

# Effect of Topographic Position and Seasons on the Micronutrient Levels in Soils and Grown Huckleberry (*Solanum scabrum*) in Bafut (North-West Cameroon)

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**Abstract** Although topography and climate are known to affect soil micronutrient mobility, some related aspects like micronutrient bioavailability to plants and implications to human intake are not fully understood. This paper aimed to study the effects of different topographic positions and seasons (dry or humid) on micronutrient levels in soils and *Solanum scabrum*. A randomized complete block design with four replications was adopted for each topographic position. Fieldwork was completed by a battery of soil and vegetable analyses. The main results revealed that soil micronutrient levels appeared as follows: Al>Fe>Mn>Zn>Cu for all positions and seasons. The soil micronutrient levels were lowest for the midslope in relation to its steeper gradient that affects downwards migration of matter. Zn and Cu were below the recommended range for agricultural soils, while Al was far above in relation to the strongly acidic pH. In *S. scabrum*, micronutrients appeared as Mn>Fe>Zn>Al>Cu. Globally, vegetable metal levels were higher in the dry season for all positions. Except Al, all metals were below permissible and toxicity levels in food, while only Fe, Mn and Zn were above recommended range for normal plant growth. Metal transfer factors, apart from midslope, were higher in the dry season. Only Mn and Zn for all positions and seasons as well as Zn at footslope, were above 1. Globally, micronutrient levels in soils and vegetables were higher in the dry seasons for all positions. Micronutrient intake rates were higher in the dry season for all positions but lowest in the midslope for all seasons. Except Fe and Zn in adults, metal levels were above the recommended daily dietary intake indicating excess micronutrients intake by the inhabitants. Overall, a combination of steep slope and humid season reduces soil micronutrient level, limit uptake by vegetables and hence reduce mean daily intake in humans.

**Keywords:** Soil catena, *Solanum scabrum*, micronutrients, bioavailability, transfer factors, daily intake

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## 1. Introduction

Topography and climate are two important factors influencing soil properties at regional scale due to their role in weathering and lateral migration of matter [1,2,3,4]. Movement of matter plays a vital role in soil nutrient status, plant nutrient uptake and crop performance [5,6]. One of the causative factors of nutritional deficiency of crops is poor soil fertility [7,8]. Plants obtain their nutrients directly from the soil substratum on which they grow [2,4]. Soil-plant nutrient interaction is thus vital for plant performance and has a direct bearing on effects related to deficiency and toxicity to plants as well as secondary consumers including humans [9,10,11]. Micronutrients are essential plant nutrients, although

needed by plants in minute quantities without which they may not be able to complete their life cycles [12,13,14,15,16]. Through their involvement in various enzymes and other physiologically active molecules, these micronutrients are important for gene expression, biosynthesis of proteins, nucleic acids, growth substances, chlorophyll and secondary metabolites, metabolism of carbohydrates and lipids, stress tolerance etc [17,18]. *S. scabrum* is one of the most cultivated vegetables in Cameroon, especially in the Cameroon Western Highlands [19,20]. Considerable interest has been manifested in the cultivation of huckleberry to combat the ever increasing hunger and micronutrient deficiencies especially in children and expectant mothers from the developing countries [19,21-25]. It is one of vegetables that easily absorbs micronutrients from the soil and easily accumulates them in edible parts (leaves and stems) often

to toxic levels [16,26,27,28]. These vegetables are cultivated in several locations in the humid Cameroon Western highlands at different topographic positions and at different seasons [19,25,30]. Much works have been reported on the micronutrient contents of soils [31-36], as well as heavy metal contents of *S. scabrum* [8,21-26]. However, works that describe the distribution of micronutrients in soils and supported *S. scabrum* at various topographic positions and at different seasons are rare. The lack of attention is due to a number of constraints including the need for multiplicity of experimental points and at different seasons, the time required for land preparation, planting, sampling and analysis, the high number of samples and a wide battery of laboratory analyses that prevent many investigators from conducting such studies in most developing countries. The objective of this work was to assess the surface soil general characteristics, levels of some micronutrient in soils and grown *S. scabrum* along a soil catena and to estimate the mean human daily intake of micronutrients. The results obtained will supplement the available data on the micronutrients levels of soils and bioavailability in vegetables commonly consumed in Cameroon and beyond.

## 2. Materials and methods

### 2.1. Study area

Bafut Sub-division is located in the north of Mezam Division (North West Region of Cameroon) between latitude 06°05'-06°11' N and longitude 09°58'-10°11' E (Figure 1) [37]. It is situated at about 20 km northwest of Bamenda and covers a surface area of 340 Km<sup>2</sup>. The mean annual precipitation is 2657.2 mm, with a long rainy season from March to November and a dry one from December to February. The mean annual temperature is 22.3°C [38]. The natural vegetation of Bafut is the grassland savannah, marked by grasses mixed with deciduous shrubs and stunted trees here and there, meanwhile the swampy valleys are dominated by raffia bushes and palm trees [39]. This natural vegetation is strongly modified by human activities mainly farming and demographic pressure imposed by a rapidly increasing population [40]. On a hydrographic point of view, Bafut Sub-division is drained by River Mezam (main collector) and its tributaries [41]. The drainage system forms a sparse and more or less angular drainage pattern [42]. Geologically, Bafut sub-division is located along the Cameroon Volcanic Line and comprises three main geological formations: volcanic rocks, metamorphic rocks and alluvial deposits [43]. The metamorphic rocks, mainly gneiss and schist, outcrop mainly in the North especially on slopes of high plateaus and constitute the basement. The volcanic rocks, mostly basalts, outcrop in south Bafut. The alluvial deposits cover the Mezam River valley. The distribution of soils in Bafut is conditioned chiefly by topography and climate. Thus, ferrallitic soils occur in the southern high plateaus. In the north, most of the hill slopes are covered by brunified soils; alluvial soils are abundant in the Mezam river valley. Hydromorphic soils are common in the swampy valleys [44]. The estimated population of 80305 inhabitants (2005 census) is settled in

