content and amount of soil organic carbon in the plantation. Litter production contributes to primary productivity by continuing the nutrient cycle and exporting nutrients and organic detritus to the ecosystem (Mfilinge et al., 2005; Hossain & Hoque, 2008). The absorption of nutrients by plants and their capacity to return these to the soil through litter changes chemical and physical soil properties (Rawat, 2005; Shukla et al., 2015).

Vegetable, cereal, and fruit-based cropping systems had a lower (acidic) soil pH than the other cropping systems and control in both the Kauwi and Zombe wards. The continual use of acid-forming chemical fertilisers is responsible for the lower soil pH in vegetable, cereal, and fruit-based cropping systems. The chemical fertilisers undergo nitrification, the process by which ammonium-containing compounds are converted to nitrate in the soil, resulting in acidity. Soil acidity decreases when ammoniacal nitrogen fertiliser is applied in more significant quantities (Alexander, 1965). However, soil pH was found to be within a normal range, indicating that long-term cropping techniques in the study region had not had a deleterious effect on soil quality. Further, the study results revealed that the soil pH under vegetable-based, cereal-based, and orchard-based conditions was lower in the Zombe ward than in the Kauwi ward. The current trend of results can be attributed to the intensive agriculture practised along the Thua River basin in Zombe ward, where farmers use chemical fertilisers on their small pieces of land to get high farm yields. Inorganic fertilisers commonly used by farmers are CAN and DAP. On the other hand, farmers in Kauwi ward practice traditional agriculture, whereby organic fertilisers such as animal waste, compost, and plant residues are used to increase crop yields on the farms.

The study also established that, on average, the application of inorganic fertilisers impacted soil quality with significantly increased E.C. compared to manure application. The possible explanation for this trend is the high application of fertilisers on vegetable and orchard-based cropping systems, which leads to excess nitrification that accelerates soil salinisation under such systems. Salinisation tempers with nitrogen uptake, which slows plant development and causes yield loss. It also causes ionic stress in crops when harmful ions in soil salts, e.g., chloride or sodium, impede the acquisition of other positively charged ions vital for crop growth, particularly potassium and calcium, leading to crop loss (Bresler et al., 2012). The low E.C. observed under control, cereal, and agroforestry cropping systems can be attributed to the low soil disturbance under such systems. The results agree with the findings by (Ram, Singh et al.), who studied the effects of different land use systems on soil pH, Electrical conductivity, and micronutrients in Mollisols of Uttarakhand, India, whereby E.C. was found low under agroforestry-based treatments. The results of this study are also in contrast with the findings of Ozlu & Kumar (2018), whose study found that, on average, manure treatments significantly increased E.C. compared with fertiliser treatments. Further, the results revealed that electrical conductivity was higher in the Zombe ward compared to the Kauwi ward. This can be attributed to the excessive accumulation of salts in the soil. The higher E.C. in Zombe can also be attributed to intensive agricultural activities along the Thua River basin, where irrigation of crops is done probably with salt-rich water, which amplifies salt content in the soils.

In the Zombe ward, the vegetable-based cropping system recorded the highest soil total nitrogen, followed by the orchard, while the cereal-based came third. The lowest amount of total nitrogen was recorded under uncultivated land and agroforestry cropping systems. These trends can be attributed to the application of inorganic fertilisers on vegetable, orchard, and cereal-based systems under intensive agricultural practices. The pressure to get high yields on a small piece of land along the Thua River compels farmers to use chemical fertilisers on vegetables, fruits, and cereals. In the Kauwi ward, the highest amount of nitrogen was observed under cereal, agroforestry, and orchard-based cropping systems. The possible explanation for this is that there is high nutrient cycling due to litter falling under agroforestry and orchard cropping systems. Moreover, the results show trends of high total nitrogen under all the cropping systems in the Zombe ward compared to the Kauwi ward. This is because farmers in Zombe ward practice intensive agriculture while farmers in Kauwi practice traditional agricultural practices with minimal or no use of agrochemicals. The finding is in tandem with similar studies by Chen et al. (2011), who also reported a high amount of available nutrients in vegetable and fruit-based cropping systems compared to cereal crops while working in China.

Available phosphorus in Zombe ward was highest in the vegetable-based cropping system, followed by orchard and agroforestry. Cereal-based and uncultivated land exhibited the lowest amount of available phosphorus, respectively. This trend can be attributed to the high application of agrochemicals on vegetable and orchard-based cropping systems under intensive agricultural practices. The observed relatively higher amounts of phosphorus under agroforestry compared to cereal-based can be attributed to litter falling under agroforestry-based systems that aid in nutrient cycling. The results agree with the findings by Bal & Toky (1993), who reported soil surface enrichment with nutrients from the fall of trees of litter, twigs, branches, and fruits in agroforestry systems. Moreover, the results revealed that the orchard-based cropping system had the highest amount of phosphorus in the Kauwi ward. This was followed by an uncultivated land and cereal-based cropping system. Further, the lowest amount of phosphorus was observed under agroforestry-based and vegetable-based cropping systems. The highest amount of available phosphorus observed under the orchard-based cropping system in the Kauwi ward can be attributed to the higher application of organic manures under such cropping system under traditional agricultural practices to get better yields. In addition, the results revealed higher amounts of available phosphorus in the Zombe ward compared to the Kauwi ward. Again, this can be attributed to the intensive agriculture practised in the Zombe ward along the Thua River basin as compared to the Kauwi ward, where farmers practice traditional agriculture.

