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Research Article

Variability of Soil Micronutrients Concentration along the Slopes of Mount Kilimanjaro, Tanzania

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Soil micronutrients are important elements for plant growth despite being required in small quantities. Deficiency of micronutrients can result in severe crop failure while excess levels can lead to health hazards; therefore, investigating their status in agricultural land is crucial. Fifty plots were established along an altitudinal gradient from 680 to 1696 m a.s.l. on the slopes of Mount Kilimanjaro, Tanzania. Soils were sampled at the top- (0–20 cm) and subsoils (21–50 cm) in four locations within each plot. Fourier Transform Mid-Infrared (FT-MIR) spectroscopy and wet chemistry were used for soil analysis. Results indicated that the mean concentrations of the micronutrients in the topsoil were Fe (130.4 ± 6.9 $\mathrm{mgkg^{-1}}$), Mn (193.4 ± 20.5 $\mathrm{mgkg^{-1}}$), Zn (2.8 ± 0.2 $\mathrm{mgkg^{-1}}$), B (0.68 ± 0.1 $\mathrm{mgkg^{-1}}$), and Cu (8.4 ± 0.8 $\mathrm{mgkg^{-1}}$). Variations of the micronutrients were not statistically different by elevation (df = 41, $p > 0.05$) and by soil depth (df = 49, $p > 0.05$). Correlations among micronutrients were significant for Fe *versus* Mn ($r = 0.46$, $p < 0.001$), B *versus* Zn ($r = 0.40$, $p = 0.003$), B *versus* Cu ($r = 0.34$, $p = 0.013$), and Cu *versus* Zn ($r = 0.88$, $p < 0.001$). The correlated micronutrients implied that they were affected by similar factors. Soil pH correlated positively with B, Fe, and Mn and negatively with Cu and Zn, hence probably influencing their availability. Therefore, the need for sustaining micronutrient at sufficient levels is crucial. Management interventions may include moderating soil pH by reducing acidity through liming in the higher elevations and incorporation of organic matter in the lowlands.

1. Introduction

Soil nutrients are important elements that support plant growth and crop productivity [1]. Maintenance of soil nutrients at sufficient levels for macro- and micronutrients remains prerequisite in ensuring sustained crop yields [2, 3]. Usually macronutrients, required in large quantities, are the focus of many interventions, unlike micronutrients that are required in small quantities [4–6]. In sub-Saharan Africa, soil infertility remains one of the key factors responsible for declining crop productions [7, 8]. Challenges of soil infertility caused by various factors such as reduction in crop diversity have led to application of various interventions including use of inorganic fertilizers and agroforestry practices that deploy leguminous species [9–11].

Micronutrients quantities required by plants are very small, and the thresholds for sufficient, deficient, and toxic levels are also very close. Several review studies have summarized and suggested the micronutrients range based on extraction methods [4, 12]. Major sources of soil micronutrients are inorganic forms from parent material and organic forms within humus, though deficiency or toxicity can mostly be attributed to the parent material [13, 14]. Furthermore, factors which play important roles in regulating micronutrients include soil pH, oxidation state, organic matter, mycorrhizae, organic compounds, and stability of chelates [15, 16].

Most soils vary in their micronutrient content, and deficiencies in supplying micronutrient are alarming [17]. Deficiency of micronutrients can result in severe crop failure; hence attempts to improve crop production and soil management [18–21] must be in line with micronutrients amendments [22, 23].

Normally, concentrations of soil nutrients are affected by soil types, climate, topography, and management practices [24–26]. For instance, declined vegetation cover and heavy precipitation may accelerate micronutrients leaching. Increased chances of leaching for micronutrients are due to their occurrence as free ions or soluble complexes in solution [27]. Therefore, translocation of micronutrients along the elevation due to surface runoff in sloping terrains and depositions in the valley bottoms calls for proper soil management practices to address both nutrient transfers and crop yield [28].

In Tanzania, few studies have attempted to assess concentration of soil micronutrients in relation to supporting crop productions. Such trend has led to partial understanding of the status and variability of micronutrients in various agricultural soils [18, 29, 30]. This study, therefore, aimed at determining concentration levels and variability of soil micronutrients along the slopes of Mount Kilimanjaro, Tanzania. The information generated can serve for planning soil management interventions to sustain soil micronutrients sufficient levels and addressing deficiencies in the study site.