three main zones: the Mumala'a (heart of the country) at the Centre clustered around the Fon's palace, the Ntare (ridge area) to the South and the Mbunti (lower) to the North which descends abruptly to the Menchum valley. In Bafut Sub-division, vegetable cultivation is all year round to ensure a continuous supply, but cultivation is intensified in the dry season when it is more lucrative. In the rainy season, vegetable is grown both in uplands and lowlands. In the dry seasons, it is cultivated only in lowlands close to the banks of the Mezam River, main water course which runs through the Bafut municipality and whose water serves for irrigation. Hand watering with cans is common but flood irrigation is more common in the valleys. Most of the farmers usually have a home garden for home consumption and a garden for commercial purposes usually some distance away from the home. A topographic survey of the study area was carried out and the study area (interfluvium) was divided into three topographic positions (upslope, midslope and footslope) across three neighborhoods (Mambu, Manka'a and Bujong, respectively) following a NE-SW transect (Figure 2).

## 2.2. Methodology

### 2.2.1. Experimental Design and Land Preparation

The studied topographic positions were upslope, midslope and footslope (Figure 2). A randomized complete block design with four replications was adopted for each position. For each position, the experimental procedure was done in the rainy season and dry season making a total number of 24 studied experimental units.

The soil was cultivated using a digging fork to improve water infiltration. All plant residues were removed during cultivation and irrigation was done to improve soil moisture before planting.

### 2.2.2. Planting and Management

The *S. scabrum* seeds were purchased in the Bafut Main Market at 150 FCFA (about \$ 0.3) per glass and planted in mid-March 2015 (rainy season) and in December 2015 (dry season). Experimental units were watered where after there was need to keep the soil moist throughout the study. Weeds were removed by uprooting each time they appeared in the experimental units for the entire duration of the study. No fertilizer was applied throughout the growing period.

### 2.2.3. Sample Collection and Pre-treatment

The vegetable shoots were harvested at six weeks after planting. Thus, the stems were randomly cut at about 15 cm from the soil surface within each demarcated 5 m by 5 m sub-plot using a ceramic scissors to form a final composite sample of about 1 kg. All together, four composite vegetable samples were obtained per 10 m x 10 m plot making a total number of 24 samples.

In each sub-plot, before transplantation, four soil samples were randomly collected at 0-20 cm depth (rooting zone) using a plastic shovel to avoid any metal contamination. These samples were mixed together to obtain a composite sample per sub-plot, thus making four composite soil samples per plot per season. All together,

24 composite soil samples were obtained. Samples were stored in clean plastic bags immediately after collection and conveyed to the laboratory for further description and analysis. In the laboratory, the soil samples were air-dried at room temperature for one week and passed through a 2-mm polyethylene sieve to remove plant debris and pebbles. Afterwards, they were lightly crushed in an agate mortar into fine powder and passed through a 0.149-mm

nylon sieve. The vegetable samples were washed three times with distilled water to remove soil particles and were then oven-dried at 75°C to a constant weight for 48 hours. The dried vegetable samples were crushed into fine powder in an agate mortar and passed through a 0.149-mm nylon sieve. The soil and vegetable powders were then stored in glass containers and preserved under ambient conditions pending analysis.

