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Research Article

Levels of Cadmium, Copper, and Lead in Soils and Cassava Tubers Grown in Machakos County, Kenya

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Large quantities of agrochemicals are regularly applied in coffee farms to control pests and diseases and provide adequate nutrients to boost yields. Agrochemicals have varied amounts of heavy metals and their prolonged use to attain maximum yields contributes to the contamination of soil, surface, and groundwater. The study determined the levels of lead, cadmium, and copper in soil and cassava tubers (*Manihot esculenta*) grown in single-cropped and intercropped farms in Kathiani Subcounty, Machakos County, Kenya. Soil and cassava tuber samples were obtained in a zigzag of five cores across the farms. Cadmium, copper, and lead levels in the collected samples were determined using the atomic absorption spectrometer (AAS) Shimadzu AA-6200 model. Data were presented using tables and figures. One-way ANOVA was used to examine the mean differences of heavy metals between locations. Significant treatment difference was tested at $\alpha = 0.05$ using the Tukey test. The results revealed that soils from single-cropped farms had a range of 0.09–0.59, 4.1–4.6, and 0.021–0.032 $mg \cdot kg^{-1}$ for cadmium, copper, and lead, respectively, while soils from intercropped farms had a range of 0.25–0.83, 4.9–10.1, and 0.022–0.037 $mg \cdot kg^{-1}$ for cadmium, copper, and lead, respectively. Considering cassava tubers in the single-cropped system, the mean values ($mg \cdot kg^{-1}$) of Cd, Cu, and Pb for the pith were 4.7, 6.8, and 0.028, for the bark were 4.4, 4.3, and 0.02, and for the epidermis were 3.1, 4.0, and 0.02, while flesh had 2.6, 1.4, and 0.05, respectively. Analysis of the tubers in the intercropped system indicated that the pith had a mean value of 7.8, 7.0, and 0.20 $mg \cdot kg^{-1}$ for Cd, Cu, and Pb, respectively. Similarly, the bark had 5.8, 4.6, and 0.16 $mg \cdot kg^{-1}$ for cadmium, copper, and lead. The epidermis indicated a concentration of 5.1, 4.6, and 0.12 $mg \cdot kg^{-1}$ for cadmium, copper, and lead, while the flesh had 2.8, 1.5, and 0.06 $mg \cdot kg^{-1}$, respectively. The results revealed the presence of heavy metals in both single-cropped and intercropped farms. The observed means for cadmium, copper, and lead in both sets of farms were within the WHO recommended levels for agricultural soils. However, the study observed higher cadmium, copper, and lead levels in soils and cassava tissues from intercropped farms compared to single-cropped farms.

1. Introduction

Environmental pollution by heavy metals has caused serious environmental problems which threaten the existence of various ecological systems, agriculture, and human health [1]. Pollution occurs when an element or a substance is present in concentrations greater than natural [2] and has a net detrimental effect on the environment and its components. Soils are not considered polluted unless a threshold concentration exists that begins to affect biological processes [2]. Due to increased demand and the need for higher productivity, farmers have adopted modern farming methods which include the use of fertilizers and pesticides [3, 4]. Fertilizers and pesticides are important inputs and integral components of crop production systems [5]. However, these agrochemicals contain varying levels of heavy metals as impurities, and thus their prolonged use contributes to heavy metal contamination in the soils [6]. The levels of heavy metals such as cadmium (Cd), copper (Cu), and lead (Pb) should be within the recommended limits in soil and cassava tissues [1]. Low levels of these elements may not pose risks as some are essential to plants and animals. However, even the essential elements are toxic when present at high levels in the environment [7]. In addition to soil contamination, heavy metal accumulation in agricultural soils affects food quality and security [8, 9]. Exposure to heavy metals especially when contained in small proportions in food items popularly consumed by young and old can pose a major health risk to consumers [10]. Cadmium (Cd) has no known biological functions in the body but interferes with some essential functions of zinc, thereby inhibiting enzyme reactions and nutrient utilization. It catalyzes oxidation reactions, generating free radical tissue damage [11]. Lead (Pb) is nonessential, and high Pb levels in the body cause anemia, headache, brain damage, and central nervous system disorders [12]. Copper (Cu) is an essential element but high doses cause anemia, liver damage, kidney dysfunction, stomach and intestinal irritation, neurological complications, and hypertension [13]. Coffee (*Coffea arabica*) was introduced in Kenya in 1893 by white settler farmers [14]. After independence, smallholder coffee farming expanded rapidly to the extent that now 80% of Kenyan coffee is produced by smallholder coffee farmers [15]. Kenya grows arabica coffee which is highly susceptible to coffee leaf rust and coffee berry disease [14]. This requires regular application of pesticides and fungicides to control the diseases. Smallholder coffee farmers in Kenya often intercrop coffee with fruit trees such as guavas (*Psidium guajava*), loquats (*Eriobotrya japonica*), bananas (*Musa sapientum*), macadamia (*Macadamia integrifolia*), and avocadoes (*Persea americana*) [16]. Crop diversity lowers levels of uncertainty or vulnerability to upcoming disturbances by ensuring food availability, utilization, and stability [17]. Consequently, smallholder coffee farmers in Machakos County, Kenya, intercrop cassava (*Manihot esculenta*) with coffee (Figure 1). Cassava production is important for food, income, and livestock feed in the study area. Food crops such as cassava can be contaminated by heavy metals from the soil due to the fact that cassava roots have the ability to absorb these metals from the soil they are planted [18]. Levels of heavy metals in many edible plants especially tubers are yet to be established. Previous studies on heavy metals have focused on other food crops especially vegetables; however, nothing has been published on the levels of heavy metals in soils and cassava tubers grown intercropped with coffee in Kathiani Subcounty, Machakos County, Kenya. This study, determined the presence and concentration of heavy metals (Cd, Cu, and Pb) in soils and cassava tuber tissues from farms in Kathiani Subcounty, Machakos County, Kenya.