2. Material and Methods

2.1. Study Site. The study was carried out on farmland along the southern slopes of Mount Kilimanjaro, in Moshi rural district, northern Tanzania (Figure 1). In general, soils in the study site originated from volcanic rocks which are rich in Ca and Mg [32, 33]. Mount Kilimanjaro is a stratovolcano found in the East Africa Rift Valley surrounded by the Precambrian rocks of the Mozambican Belt [32, 34]. Hydrological processes across the study area are very complex, comprising heavy precipitation and deep ground water infiltration [35]. The total population of the Kilimanjaro region is 1,640,087 with average household size of 4.3 [36]. The Chagga tribe forms the dominant inhabitants in the study site, with other ethnic groups including Pare and Taita.

2.2. Land Use Systems. Study transect was categorized into three land use zones based on altitude, climate, and soils. These land use zones exhibited variation in farming systems and were divided into upland (highland), midland (intermediate zone), and lowland.

The upland lies between 1438 and 1696 m a.s.l. Soils are dominated by Humic Nitisol [6, 37]. Mean annual temperature is 24°C and rainfall ranges between 1250 and 2000 mm per year [38–40]. The terrain is gentle slope. Chagga homegarden system is the dominant farming system, comprising multistrata agroforestry with banana plantations and coffee as main crops. Livestock keeping is done through zero grazing. For dairy cattle it includes Friesian, Jersey, Ayrshire, and crossovers between the improved and local breeds (Kilimanjaro Zebu). Other livestock include meat cattle, dairy and meat goats, sheep, and pigs. Open spaces are also found for fodder and maize cultivation. Other crops spatially distributed on farms include yams, round potato, and vegetables [40, 41].

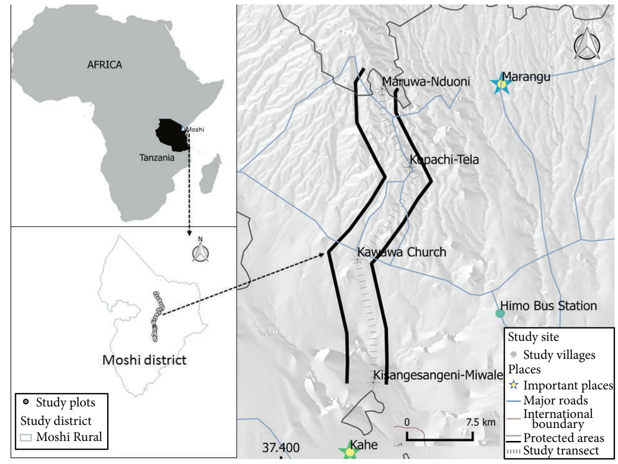

Figure 1: Location of the study site on the southern slopes of Mount Kilimanjaro, Tanzania. Insert map indicates the location of Tanzania within Africa continent [31].

The midland forms the transition where highland and lowland converge. It lies between 900 and 1438 m a.s.l [40]. Major soils are Haplic Phaeozem [6, 37]. It has mean annual temperature of 26°C and rainfall range of 1000–1200 mm per year [38, 39]. The terrain is gentle slope. Mixture of Chagga homegarden and maize monocropping systems is the major farming system. As moving downslope, the midland, the maize is very predominant, such that the area is partly referred to as maize belt. Other crops found include coffee, banana, cardamom, and beans, which are intercropped together. Livestock keeping is a mixture of staff-fed and open field grazing, with dominant species being cattle, goats, and sheep.

The lowland zone extends below 900 m a.s.l. with an annual precipitation of 400–900 mm per year and a mean temperature of 33°C [40]. Major soils include Eutric Fluvisol [6, 37]. The terrain is plain and flat. Main annual crops include sunflower, cotton, maize, sorghum, cassava, paddy rice, and pigeon peas. Free livestock grazing mainly of indigenous breeds of cows (Kilimanjaro Zebu), goats, and sheep is commonly practiced on farms after the crops' harvest [40].

2.3. Soil Sampling and Analysis. Fifty plots were established for soil along 25 km long preselected transect running from 680 to 1696 m a.s.l: 12 plots in the upland, 14 in the midland, and 24 in the lowland. The African Soil Information System (AfSIS) protocol for soil sampling was adapted where inverted Y-shaped design was used in sampling 4 subplots within each plot [42]. Soils were sampled at the top- (0–20 cm) and subsoils (21–50 cm) using auger and sampling plate. Soils were mixed in buckets separately for the sub- and topsoils to prepare composite samples. Coning and quartering method was used to reduce each sample to 500 g, each from the top- and subsoils per plot [43]. Samples were packed

Table 1: Calibration results of soil properties on the southern slopes of Mount Kilimanjaro, Tanzania.