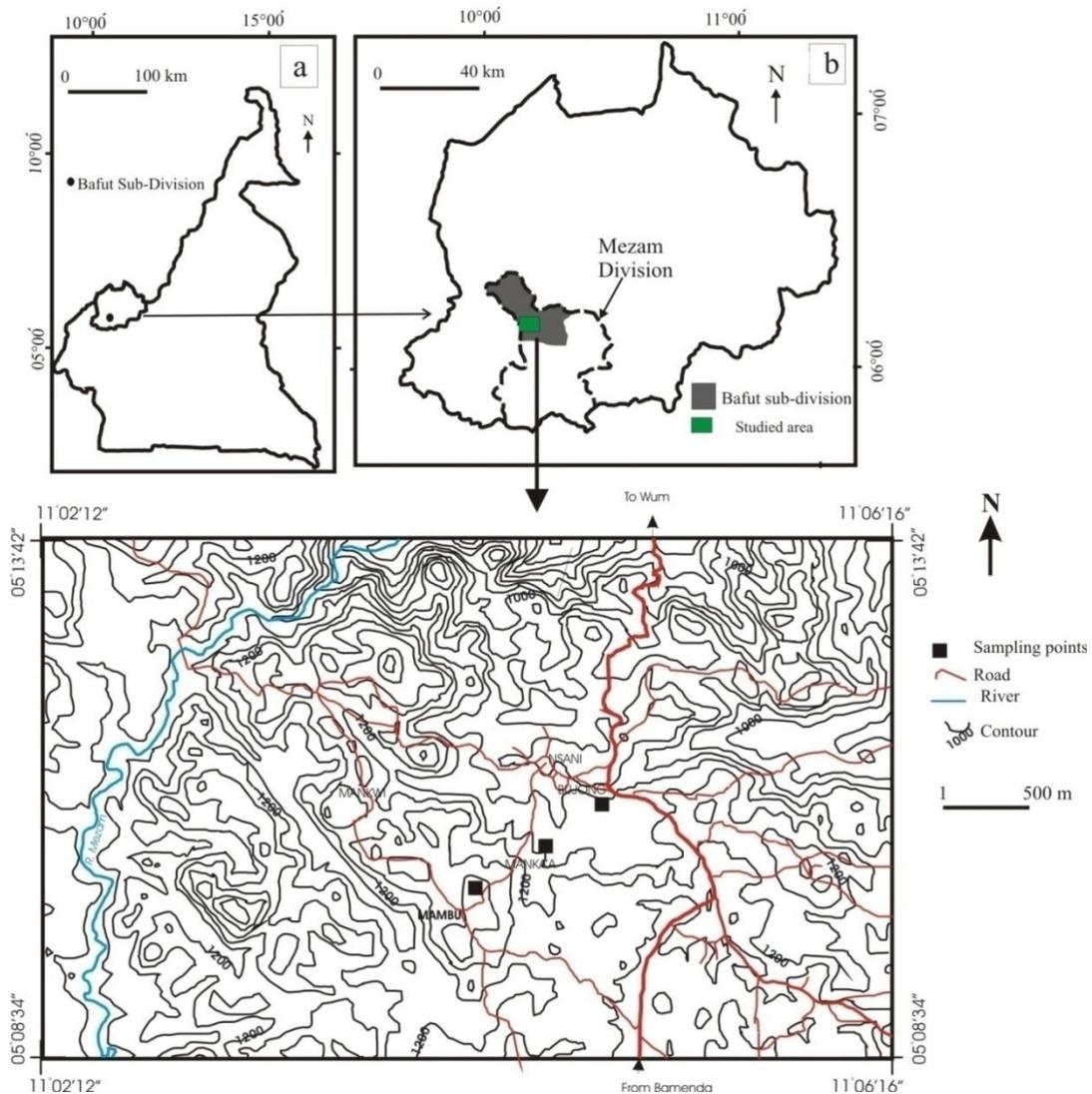


Figure 1. Relief and location of studied area

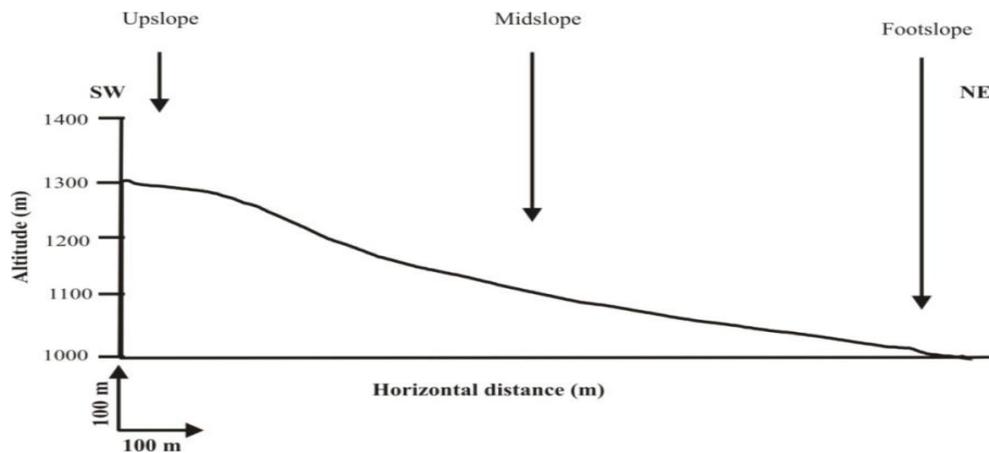


Figure 2. Topographic cross section along the studied transect

### 2.2.4. Laboratory Analyses of Soils and Vegetables

The soil physico-chemical analyses and micronutrient analyses of soils and vegetables were done at the Soil Science Laboratory of the Faculty of Agronomy and Agricultural Sciences (FASA) of the University of Dschang (Cameroon). The soil relative humidity was determined by noting the weight-loss of an air-dried sample, after subjecting it to an oven temperature of 105°C for 24 hours [45]. The bulk density was determined in reference to Archimedes' principle and particle density was measured by pycnometer method [45]. Soil porosity was deduced from bulk density and particle density [45]. The particle size distribution was measured by Robinson's pipette method [45]. The pH-H<sub>2</sub>O was determined in a soil/water ratio of 1:2.5 and the pH KCl was determined in a soil/KCl composition of 1:2.5 [46]. The organic carbon (OC) was measured by Walkley-Black method [47]. Organic matter (OM) was obtained from organic carbon (OC) using the Sprengel factor as in equation (1) [47].