2. Methodology

2.1. Description of Study Area. The study was carried out in Machakos County, Kenya (Figure 2). The County has hills and a small plateau rising to 1800–2100 m above sea level constituting the central part of the county. To the west, the county has a large plateau elevated to about 1700 m which is south-east sloping. In the north-west, the county has stand-alone hills. Machakos County lies between latitudes 0° 45″ south and 1° 31′ south and longitudes 36° 45′ east and 37° 45′ east. [19]. Machakos County borders Nairobi and Kiambu Counties to the west, Embu to the north, Kitui to the east, Makueni to the south, Kajiado to the southwest, and Murang`a and Kirinyaga to the northwest. The county has eight administrative subcounties, namely, Machakos, Athi River. Masinga, Yatta, Kangundo, Kathiani, Matungulu, and Mwala [19]. The soil and cassava samples were collected from Kaewa, Kalunga, Kombu, and Kaliluni in Kathiani Subcounty (Table 1). Kathiani Subcounty covers 3 percent of the total 6208.2 km^2 area of Machakos County. The subcounty has a coverage area of 207 km^2 [20]. The soils comprise alfisols, acrisols, ferralsols, vertisols, and andisols. Alfisols and acrisols are classified as sandy loams to loamy sands. They are characterized by low water-holding capacity, low organic matter content, and high erodibility. Ferralsols are light-textured, strongly leached, and permeable and are suitable for drought-tolerant cereals and legumes. Vertisols are referred to as black cotton soils characterized by cracking clays with low water permeability and high water-holding capacity. They majorly sustain maize (*Zea mays*), cotton (*Gossypium herbaceum*), and chicken peas (*Cicer arietinum*). Andisols are moderately fertile and are used for coffee (*Coffea arabica*) growing and production of drought-tolerant legumes [21]. In addition, they sustain forestry and livestock farming. The altitude of the subcounty ranges from 1450 to 2100 m above sea level and experiences a bimodal rainfall pattern [22]. The increase in population density in Machakos County exerts more pressure on the agricultural land which results in smaller land sizes, lower incomes, and higher off-farm enterprises [23]. The main cash crop in the subcounty is coffee (*Coffea arabica*). In the last three decades, smallholder coffee farmers have suffered grossly from persistent declines in international coffee prices [24]. The declining coffee prices and reduced farm sizes have led farmers to intercrop food crops with coffee (Figure 1). This practice exposes the food crops to the risk of contamination from the agrochemicals used in coffee farming. Therefore, it becomes pertinent to closely monitor the levels of heavy metals in food crops intercropped with coffee to determine the impact of this agricultural practice. Cassava is a dominant crop intercropped with coffee in the area and its peels serve as livestock food.

2.2. Experiment. This study adopted an experimental research design which involved zigzag sampling of soil and cassava tubers from purposively selected farms where they had already been planted in Kathiani Subcounty, Machakos County. Fertilizers were not applied in the months of May, June, and December. Samples were collected in the month of December 2022. The study involved the use of atomic absorption spectrometry technique to determine the levels of cadmium, copper, and lead in soils and cassava tubers sampled from single-cropped and intercropped farms in Machakos County, Kenya.

2.3. Sample Collection

2.3.1. Soil Sample. Soil samples were collected from single-cropped and intercropped farms where agrochemicals were regularly applied to enhance fertility and control weeds and pests in coffee farms. Soil samples from intercropped farms

Figure 1: Cassava plants intercropped with coffee.