Soil property	Number of principal components	Calibrations	
		RMSEC	R-squared
Fe ($mgkg^{-1}$)	5	0.54	0.31
Mn ($mgkg^{-1}$)	5	0.74	0.34
Zn ($mgkg^{-1}$)	5	0.57	0.46
B ($mgkg^{-1}$)	5	0.76	0.78
Cu ($mgkg^{-1}$)	5	0.90	0.32
Soil pH	5	0.06	0.93

Note. Fe: iron; Mn: manganese; Zn: zinc; B: boron; and Cu: copper.

in zip-lock bags and labelled. Samples were then air-dried, ground using a wooden rolling pin, and sieved through a 2 mm mesh.

2.3.1. Spectral Data Analysis. Air dried subsamples from all plots and soil depths each with approximately 20 g were loaded into four wells. The soils were then analysed using Fourier Transform Mid-Infrared Reflectance Spectroscopy at waveband range from 4001.6 to 601.7 cm, at World Agroforestry Centre (ICRAF) Soil-Plant Spectral Diagnostics Laboratory in Nairobi (Bruker Optik GmbH, Germany [44]). Soil samples were scanned 32 times and their four spectra averaged to account for variability within sample and differences in particle size and packaging in wells [43].

2.3.2. Reference Soil Analysis. About 30% of the soil subsamples were randomly selected for wet chemistry analysis at the Crop Nutrition Laboratory in Nairobi as calibration set [45]. Soil pH was analysed by standard potentiometric method using soil-to-water ratio of 1 : 2 on weight/volume basis [43]. Micronutrients (B, Cu, Fe, Mn, and Zn) were analysed using inductively coupled plasma atomic emission spectroscopy (ICP-AES) using Mehlich 3-Diluted ammonium fluoride-EDTA and ammonium nitrate [46].

2.3.3. Chemometric Analysis. Chemometric procedures were used in analysing data from soil spectra and measured values of the reference soil samples. Soil spectra were processed by cubic smoothing splines and, thereafter, the first derivatives were taken with a smoothing interval of 21 data points using "*trans*" function in the "*soil.spec*" in R-software. Measured soil properties were then calibrated using first derivative of the reflectance spectra by use of partial-least squares regression [47–49]. The regression model developed was used to predict the soil properties (Table 1) for the rest of the samples and their coefficient of correlation (R^2) and root mean standard errors of calibration (RMSEC):

$$\text{RMSEC} = \sqrt{\frac{\sum_{i=1}^{N}(y_i - X_i)^2}{N - A - 1}}, \quad (1)$$

where y is the predicted reference value, X is the measured reference value, N is the number of samples, and A is the number of principal components used in the model.

2.4. Statistical Analysis. Descriptive statistics (maximum, minimum, and mean and standard error of the mean, standard deviation, skewness, kurtosis, and coefficient of variation) were computed for the soil properties. A non-parametric Kruskal-Wallis test (K-W test) was performed to determine the relationship of soil micronutrients with elevation and soil depths. Pearson's correlation was used to compare variables with different dimensional units [50], to determine relationships between soil pH and micronutrients, and to determine correlations among micronutrients. R-statistics software was used in all statistical analyses [48].

3. Results

Correlation coefficients (R^2) of calibration for the wet chemistry and MIR results (Table 1) were large for B and soil pH ($R^2 = 0.78$ and 0.93), indicating large correlation between wet chemistry and MIR analysis procedure. Results for Cu, Fe, Mn, and Zn showed medium correlations ($R^2 = 0.31$–0.46).

Concentration of B, Cu, Fe, Mn, and Zn varied with soil depth across the entire elevation range (Table 2). Variation of concentrations of micronutrients observed by this study (Table 2) ranges from deficient to sufficient, as required for plant growth as suggested by other studies [12].

Mean concentrations of Cu, Fe, Mn, and Zn were higher in the topsoil than in the subsoil except for boron (Table 2) across the elevation. However, there was no significant difference in variation of top- and subsoil concentrations (K-W test: df = 49, $p > 0.05$). Skewness was positive for topsoil (range of 1.2–2.0) and subsoils (0.99–2.05), with the exception of Fe which was close to symmetrical distribution. Kurtosis was positive in all soil micronutrients indicating a peaked distribution, with exception of Fe in the subsoil (Table 2) which was negative, indicating a flatter distribution.