$$OM = OC \times 1.724. \quad (1)$$

Total nitrogen (TN) was measured by the Kjeldahl method [48]. Available phosphorus was determined by concentrated nitric acid reduction method [49]. Exchangeable cations were analyzed by ammonium acetate extraction at pH 7 [50]. The cation exchange capacity was measured by sodium saturation method [51]. The base saturation was calculated as the percentage of the sum of exchangeable cations (S) divided by the cations exchange capacity (CEC). The exchangeable aluminum was extracted in a 1M KCl solution and evaluated by colourimetry with the violet pyrocatechol method [52]. Structural stability index and slaking index were calculated according to [54] and [55], respectively. Aluminum toxicity was defined by the Kamprath method [53] as in equation (2).

$$m = \frac{Al}{Al+S} \times 100. \quad (2)$$

Soil micronutrient levels were measured by total digestion method [56]. Thus, aliquots of 0.5 g of dried soil samples were digested with HNO<sub>3</sub> acid, H<sub>2</sub>O<sub>2</sub> and HCl acid mixture in the ratio 5:1:1 at 80°C until a clear solution was obtained. The solution was filtered through Whatman no. 42 filter paper and diluted to 50 ml with deionized water. The filtrates were then directly analyzed for Fe, Mn, Cu and Zn using atomic absorption spectrophotometry PG-900 Model, equipped with an air-acetylene flame and a hollow cathode lamp, under standard conditions using wavelengths and slit-widths specified for each element [57].

The dried vegetable samples were digested with HNO<sub>3</sub> acid, H<sub>2</sub>O<sub>2</sub> and HCl acid mixture in a 5:1:1 ratio, filtered, diluted to 50 ml and then analyzed for Fe, Mn, Cu and Zn by Atomic Absorption Spectrophotometry PG-900 Model [57]. All soil and vegetable samples were analyzed along with a blank solution. Calibration was performed with standard solutions while precision and accuracy were checked by repeated analyses of sub-samples of standards. Soil and vegetable micronutrient concentrations were expressed in mg kg<sup>-1</sup>. The metal transfer factors were calculated as the concentration of the metal in the vegetable relative to contents in soil before planting [58].

The daily intake (mg kg<sup>-1</sup>day<sup>-1</sup>) of each micronutrient, based on data from the Bafut District Hospital in 2015 and the results of a current vegetable consumption survey in the study area (Azinwi Tamfuh P, in preparation), was calculated from the adult mean weight (61 kg), adult's daily vegetable intake (26 g), children's mean weight (12 kg) and children vegetable daily intake (18 g) based on the equation (3) according to [16]:

$$\begin{aligned} \text{Daily intake (mg kg}^{-1}\text{)} \\ = \text{Mean micronutrient conc. in vegetable} \quad (3) \\ \times \frac{\text{Vegetable weight}}{\text{Body weight}} \end{aligned}$$

### 2.2.5. Statistical Analysis

Statistical analysis was performed using the SPSS software program (SPSS Inc., Version 12.0). The data were analyzed by one-way analysis of variance (ANOVA). The Tukey's test was used to detect the statistical significance of differences ( $P < 0.05$ ) between means.

## 3. Results

### 3.1. Soil Physico-chemical Characteristics

The soil physico-chemical characteristics are presented in Table 1. The soils showed a high bulk density and low porosity. The texture ranged from sandy clay at the upslope to clayey at the midslope and heavy clayey texture at the footslope. The silt/clay ratios of the upslope and footslope positions varied from 0.28 to 0.62, while the midslope had a silt/clay ratio of 0.93 for RMS and 0.77 for DMS (Table 1). The soil pH was very acidic. The organic matter content was average at the upslope and midslope but very high in the footslope. The exchangeable cations were as follows: Ca was low to very low, Mg was low, K was low to very low and Na was very low. The sum of exchangeable bases was low at the upslope and midslope but moderate at the footslope. The CEC was low for all the studied positions and seasons. The available phosphorus was also moderate for all the positions and seasons. The Al toxicity of these soils was moderate for all the positions and seasons, although slightly higher at the footslope.

### 3.2. Distribution and Levels of micronutrients in Soils along the Catena

The mean Fe contents of the soils ranged between 36 and 128 mg kg<sup>-1</sup> for all the topographic positions and seasons (Figure 3). Between topographic positions, all soil Fe contents showed significant differences ( $P < 0.05$ ). Between seasons, there was a significant difference ( $P < 0.05$ ) between all treatments.

The mean Mn contents of the soils were very high for all topographic positions and seasons, ranging between (27 and 103 mg kg<sup>-1</sup>) (Figure 3). Apart from the DFS and RMS, based on topography, all the Mn contents showed no significant difference ( $P < 0.05$ ). Between seasons, only DFS and RMS were significantly different from the rest of the treatments ( $P < 0.05$ ).