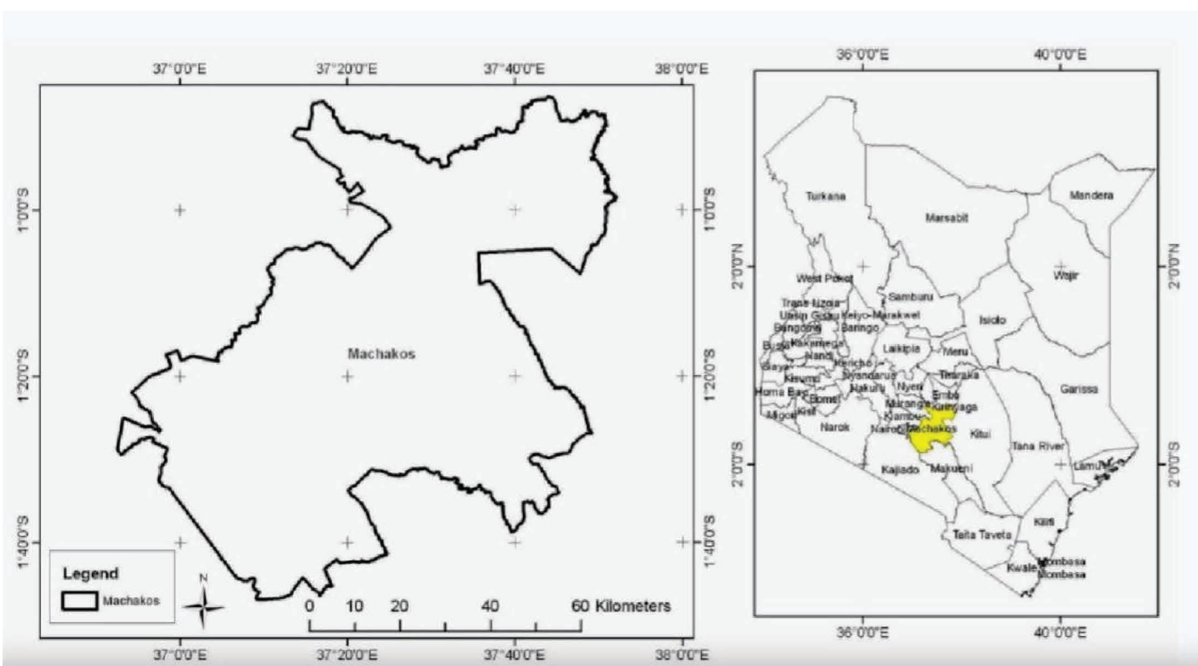

Figure 2: Map showing the location of Machakos County in Kenya [25].

Table 1: Name and location of sampling sites.

Name of the sampling point	Georeferenced data
Kaewa	−1.44811, 37.30558
Kalunga	−1.445636, 37.312566
Kombu	−1.46667, 37.33333
Kaliluni	−1.49269, 37.30864

were taken close to coffee bushes, in between rows. In each farm, samples were randomly collected at a depth of 0–30 cm using the soil auger. Sampling was performed in a zigzag of 5 cores across the field, avoiding areas of interference such as litter, manure, and rocks [26]. The farms ranged from 50 to more than 100 m^2. The five samples from each farm, each weighing 0.5 kg were mixed to form a homogeneous sample. Samples were packed in carrier bags, labelled, and transported to Kenyatta University laboratories for analysis.

2.3.2. Cassava Sample. Cassava tuber samples of different sizes representing different ages were collected from each sampled cassava plant in the single-cropped and intercropped farms from which the soil samples were obtained. Samples from different plants in each farm were combined to form a composite sample. The samples were washed with tap water to remove any surface deposits and rinsed with distilled water. They were sliced using a knife to smaller sizes and peeled to obtain the bark, epidermis, flesh, and pith. The samples were sun-dried and packed in carrier bags, labelled, and transported to the laboratories for sample preparation and analysis.

2.4. Sample Preparation

2.4.1. Soil. Soil samples from each set of farms were air-dried, ground to a fine powder, and sieved (<2 mm sieve). A mass of 1.000 g of the sample was accurately weighed into a clean 100 mL beaker followed by the addition of 15 mL aliquot of concentrated nitric acid (HNO_3) at 110°C until brown fumes appeared. After cooling, 10 mL of 70% perchloric acid was added and the heating was repeated until white fumes formed. The sample solution was allowed to cool and then filtered using the Whatman filter paper No. 42 into a 50 mL volumetric flask and diluted to the mark with distilled water. They were then transferred into labelled plastic bottles.

2.4.2. Cassava Roots. Cassava root samples from each set of farms were air-dried in the laboratory after which they were ground to a fine powder using a porcelain mortar and pestle and sieved (<1 mm). Two grams of ground cassava samples were placed in clean porcelain crucibles and placed in a furnace and the temperature was raised slowly over 2 hours to 500°C. The samples were ashed at this temperature for 4 hours. The samples were thereafter removed and cooled in desiccators at room temperature. After cooling, each sample was dissolved in 5 mL acid mixture of 20% (v/v) nitric acid and 20% (v/v) hydrochloric acid in a volume ratio of 1 : 1. The solution was slowly warmed to dissolve any residues until almost dry. 0.05 mL of 25% (v/v) HCl of volume was added to the heated mixture and filtered using Whatman filter paper No. 42 into a 50 mL volumetric flask. The solution was diluted to the mark using distilled water ready for elemental analysis using an atomic absorption spectrophotometer (AAS).

2.5. Analysis of Samples. Both cassava roots and soil samples were analyzed for their levels of cadmium (Cd), copper (Cu), and lead (Pb) using the AAS Shimadzu AA-6200 model. AAS calibration was performed with the standard reference material of 1000 ppm (mg/kg) from which the respective metal standards were prepared. A series of standards were used to draw a linear calibration curve of absorbance versus concentration. The absorbencies obtained with the samples were used to calculate the unknown concentrations of the metals by interpolation of their absorbencies on the calibration curve of each metal. A total of 100 samples for each cropping system consisting of (20) soil and (80) cassava tuber tissues were analyzed. Variations in levels of heavy metals were inferred using statistical measures.