Soil micronutrients indicated high variability especially for concentrations of B, Cu, Mn, and Zn (CV > 0.5). However, the concentration levels did not differ significantly with elevation (K-W test: df = 41, $p > 0.05$). This implied that the concentration levels varied within and between elevations, as further indicated by a scatter plot (Figure 2).

Soil pH was strongly acidic in the upland with estimated value of 5.2 and elevated to very strong alkaline with a value of 9 in the lowland (Table 2, Figure 2). Similarly, soil pH indicated positive correlation with B, Fe, and Mn and negative correlation with Cu and Zn (Table 3). This implied that soil pH influenced the availability of soil micronutrients in the study site.

Correlations among micronutrients were found to be statistically significant for Fe *versus* Mn, B *versus* Zn, B *versus* Cu, and Cu *versus* Zn, implying that these correlated micronutrients were affected by similar factors.

4. Discussion

Mean concentrations of B, Cu, Fe, Mn, and Zn ($n = 50$) were found to be in sufficient range (Table 2), while the minimum levels for B (0.000078 $mgkg^{-1}$), Cu (0.75 $mgkg^{-1}$), and Zn (0.92 $mgkg^{-1}$) indicated deficiencies. The deficiency,

Table 2: Descriptive statistics for the soil micronutrients on the southern slopes Mount Kilimanjaro, Tanzania.

Soil property	Max	Min	Mean (SE)	Std. dev.	Kurtosis	Skewness	CV
0–20 cm							
Fe ($mgkg^{-1}$)	310.60	39.29	130.41 (6.9)	49.2	2.54	1.12	0.38
Mn ($mgkg^{-1}$)	757.04	14.33	193.43 (20.56)	145.39	0.33	1.75	0.75
Zn ($mgkg^{-1}$)	10.34	0.92	2.82 (0.27)	1.97	4.35	2.00	0.69
B ($mgkg^{-1}$)	3.50	0.000078	0.68 (0.1)	0.72	4.24	1.92	1.06
Cu ($mgkg^{-1}$)	24.67	0.75	8.49 (0.85)	6.03	0.70	1.23	0.71
Soil pH (1 : 2 soil : water)	9.03	5.21	6.58 (0.13)	0.93	−0.41	0.59	0.14
21–50 cm							
Fe ($mgkg^{-1}$)	229.70	28.36	119.06 (6.12)	43.26	−0.03	0.31	0.36
Mn ($mgkg^{-1}$)	827.58	8.9	185.45 (22.1)	156.3	5.26	2.05	0.84
Zn ($mgkg^{-1}$)	7.24	0.51	2.18 (0.18)	1.24	3.8	1.64	0.57
B ($mgkg^{-1}$)	3.74	0.00001	0.77 (0.12)	0.86	2.21	1.65	1.11
Cu ($mgkg^{-1}$)	19.8	0.47	7.4 (0.72)	5.06	0.03	0.99	0.68
Soil pH (1 : 2 soil : water)	9.55	5.23	6.78 (0.15)	1.08	0.01	0.85	0.16

Note. max = maximum, min = minimum, SE = standard error of the mean, std. dev. = standard deviation, and CV = coefficient of variation.

Table 3: Pearson product-moment correlation coefficient among soil properties on the southern slopes of Mount Kilimanjaro, Tanzania.

Soil micronutrients	pH (1 : 2 soil : water)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	B (mg/kg)
0–20 cm					
Fe ($mgkg^{-1}$)	0.05 (0.69)				
Mn ($mgkg^{-1}$)	0.30 (**0.03**)	0.46 (<**0.001**)			
Zn ($mgkg^{-1}$)	−0.12 (0.37)	0.20 (0.14)	0.08 (0.57)		
B ($mgkg^{-1}$)	0.60 (<**0.001**)	−0.18 (0.2)	0.19 (0.169)	0.40 (**0.003**)	
Cu ($mgkg^{-1}$)	−0.17 (0.21)	0.17 (0.23)	−0.06 (0.65)	0.88 (<**0.001**)	0.34 (**0.013**)
21–50 cm					
Fe ($mgkg^{-1}$)	−0.04 (0.79)				
Mn ($mgkg^{-1}$)	0.47 (<**0.001**)	0.26 (0.07)			
Zn ($mgkg^{-1}$)	−0.0089 (0.95)	0.099 (0.49)	0.051 (0.72)		
B ($mgkg^{-1}$)	0.64 (<**0.001**)	−0.4 (**0.004**)	0.22 (0.12)	0.29 (**0.04**)	
Cu ($mgkg^{-1}$)	−0.14 (0.33)	0.096 (0.51)	−0.15 (0.3)	0.84 (<**0.001**)	0.23 (0.12)

Note. r (p value), significant level, $\alpha = 0.05$.

sufficiency, and toxicity range of micronutrients is very small [4, 12]; therefore, it is important to understand their concentration levels for proper land management. Overall, the concentration levels of micronutrients observed by this study falls under similar range with other studies in Tanzania [30, 51].