Table 1. Soil characteristics (0-20 cm depth) along the soil catena in Bafut sub-division

Soil properties		Footslope		Midslope		Upslope	
		RFS	DFS	RMS	DMS	RUS	DUS
Moisture content (105°C)		16.3	15.80	15.2	8.20	14.3	7.12
Particle density (g cm <sup>-3</sup> )		2.6	2.6	2.6	2.6	2.6	2.6
Bulk density (g cm <sup>-3</sup> )		1.7	1.7	1.5	1.5	1.5	1.5
Porosity (%)		34.6	34.6	42.3	42.3	42.3	42.3
Texture	Sand	32	26	21	23	51	55
	Silt	16	20	38	34	17	10
	Clay	52	54	41	43	32	35
	Textural class	Heavy clay	Heavy clay	Clay	Clay	Sandy clay	Sandy clay
pH (H <sub>2</sub> O)		4.3	4.6	4.2	4.4	4.9	4.6
pH(KCl)		4.0	4.4	4.9	4.3	4.7	4.4
ΔpH		0.3	0.2	0.3	0.1	0.2	0.2
Organic carbon (%)		4.8	5.1	2.8	3.7	4.06	3.9
Organic matter (%)		8.3	8.9	4.9	6.36	7.07	6.79
Total nitrogen (%)		0.42	0.56	0.16	0.08	0.11	0.07
Exchangeable bases (cmol+kg <sup>-1</sup> )	Ca <sup>2+</sup>	3.4	3.6	1.6	1.9	1.46	1.6
	Mg <sup>2+</sup>	1.3	1.5	0.98	1.12	1.2	1.40
	K <sup>+</sup>	0.38	0.29	0.15	0.16	0.11	0.2
	Na <sup>+</sup>	0.11	0.10	-	-	0.05	0.08
Sum of exchangeable bases (cmol+kg <sup>-1</sup> )		5.19	5.49	2.73	3.18	3.42	3.55
CEC (cmol+kg <sup>-1</sup> )		17.9	18.6	12.2	12.5	10.5	11.01
Available phosphorus (ppm)		30.9	27.06	17.22	22.1	24.8	34.1
Exchangeable Al (cmol+kg <sup>-1</sup> )		1.85	1.59	0.99	0.56	0.92	0.77
Al toxicity (%)		35.65	28.96	36.26	17.61	26.90	21.69
C/N ratio		11.43	9.11	17.50	46.25	36.91	55.71
Ca/Mg ratio		2.6 <sup>a,1</sup>	2.4 <sup>a,1</sup>	1.6 <sup>a,1</sup>	1.6 <sup>a,1</sup>	1.2 <sup>a,1</sup>	1.1 <sup>a,1</sup>
Mg/K ratio		3.4 <sup>a,1</sup>	5.2 <sup>a,1</sup>	6.5 <sup>a,1</sup>	7.0 <sup>b,1</sup>	10.9 <sup>b,1</sup>	7.0 <sup>b,1</sup>
Exchangeable sodium % (ESP)		0.61 <sup>a,1</sup>	0.54 <sup>a,1</sup>	-	-	0.47 <sup>a,1</sup>	0.72 <sup>a,1</sup>
S/CEC (%)		28.9 <sup>a,1</sup>	29.5 <sup>a,1</sup>	22.62 <sup>a,1</sup>	25.35 <sup>a,1</sup>	32.57 <sup>a,1</sup>	32.24 <sup>a,1</sup>
Ca/Mg/K ratio		66.9:25.6:7.5	66.8:27.8:5.4	58.6:35.9:5.5	59.8:35.2:5.0	52.7:43.3:4.0	50.0:43.8:6.3
CEC/Clay ratio		0.34	0.34	0.30	0.28	0.33	0.31
Structural stability index		12.2	12.0	7.9	9.1	14.4	15.1
Slaking index		0.68	0.64	0.65	0.55	0.42	0.21

RFS: Rainy season footslope soils; DFS: Dry season footslope soils; RMS: rainy season midslope soils; DMS: dry season midslope soils; RUS: rainy season upslope soils; DUS: dry season upslope soils.

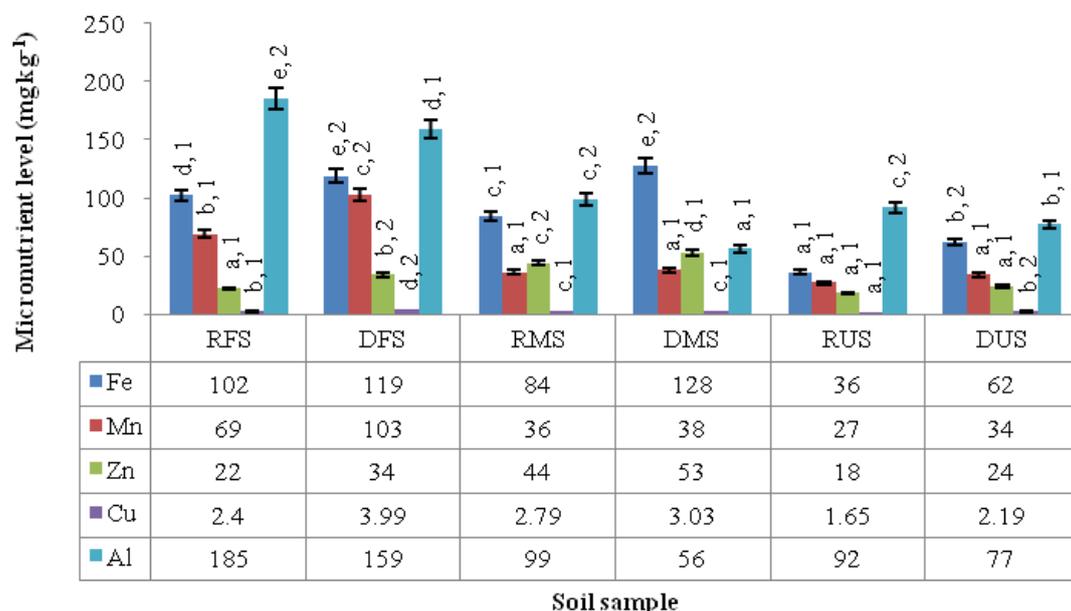


Figure 3. Mean micronutrient composition of soils along the catena (RFS: Rainy season footslope soils; DFS: Dry season footslope soils; RMS: rainy season midslope soils; DMS: dry season midslope soils; RUS: rainy season upslope soils; DUS: dry season upslope soils). Between topographic positions, bars with same shades, followed by different letters are significantly different at  $P < 0.05$ ; within topographic position, bars with the same shade followed by different numbers are significantly different at  $p < 0.05$  for different seasons)