2.6. Statistical Analysis. Data on initial levels of the three heavy metals were analyzed for means. One-way ANOVA was conducted to test mean differences for contents of heavy metals in soil and cassava tuber samples. Significant treatment difference was tested at $\alpha = 0.05$ using the Tukey test. All the statistical tests were performed using R software.

3. Results and Discussion

3.1. Mean Levels of Cadmium, Copper, and Lead in Soils under the Two Cropping Systems. All the three heavy metals were detected in farm soils under the two cropping systems. Results in Figure 3 present levels (mg/kg) of the heavy metals in farm soils from intercropped and single-cropped (control) systems. The mean levels of Cd, Cu, and Pb in the intercropped farms were 0.64 mg/kg, 7.50 mg/kg, and 0.029 mg/kg, respectively, while in single-cropped farms, the mean levels were 0.29 mg/kg, 4.33 mg/kg, and 0.025 mg/kg, respectively. There was a significant difference between the levels of cadmium and copper in single-cropped and intercropped farm soils. However, the mean levels of the elements in both sets of farm soils were within WHO allowable limits for agricultural soils of 0.8, 36, and 85 (mg/kg) for Cd, Cu, and Pb, respectively [11]. The elevated mean levels of Cd, Cu, and Pb in intercropped farm soils suggest an anthropogenically induced source [7]. Inorganic fertilizers have been reported to be among sources of heavy metals input into agricultural systems [7]. Thus, repeated use of herbicides, pesticides, and phosphate fertilizers in coffee farms in the study area may result in the accumulation of these elements and increase the contamination potential in soil. Ogbonna et al. [5] in their study on the distribution of heavy metals in soil and accumulation in plants at an agricultural area in Umudike, Nigeria, that had been contaminated by agrochemicals reported levels of Cd, Cr, and Zn in the range of 27.97–61.33, 24.97–145.43, and 148.57–251.50 mg/kg. The study indicated that agrochemicals are one of the anthropogenic sources of heavy metals.

3.2. Mean Levels of Cadmium, Copper, and Lead in Soils from Kaewa, Kaliluni, Kalunga, and Kombu. Mean levels of Cd, Cu, and Pb were determined in farm soils from Kaewa, Kaliluni, Kalunga, and Kombu (Figure 4). Among the three heavy metals examined in this study, copper had the highest level (7.8 mg/kg) followed by cadmium (0.44 mg/kg), while lead (0.022 mg/kg) had the lowest level (Cu > Cd > Pb). The high Cu levels in the four regions could be attributed to the huge amounts of copper-based fungicides used to control coffee diseases [27]. Copper levels in farm soils from Kalunga (7.8 mg/kg) and Kombu (6.8 mg/kg) reported in this study were significantly different from those reported in farm soils from Kaewa (4.5 mg/kg) and Kaliluni (4.5 mg/kg). The same trend shown in Cu levels among the areas was also replicated in Pb, where Pb levels of soils in Kaewa (0.022 mg/kg) and Kaliluni (0.031 mg/kg) were significantly different from those from Kalunga (0.27 mg/kg) and Kombu (0.24 mg/kg). There were no significant differences in cadmium levels among soils found in Kaewa (0.44 mg/kg), Kalunga (0.44 mg/kg), and Kombu (0.46 mg/kg). Heavy metal levels fluctuated among the four areas, and Kalunga had the highest levels followed by Kombu and Kaliluni,

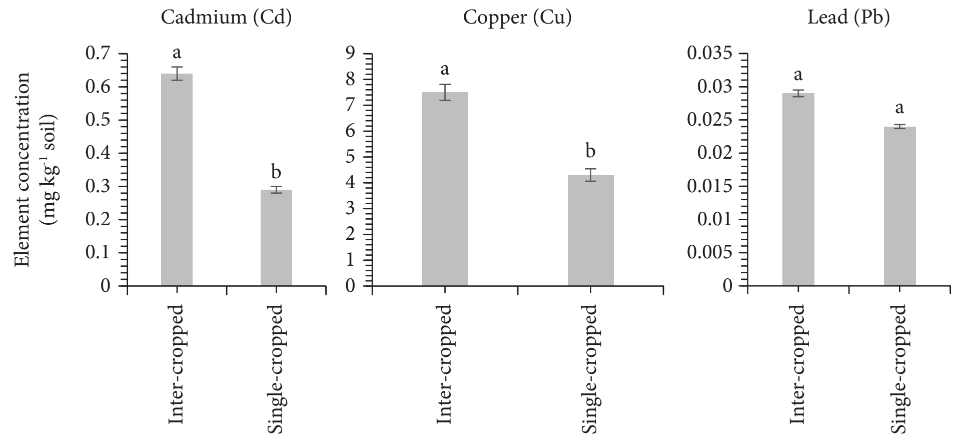

Figure 3: Overall mean levels of cadmium, copper, and lead in the soils, within the farms under the two cropping systems.