Soil pH was low in the high elevations (Table 2, Figure 2), contributed by higher concentration of Al due to the nature of the parent material as well as the higher mean annual precipitation which led to leaching of base cations. In the lower elevations, soil pH was alkaline; this was due to increased concentrations of exchangeable bases as a result of translocation and soil depositions and their exposure to the surface by evaporation. Therefore, soil pH increased with decreased elevation.

The pattern indicated by soil pH coincided with changes in the availability of the micronutrients (Figure 2), implying that it has direct influence. Other studies have indicated that soil pH influences micronutrients availability by favouring conditions which accelerates oxidation, precipitation, and immobilization [5, 17]. Positive correlations were found for B, Mn, and Fe with soil pH (Table 3), therefore providing favourable conditions for their availability. Solubility of B, Mn, and Fe is known to increase with lowering soil pH [52].

Soil pH indicated negative correlation with Zn and Cu (Table 3). This implied that strong acidity in the higher altitude and alkaline conditions in the lower altitudes in the study area reduced the availability of the Zn and Cu (Figure 2). Saline soils tend to enhance formation of insoluble oxides and hydroxides of Cu and Zn, which limits their availability [4]. Furthermore, our observation indicated that Cu was much lower than 60 $mgkg^{-1}$. Any concentration of Cu above 60 $mgkg^{-1}$ is considered to be toxic and that there was limited horizontal transmission of the Cu from the neighbouring farms unlike previous observation [30].

Correlation among micronutrients in the study site (Table 3) may explain their relationships in enhancing their availability. For instance, high concentration of Mn and Fe is