The Zn concentrations of the soils were very high for all the studied topographic and seasons (Figure 2). Between positions, RFS, RUS and DUS were significantly different from the rest of the treatments. Between seasons, only RUS and DUS did not show any significant difference in Zn concentrations.

The Cu contents of the studied soils were moderate for upland in rainy season to very high for the rest of the studied sites and seasons (Table 2; Figure 3). Between position, there was a significant difference ( $P < 0.05$ ) between the Cu contents of the different landscape positions, apart from midslope. Between seasons, only the midslope soils did not show any variations in Cu contents with seasons.

The Al contents of the studied soils ranged from 56 to 185 mg kg<sup>-1</sup> (Table 2; Figure 3). The highest values were noted at the footslope, but decreased significantly at the midslope and upslope. Between positions, there was a significant difference in soil Al concentrations between all the topographic positions and seasons.

The mean Fe/Mn ratios were high for DMS and RMS (midslope), while the rest were low, except DUS which was moderate (Figure 4). RMS and DMS were significant

different in Fe/Mn compared to the other positions.

### 3.3. Micronutrient Composition of *S. scabrum* Samples along the Catena

The micronutrient levels of the studied *S. scabrum* appeared as Mn > Fe > Zn > Cu (Figure 5).

Mn was the most concentrated micronutrient in the *S. scabrum* and ranged between 53 and 178.6 mg kg<sup>-1</sup> (Figure 5). The highest contents were observed for DMV and the lowest ones were shown by the RUV. Apart from RFV and RMV, the rest of the Mn contents did not vary significantly between topographic positions. Between seasons, the Mn contents were significantly different ( $P < 0.05$ ) for all the topographic positions.

The Zn contents of the *S. scabrum* ranged between 6.06 and 44.3 mg kg<sup>-1</sup> (Figure 5). The highest Zn contents were observed for RFV and the lowest ones were shown by RUV. Apart from RUV and RMV, there was no significant difference ( $P < 0.05$ ) in Zn contents between the *S. scabrum* for the rest of the topographic positions. Between seasons, all the topographic positions showed a significant difference between seasons.

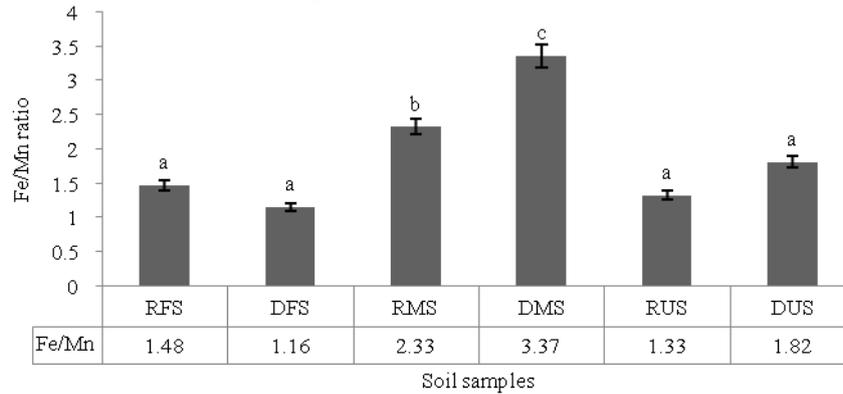


Figure 4. Fe/Mn ratio for the different soil samples. Bars with different letters are significantly different at  $p < 0.05$  for different seasons