Further, the results depicted the highest amount of available potassium on vegetable-based and orchard cropping systems in the Zombe ward. Like in the other parameters, this can be attributed to the application of agrochemicals, especially inorganic fertilisers, under intensive agriculture practised in the Thua River valley of Zombe ward. Moreover, a higher amount of potassium was observed under agroforestry-based as compared to cereal-based cropping systems. The possible explanation for this is the higher nutrient cycling for agroforestry cropping system due to litter fall. The return of crop residues, manure and urine, green manure, and transfer of nutrients from trees to crops in agroforestry through pruning, leaf drop and root decomposition were other significant processes in aid of soil nutrient recycling. In Kauwi ward, available potassium was highest in agroforestry and cereal-based cropping systems. Vegetable, orchard, and uncultivated land-based cropping systems had the lowest amount of available potassium. The highest amount of potassium observed in agroforestry can be attributed to litter fall, leading to nutrient cycling. More accessible nutrients in a system relying on agroforestry are likely the result of more efficient nutrient recycling than in a cereal cropping system. By “nutrient cycling,” we mean the process by which nutrients within the soil-plant system are transferred from one component to another; for instance, when nitrogen is released from soil organic matter as ammonium or nitrate and then taken up by plants. Nutrient cycling also includes the incorporation of leguminous green manures into the soil, the transfer of nutrients from trees to crops in agroforestry systems via pruning, leaf drop, or root decomposition, and the return of crop residues like stover to the soil.

Moreover, the results showed that available potassium was higher in the Zombe ward compared to the Kauwi ward. Field visits revealed that chemical-based fertilisers like DAP and NPK were highly used in the Zombe ward, while farmers in the Kauwi ward used organic manure like crop residues, compost, and animal droppings to improve soil nutrients in their farms.

The results of this study revealed that soil bulk density was highest under vegetable and cereal-based cropping systems in the Zombe ward. Similarly, it was higher under agroforestry-based than orchard-based cropping systems. The highest bulk density under the vegetable-based cropping system in Zombe ward can be attributed to the high level of input and output per unit of agricultural land area, which characterises intensive agriculture. Field visits revealed that different types of vegetables, e.g., kale, tomatoes, etc., are planted annually on the same small piece of land along the Thua River valley, hence the high soil bulk density on the vegetable-based cropping system. Similarly, the results reported the highest amount of soil bulk density under a vegetable-based cropping system in the Kauwi ward. The trend observed was like that in the Zombe ward in all the cropping systems under study. Again, the highest soil bulk density recorded under a vegetable-based cropping system can be attributed to high soil compaction during intensive cultivation.

The results also revealed that soil bulk density was higher in the Zombe ward as compared to the Kauwi ward under all cropping systems. This is due to the intensive agriculture practised in the Zombe ward, whereas farmers in the Kauwi ward practice traditional farming. Intensive agriculture entails high manipulation of soils that leads to excess compaction. Excess compaction restricts soil aeration and crop root development, restricting water uptake, nutrient availability, and overall crop growth. The findings are in agreement with those of (Bal and Toky 1993), who found that agroforestry systems had a low bulk density compared with cereal-based systems. Compared to cereal crops and the control group, the comparatively low soil bulk density observed in cropping systems based on fruits and vegetables may be attributed to the large amounts of organic manure applied in such systems. Generally, low soil bulk density was observed in uncultivated land, orchard, and agroforestry cropping systems due to less soil disturbance under minimum tillage practices. This allowed increased soil aeration, water uptake, and overall nutrient availability for optimum crop growth under intense application of organic manure. Also, the other possible explanation for the high soil bulk density in the Zombe ward compared to the Kauwi ward is that intensive agriculture in Zombe is practised along the Thua River valley, where soils are sandy compared to soils in Kauwi.

CONCLUSION

The current study indicated that in Kauwi and Zombe wards, soil properties and nutrient availability were significantly influenced by cropping systems and location. The level of influence of a cropping system was determined by the intensity of cultivation of the cropping system in that particular location. Cropping systems characterised by a high input of fertilisers and pesticides exhibited high means in soil pH, EC, Soil carbon, and NPK. Likewise, locations with high inputs of fertilisers, pesticides, and irrigation registered high levels of soil pH, EC, carbon density, NPK, and bulk density. Therefore, to adapt to the changing climatic situation and to mitigate its effects, farmers in the study area, especially in the Zombe ward, should be sensitised to embrace appropriate agricultural practices that promote the rightful application of fertilisers to maintain healthy soils.

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Data Availability Statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author/s.

Author Contributions

E.K. conceived the study, developed the proposal, collected data, performed laboratory experiments and analysis, and drafted the write-up. CN and MM assisted in designing the farm field experiments, supervised data collection, reviewed and corrected the data, and commended the write-up. All authors contributed to the article and approved the submitted version.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as a potential conflict of interest.

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