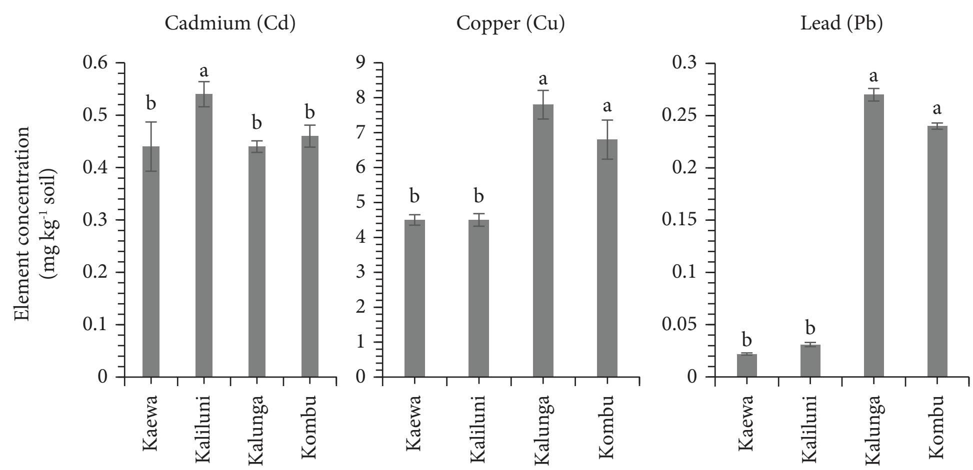

Figure 4: Initial mean levels of cadmium, copper, and lead in farm soils from Kaewa, Kaliluni, Kalunga, and Kombu.

while Kaewa had the lowest (Kalunga > Kombu > Kaliluni > Kaewa). This implied that agricultural practices in farms at Kalunga were more critical in influencing the quality of food produce [28]. In a similar study on the determination of the levels of selected metals in soil and khat grown in Kenya, Ireri [29] reported different mean values of heavy metals in Nyambene, Mbeere, and Embu. The differences in heavy metals levels in the three regions were attributed to agricultural practices employed by farmers in each region.

Table 2: Heavy metal concentration in single-cropped soils.

Crop farms	Single cropped		
	Cadmium (Cd)	Copper (Cu)	Lead (Pb)
	Element concentration (mg·kg^{-1} soil)		
Kaewa	0.16 ± 0.09^{b}	4.2 ± 0.46^{b}	0.021 ± 0.010^{ab}
Kaliluni	0.32 ± 0.008^{ab}	4.1 ± 0.12^{b}	0.024 ± 0.009^{ab}
Kalunga	0.59 ± 0.16^{a}	4.6 ± 0.43^{a}	0.032 ± 0.014^{a}
Kombu	0.09 ± 0.08^{b}	4.4 ± 0.45^{ab}	0.021 ± 0.007^{ab}

(Mean ± SD) ($P > 0.05$, Tukey test $n = 15$). The same small letters represent not significant differences within the crop farms.

3.3. Single-Cropped Cassava Farm Soils. Soils sampled from single-cropped farms in Kaewa, Kombu, and Kaliluni had Cd levels of 0.16 mg/kg, 0.09 mg/kg, and 0.32 mg/kg, respectively (Table 2). There was no significant difference ($P > 0.05$) in the level of Cd between the localities (Kaewa, Kombu, and Kaliluni). However, the farms from the three regions had lower Cd levels than those of soil samples from Kalunga (0.59 mg/kg). Higher levels of Cu (4.6 mg/kg) were recorded in farm soils from Kalunga (4.6 mg/kg), than in Kombu (4.4 mg/kg), Kaewa (4.2 mg/kg), and Kaliluni (4.1 mg/kg) although the difference was not statistically different. The highest mean Pb level observed in Kalunga (0.32 mg/kg) was statistically different from Kaliluni (0.024 mg/kg), Kaewa, and Kombu (0.021 mg/kg). These results revealed the presence of varying levels of heavy metals in the soils following the trend Cu > Cd > Pb. However, the levels of Cd, Cu, and Pb reported in this study were within the range of nonpolluted soils and below the WHO [11] maximum permissible limits of 0.8, 36, and 85 mg/kg, respectively. The results of this study are in agreement with Misoi and Nguta's [30] study on levels of heavy metals in Nakuru town and other surrounding farmland soils, and in their study, the concentrations of Cd, Cr, Cu, Ni, Pb, and Zn were below the acceptable limits for agricultural soil. The results in single-cropped farm soils were indicative of low natural levels from parent rock material in comparison with other parts of the world meaning that their natural distribution is low in this area and that agrochemicals use in single-cropped farms is minimal [31].

3.4. Intercropped Cassava Farm Soils. The levels of cadmium, copper, and lead in intercropped farm soils were higher than those recorded for single-cropped farm soils (Table 3). The highest Cd level recorded in Kombu (0.83 mg/kg) was not significantly different from Kaewa (0.73 mg/kg) and Kaliluni (0.77 mg/kg) but different from Kalunga (0.25 mg/kg). The difference in Cd level was probably due to agricultural practices employed by individual farmers in every region [29]. Higher Cd levels in Kalunga, Kaliluni, and Kombu could be attributed to the application of large volumes of phosphate fertilizers which are mainly used in coffee farms. Phosphate fertilizers invariably contain Cd as a natural contaminant [32]. Soil sampled from Kalunga (10.1 mg/kg) and Kombu (9.2 mg/kg) had the highest Cu level, whereas those from Kaliluni (4.9 mg/kg) and Kaewa (4.9 mg/kg) were low. Lead (Pb) level was highest in soils from Kaliluni (0.037 mg/kg) and was not significantly different from Kaewa (0.028 mg/kg), Kombu (0.028 mg/kg), and Kalunga (0.022 mg/kg). Generally, the results revealed elevated levels of all metals under study in the intercropped soils compared to single-cropped farm soils. The elevated levels of Cd, Cu, and Pb in intercropped soils could be attributed to agrochemicals used in coffee farming. Agrochemicals contain trace amounts of heavy metals as impurities and thus their continued use to achieve high yields leads to heavy metal contamination in the soil [33]. This study is in agreement with the results of Abah et al. [7] on the assessment of levels of some trace metals in soils and roots of cassava grown under the usage of agrochemicals in some parts of Benue state, Nigeria. The results revealed significantly ($P < 0.05$) elevated levels of trace metals in soils from farms where chemical fertilizers and herbicides were applied to enhance fertility and control weeds, respectively. However, heavy metals considered in this study were all within WHO acceptable limits of 0.8, 36, and 85 mg/kg for Cd, Cu, and Pb respectively.