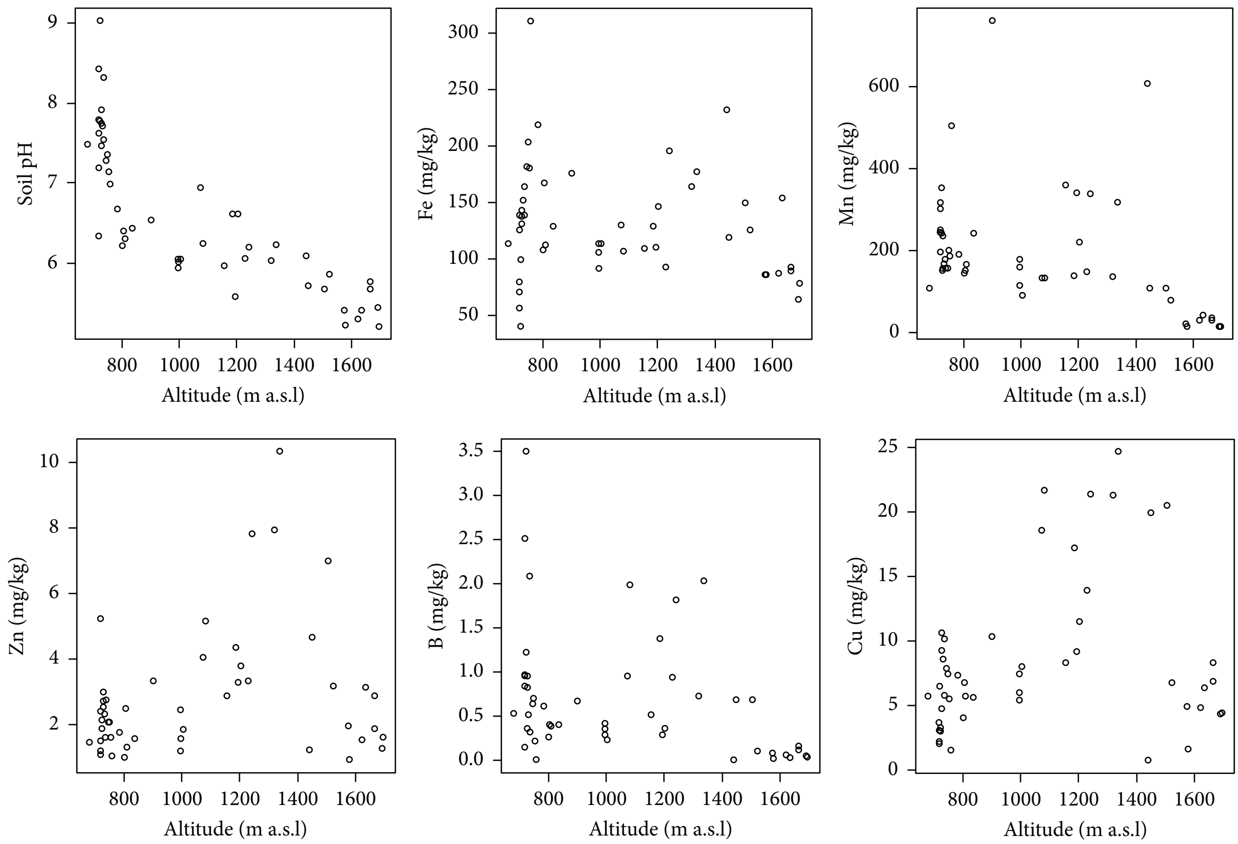

Figure 2: Patterns of soil properties along elevation gradient on Mount Kilimanjaro, Tanzania. *Note*. The upland (1438–1696 m a.s.l.); the midland (900–1438 m a.s.l); and the lowland (extending below 900 m a.s.l.).

known to suppress extractable heavy metals like Zn and Cu [53]. However, this was not the case as there was poor and statistically insignificant correlation among these elements (Table 3). Therefore, other factors, including soil pH, remain responsible. Furthermore, a positive and significant correlation between Fe and Mn existed (Table 3), which underlines the fact that Mn influences availability of Fe. This implied that, under the same soil pH level, increase in concentration of Mn was likely to increase Fe availability as previously noted [54].

Topsoil indicated higher concentrations of soil micronutrients compared to subsoils (Table 2), though the difference was not statistically significant (*K-W* test: df = 49, $p > 0.05$). This implied that the depositions and decomposition of organic matter were higher in the topsoil, therefore contributing to the release of micronutrients [1, 55]. Furthermore, leaching did not remove the extractable micronutrients from the surface layer into the subsurface, across the three land uses. This can partly be explained by less soil drainage due to dry condition and high compaction below 900 m a.s.l. Similarly, above 900 m a.s.l., farms were composed of Chagga homegardens which retain higher vegetation cover estimated at above 10% [39], tending to reduce leaching through increase litter, mulch, and root production [56].

At the same elevation (Figure 2), some soil micronutrients have shown differences in their concentration levels. This can probably be explained by differences in landforms especially in the mountainous areas which associated with localized management. It has been noted in another study that landforms and land use had impact on soil chemical properties [57]. Similarly, differences in soil micronutrients variability were observed in the Usambara Mountains in Tanzania due to differences in landforms [18].

On average, the sufficient concentration levels of soil micronutrients (Table 2) provide prospects for plant productions and human health. A study in Malawi noted that soil rich in micronutrients influenced their concentration in food crops [14]; therefore, observed concentrations of Fe (Table 2) could result in addressing Fe deficiency in diet in the study area. It has been established that Fe deficiency is a serious problem in Tanzania, affecting 30% of all women, and responsible for 50% of anaemia due to low consumption of Fe-rich foods [58].

5. Conclusion

Soil micronutrients in the study area varied with depth and elevation, though the variations were not statistically significant. The average concentrations of B, Cu, Fe, Mn, and Zn were in sufficient ranges for supporting plant growth. Soil pH increased as descending downslope from strong acidic in the high elevation to strong alkaline in the lowlands. Soil pH was shown to correlate positively with B, Fe, and Mn and negatively with Cu and Zn. Correlations among micronutrients were significant for Fe *versus* Mn, B *versus* Zn, B *versus* Cu, and Cu *versus* Zn. The observed soil micronutrients correlation implied that they were affected by similar factors. Soil pH has shown to influence the availability of soil micronutrients, including restricting B, Cu, and Zn. Improving crop production in the study area needs to take into account soil management to sustain micronutrient sufficient levels and addressing deficiencies in some parts for B, Cu, and Zn. Management interventions may include moderating soil pH by reducing acidity through liming in the higher elevations and addition of organic matter in the lowlands. Application of organic matter in the lowland may ensure slow release of the micronutrients at levels which are sufficient to support plant growth.

Competing Interests

The authors declare that they have no competing interests.

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