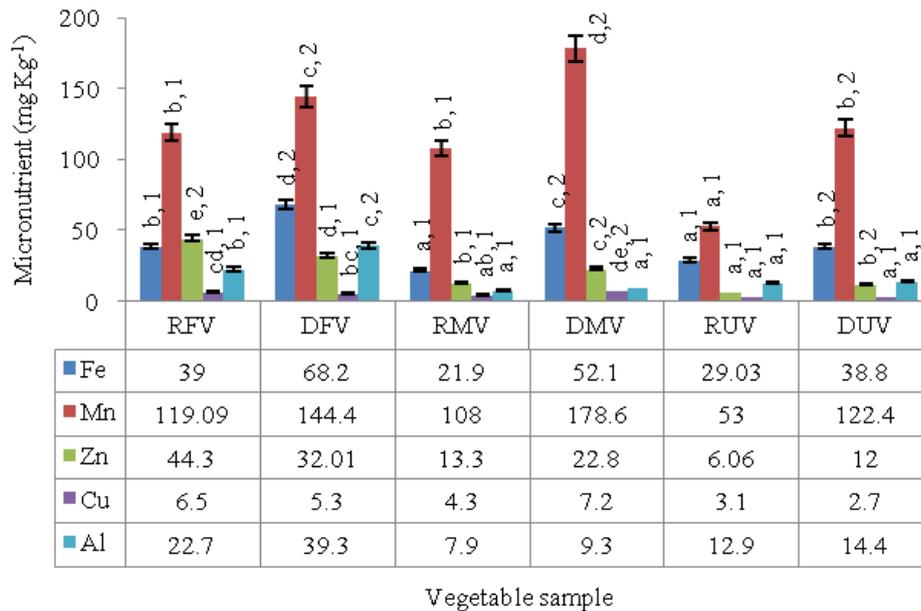


Figure 5. Micronutrient composition of *S. scabrum* along the catena (RFV: Rainy season footslope vegetables; DFV: Dry season footslope vegetables; RMV: rainy season midslope vegetables; DMV: dry season midslope vegetables; RUV: rainy season upslope vegetables; DUV: dry season upslope vegetables; between topographic positions, bars with same shades, followed by different letters are significantly different at  $P < 0.05$ ; within topographic positions (between seasons), bars with the same shade followed by different numbers are significantly different at  $p < 0.05$  for different seasons)

The Fe contents in *S. scabrum* ranged from 21.9 to 68.2mg kg<sup>-1</sup> (Figure 5). The highest Fe contents were observed for DFV and the lowest ones were shown by the RMV. There was a significant difference ( $P<0.05$ ) in Fe contents for all the topographic positions. Season-wise, there is a significant difference ( $P<0.05$ ) in Fe contents for all seasons.

The Cu contents in the *S. scabrum* ranged between 2.7 and 7.2 mg kg<sup>-1</sup> (Figure 5). The highest values were observed for DMV while the lowest ones were noted for DUV. However, the upslope vegetables showed lower Cu contents compared to those of the footslope. Apart from upslope, There was a significant difference ( $P<0.05$ ) in Cu contents between all the seasons.

The mean Al contents of the vegetables ranged from 7.9 to 39.3 mg kg<sup>-1</sup> (Figure 5). The highest Al values were found in DFV while the lowest ones were recorded in RMV. Amongst topographic positions, there was a significant difference in Al concentration between RMV and RUV and the rest of the landscape positions. Among seasons, only footslope vegetables showed a significant difference between seasons ( $P<0.05$ ).

### 3.4. Soil-plant Metal Transfer Factors (TF)

Soil-plant metal transfer factors were high (>1) for Mn and Cu, but low for Zn, Fe and Al (<1) (Figure 6).

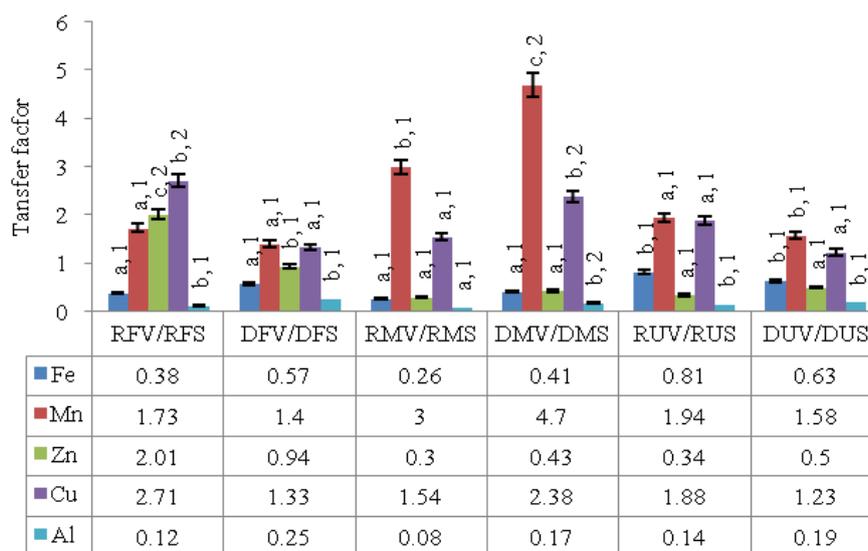
The TF of Mn globally ranged between 1.4 and 4.7. The highest TF values were recorded for the midslope (4.7 for the dry season and 3.0 for the rainy season), while the lowest values were observed in the dry season at upslope and footslope. Based on position, the upslope showed a significant difference in TF values for Fe meanwhile there was no significant difference between seasons. For Mn, only the midslope vegetables were significantly different from the other positions and between seasons. The TF of Cu ranged between 1.23 and 2.71. Only the dry season footslope, rainy season midslope values were not

significantly different from the rest of the TF for the different positions. Meanwhile, a significant difference ( $P<0.05$ ) was observed between Cu TF of at midslope for the rainy and the dry season. The iron TF showed no significant difference between positions and seasons. The TF of Zn showed the same trend as Fe except for footslope at rainy season, which is high (2.01) and also significantly different from all other TF values. The TF values of Al were the lowest of all the micronutrients. Apart from rainy season midslope, there was no significant difference in Al TF values between positions and seasons.