3.5. Levels of Cadmium, Copper, and Lead in Whole Cassava Tubers. Cadmium, copper, and lead analysis in whole cassava tubers grown under the two cropping systems revealed varying levels (Figure 5). Cadmium level was significantly high in cassava tubers grown in an intercropped system (5.38 mg/kg) compared to single-cropped systems (3.7 mg/kg). There was no significant difference between the levels of Cu in cassava root tubers that were either intercropped or single-cropped. Besides, the level of Cu was higher in cassava tissues that were intercropped (5.4 mg/kg) than those that were single-cropped (4.4 mg/kg). There was a significant difference between the level of Pb in the cassava root tubers from the intercropped system (0.14 mg/kg) and the single-cropped system (0.037 mg/kg). Cassava tubers grown in intercropped farms accumulated

Table 3: Heavy metal levels in intercropped soils.

Crop farms	Intercropped		
	Cadmium (Cd)	Copper (Cu)	Lead (Pb)
	Element concentration ($mg{\cdot}kg^{-1}$ soil)		
Kaewa	0.72 ± 0.31^a	4.9 ± 1.7^b	0.028 ± 0.005^b
Kaliluni	0.77 ± 0.05^a	4.9 ± 1.0^b	0.037 ± 0.004^b
Kalunga	0.25 ± 0.10^b	10.1 ± 4.2^a	0.022 ± 0.006^c
Kombu	0.83 ± 0.09^a	9.2 ± 2.8^a	0.028 ± 0.005^b

(Mean ± SD) ($P > 0.05$, Tukey test $n = 15$). The same small letters represent not significant differences within the crop farms.

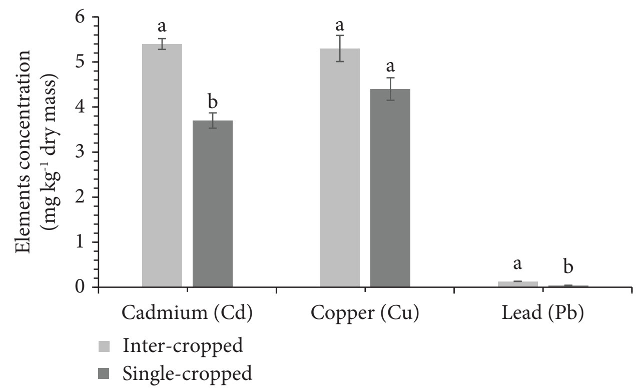

Figure 5: The overall mean levels (mg/kg dry mass) of cadmium, copper, and lead in the whole cassava tubers ($P > 0.05$, Tukey test, $n = 240$). The bars marked with the same small letters on top indicate no significant differences between cropping systems.

more heavy metals than those grown in single-cropped farms. Plants grown in heavy metal-contaminated soils accumulate higher levels of metals than those grown in uncontaminated soils [34]. The trend in levels was Cd > Cu > Pb. A similar trend was reported by Aihakwo et al. [35] in their study on the assessment of heavy metals (Zn, Cu, Pb, Cr, Cd, and Ni) concentration in the leaves, stem, and tubers of *Manihot esculenta* harvested from the Egi community, Rivers state, Nigeria. The results further revealed that Cd accumulated more in cassava tubers than Cu and Pb. Several studies have reported that cadmium is a highly mobile metal that is easily absorbed by plants through the root surface Adu et al. [36]. The high levels of cadmium in whole cassava tubers from the two sets of farms could be attributed to the rate with which cadmium is taken up from the soil through the roots [37] The levels of Cu and Pb in the current study were lower than WHO [11] permissible limits of 10 mg/kg and 2 mg/kg, respectively, in plants, while Cd was above the limit of 0.02 mg/kg.

3.6. Heavy Metal Analysis in Cassava Tuber Tissues. Heavy metals analysis in different cassava tuber tissues were analyzed for Cd, Cu, and Pb and the results revealed that Cd, Cu, and Pb levels were highest in the pith and bark, and lowest in the epidermis and flesh (Figures 6 and 7). Cadmium level in the bark, epidermis, flesh, and pith was 5.14 mg/kg, 4.2 mg/kg, 2.7 mg/kg, and 6.3 mg/kg, respectively, while copper level was 4.45 mg/kg, 4.3 mg/kg, 1.45 mg/kg, and 6.9 mg/kg, respectively. Lead analysis in

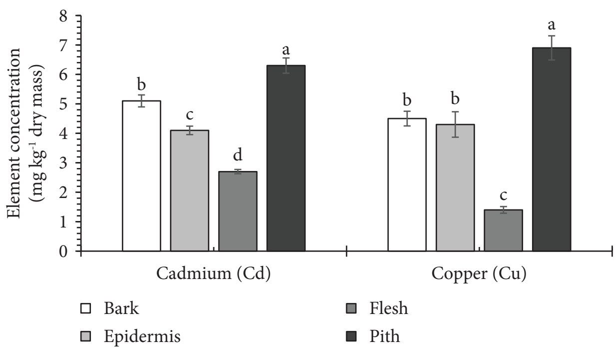

Figure 6: Cadmium and copper levels in cassava tuber tissues. The bars marked with the same small letters on top indicate no significant differences between cropping systems ($P > 0.05$, Tukey test, $n = 120$).

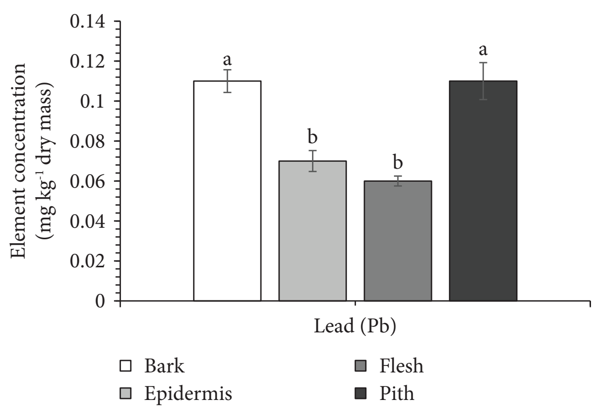

Figure 7: Lead levels in cassava tissues. The bars marked with the same small letters on top indicates no significant differences between cropping systems ($P > 0.05$, Tukey test, $n = 120$).

cassava tuber tissues revealed that the bark, epidermis, flesh, and pith had 0.116 mg/kg, 0.072 mg/kg, 0.041 mg/kg, and 0.114 mg/kg of lead, respectively. Generally, the results indicated that the pith and the bark had the highest tendency to accumulate heavy metals among the four parts of a cassava tuber considered in this study. This is because the bark is the route through which heavy metals enter the plant and it is exposed directly to the soil while the pith contains vascular bundles that are responsible for transporting these elements throughout the plant [38]. A similar observation was reported by Ogah et al. [1] on comparative analysis of some heavy metal levels in leaves, peels, and tubers of cassava planted East-West road in river state, Nigeria. In their study, the highest levels of heavy metals were found in the bark, while the lowest levels were found in peeled tubers.

3.7. Cadmium Levels in Cassava Tuber Tissues. Cadmium analysis in the bark, epidermis, flesh, and pith revealed that Cd levels were highest in the pith with 4.7 ± 2.0 mg/kg for single-cropped farms and 7.8 ± 2.6 mg/kg for intercropped farms and lowest in the flesh at 2.6 ± 0.8 mg/kg and 2.8 ± 0.7 mg/kg in single-cropped and intercropped farms, respectively (Table 4). The levels of Cd in the cassava tuber tissues differed significantly between single-cropped and intercropped farms and among the cassava tuber tissues. Intercropped cassava tubers may absorb fertilizers contaminated with Cd. The mean levels of cadmium reported in the present study were higher than those reported by [39] (2.6 mg/kg) and lower than those reported by Bett et al. [34] (10.33–29.00 mg/kg), in vegetables in Kericho West Sub-county, Kenya. The Cd levels in the cassava tuber tissues in the present study are enough to cause toxicity as they are above the WHO recommended limit of 0.02 mg/kg.

Table 4: Mean levels (mg/kg dry mass) of cadmium in cassava tissues grown in intercropped and single-cropped farms (mean ± standard deviation).

Cadmium (Cd) levels		
Plant parts	Single cropped	Intercropped
Element concentration (mg·kg^{-1} dry mass)		
Bark	4.4 ± 2.2^{aA}	5.8 ± 2.0^{bA}
Epidermis	3.1 ± 1.0^{bB}	5.1 ± 1.3^{bA}
Flesh	2.6 ± 0.8^{cA}	2.8 ± 0.7^{cA}
Pith	4.7 ± 2.0^{aB}	7.8 ± 2.6^{aA}

Mean marked with the same letters within a column indicate no significant differences among plant parts, while the same capital letters denote no significant differences between the cropping systems ($P > 0.05$, Tukey, let $n = 60$).

3.8. Copper Levels in Cassava Tuber Tissues. Copper analysis in cassava tuber tissues revealed Cu levels were highest in the pith at 6.8 ± 3.2 mg/kg and 7.0 ± 5.0 mg/kg for single-cropped and intercropped farms, respectively, and lowest in the flesh at 1.4 ± 1.1 mg/kg in the single-cropped system and 1.5 ± 1.1 mg/kg in the intercropped system (Table 5). There was no significant difference in Cu levels between cassava tuber tissues grown under the two sets of farms. Higher levels of Cu in intercropped farms could be attributed to the application of copper-based pesticides meant to control coffee pests and diseases. The levels of copper in cassava tuber tissues reported in this study were higher than those reported previously by Ahiakwo et al. [35] (0.002–0.023) but lower than those reported by Akenga et al. [40] (33.043 ± 1.289). Remarkably, the Cu levels reported in this study were below the WHO permissible limit of 10 mg/kg.

3.9. Lead Levels in Cassava Tuber Tissues. Lead analysis in cassava tuber tissues revealed that Pb levels in cassava tuber tissues were highest in the bark at 0.073 ± 0.005 mg/kg for single-cropped system and in the pith at 0.20 ± 0.009 mg/kg for intercropped system. The levels were lowest in the flesh at 0.022 ± 0.002 mg/kg in single-cropped and at 0.06 ± 0.004 mg/kg in intercropped systems (Table 6). The levels of Pb in cassava tuber tissues differed significantly between single-cropped and intercropped farms. Higher Pb levels in intercropped farms could be attributed to the application of synthetic pesticides and fertilizers in coffee farming. The levels of Pb reported in this study were higher than those

Table 5: Mean levels (mg/kg) dry mass of copper in plant parts grown in intercropped and singlecropped farms.

Copper (Cu) levels		
Plant parts	Single cropped	Intercropped
Element concentration ($mg{\cdot}kg^{-1}$ dry mass)		
Bark	$4\ 3 \pm 5.3^{aA}$	4.6 ± 2.9^{bA}
Epidermis	4.0 ± 5.3^{aA}	4.6 ± 1.8^{bB}
Flesh	1.4 ± 1.1^{dA}	1.5 ± 1.1^{cA}
Pith	6.8 ± 3.2^{bA}	7.0 ± 5.0^{aA}

(Mean ± SD). Mean values marked with the same small letters within a column indicate no significant differences among plant parts, while capital letters denote no significant differences between cropping systems ($P > 0.05$, Tukey, let $n = 60$).

Table 6: Mean levels (mg/kg) dry mass of lead in plant parts grown in intercropped and singlecropped farms.

Lead (Pb) levels		
Plant parts	Single cropped	Intercropped
Element concentration ($mg\ kg^{-1}$ dry mass)		
Bark	0.073 ± 0.005^{aB}	0.16 ± 0.006^{b}
Epidermis	0.023 ± 0.002^{cB}	0.12 ± 0.005^{cA}
Flesh	0.022 ± 0.002^{cB}	0.06 ± 0.004^{dA}
Pith	0.028 ± 0.003^{cA}	0.20 ± 0.009^{aA}

(Mean ± SD). Mean values marked with the same small letters within a column indicate no significant differences among plant parts, while capital letters denote no significant differences between cropping systems ($P > 0.05$, Tukey, let $n = 60$).

reported by Osabohien et al. [41] (0.012–0.018 mg/kg) for peeled cassava tubers from oil spills and gas flaring zones of Delta state, Nigeria, but lower than those previously reported by Nkwocha et al. [42] (2.00–2.41 mg/kg) for cassava tubers grown around oil flow stations in Bayelsa state, Nigeria. Lead levels reported in this study were below the WHO [11] safe limit of 2 mg/kg.

4. Conclusions and Recommendations

The study focused on levels of three heavy metals in soil and cassava tubers grown in intercropped and single-cropped (control) farming systems in Machakos County, Kenya. The study revealed the following:

(i) All the investigated heavy metals in soil from the two cropping systems were detected and were within the WHO range set for agricultural soil

(ii) All the investigated heavy metals were present in cassava tuber tissues, and Cu and Pb were within the WHO set limit, while Cd exceeded the WHO set limit

(iii) There were significant differences between Cd and Pb levels in cassava tubers grown under the two cropping systems

Thus, cultivation of crops for human or animal consumption in soils with elevated metal levels could lead to the uptake and accumulation of dangerous concentrations of metals in edible crop tissues. The study concluded that agrochemical usage could be responsible for the significant difference observed between levels of heavy metals (Cd, Cu, and Pb) in soil and cassava tuber tissues in intercropped and single-cropped farms (controls) in Kathiani Subcounty, Machakos County.

The study recommends monitoring of heavy metals in agricultural soils in farm fields for environmental protection and to safeguard human nutrition. Coffee farmers should also be discouraged from intercropping cassava with coffee.

The study however had the following limitations:

(i) The age and species of the cassava plants were not considered

(ii) Seasonal variations were not considered

(iii) Nature of soil and physiochemical parameters were not considered

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the research, authorship, and/or publication of this manuscript.

Authors' Contributions

Emmanuel Kasyoka conceptualised and designed the study, wrote the proposal, collected the sample from the field, analyzed the samples, and prepared and drafted the manuscript. Gerald Mbugua designed the study and the proposal and developed the methodology, prepared the draft and the manuscript, and supervised the study. Ruth Wanjau conceptualised the study, developed the methodology, reviewed the proposal, drafted and prepared the manuscript, and supervised the study. Godfrey Nambafu performed the formal analysis and drafted and prepared the manuscript. James Ndiritu conceptualised the study, reviewed the proposal, and wrote the original draft. All the authors reviewed and corrected the manuscript before it was submitted for publication.

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