### 3.5. Linear Correlations (r)

Most of the vegetable micronutrients were correlated, either negatively or positively, with the soils physicochemical characteristics and micronutrients (Table 2). Nevertheless, it was observed that Al and clay were positively correlated with most of the other soil metals, while pH (H<sub>2</sub>O) and organic matter were negatively correlated with most of the soil characteristics and micronutrients. Except for DFS, there was a strong positive correlation ( $p<0.01$ ) between Fe and Al in the soil as well as with most of the other metals especially at mid-slope and footslope. The rest of the metals showed strong correlations mainly at footslope and midslope. Many redundancies were however observed implying that similar variables showed positive correlations in one topographic position and seasons and negative correlations in the next position.

Mn, Zn and Cu correlated positively with most of the other metals between plants and soils (Table 3). Al showed strong and weak negative correlations with most of the other metals but for all Mn (except RUS). Soil and plant iron were negatively correlated for almost all position, except RMS. Soil Al was negatively correlated with plant Al. Mn versus Mn, Zn versus Zn and Cu versus copper were positively correlated for most of the positions and seasons.



Vegetable micronutrient/soil micronutrient ratio

**Figure 6.** Soil-to-plant micronutrient transfer factors for the different topographic positions and seasons (RFS: Rainy season footslope soils; DFS: Dry season footslope soils; RMS: rainy season midslope soils; DMS: dry season midslope soils; RUS: rainy season upslope soils; DUS: dry season upslope soils; between topographic positions, bars with same shades, followed by different letters are significantly different at  $P < 0.05$ ; within topographic positions (between seasons), bars with the same shade followed by different numbers are significantly different at  $p < 0.05$  for different seasons)

**Table 2. Correlation coefficients (r) amongst soil micronutrients concentrations plus soil physico-chemical characteristics for the different sites and seasons**

	Clay	pH (H <sub>2</sub> O)	OM	Ca	Mg	K	S	CEC	Avail. P	Fe	Mn	Zn	Cu	Al
RFS														
Fe	0.22	0.82**	0.60**	0.63**	0.84**	0.95**	0.78**	0.95**	0.01	1	0.76**	-0.33*	0.54**	0.59**
Mn	0.80**	0.94**	-0.84**	-0.81**	-0.85**	-0.10	-0.06	0.81**	0.79**		1	0.32*	-0.56**	0.37*
Zn	0.33*	-0.95**	-0.63**	-0.70**	-0.92**	0.01	-0.27	-0.89**	-0.35*			1	-0.43*	-0.22
Cu	0.92**	-0.73**	0.96**	0.77**	-0.97**	-0.25	-0.40**	-0.98**	0.96**				1	0.08
Al	-0.95**	-0.98**	-0.98**	0.01	0.01	0.18	0.68**	-0.27	0.16					1
DFS														
Fe	0.97**	-0.89**	-0.66**	0.59**	-0.79**	0.26	0.47**	0.87**	0.95**	1	-0.23	0.06	0.91**	0.66**
Mn	-0.76**	-0.98**	-0.71**	-0.04	-0.35*	0.44*	0.54**	0.75**	0.23		1	0.28	-0.89**	0.71**
Zn	0.99**	0.99**	0.42*	0.71	-0.96**	0.04	-0.66**	-0.56**	-0.99**			1	0.32*	0.99**
Cu	0.85**	-0.95**	0.30*	-0.98**	0.42*	-0.10	-0.48**	-0.27	0.99**				1	0.30*
Al	-0.90**	-0.95**	-0.58**	-0.84**	-0.79**	0.54**	-0.60**	-0.87**	-0.56**					1
RMS														
Fe	0.82**	0.83**	0.24	0.16	0.78**	0.62**	-0.17	0.75**	-0.43*	1	0.90**	-0.79**	0.20	0.71**
Mn	0.05	-0.57**	-0.65**	-0.86**	-0.19	-0.13	0.52**	0.93**	0.98**		1	0.32*	-0.86**	0.49**
Zn	0.16	-0.61**	0.38*	-0.98**	-0.88**	0.10	0.87**	-0.27	-0.98**			1	-0.10	-0.60**
Cu	0.72**	0.96**	-0.97**	0.93**	0.86**	-0.27**	-0.63**	-0.70**	0.08				1	0.57**
Al	-0.64**	-0.68**	-0.89**	-0.27	0.55**	-0.27	-0.28	0.75**	-0.89**					1
RMS														
Fe	-0.49**	0.48**	-0.42*	0.87**	-0.99**	-0.27	-0.22	0.83**	-0.49**	1	0.92**	-0.34*	0.64**	0.36*
Mn	0.16	-0.70**	-0.48**	0.75**	0.16	0.24	-0.74**	-0.57**	0.98**		1	-0.51**	0.76**	0.68**
Zn	0.77**	0.90**	0.97**	0.93**	-0.50**	-0.55**	-0.80**	-0.87**	0.55**			1	0.23	0.52*
Cu	-0.65**	-0.97**	0.58**	-0.62**	-0.23	-0.26	0.17	-0.26	0.60**				1	-0.14
Al	-0.10	0.61**	-0.32*	-0.94**	-0.79**	-0.22	-0.09	-0.93**	0.93**					1
DUS														
Fe	-0.27	0.71**	-0.04	0.82**	0.82**	0.08	-0.14	-0.27	-0.27	1	0.52**	0.54**	0.75**	-0.25
Mn	0.97**	0.79**	-0.93**	0.93**	0.91**	-0.11	0.47**	0.87**	0.24		1	-0.33*	0.09	0.18
Zn	0.99**	-0.59*	0.32*	0.97**	0.83**	0.05	0.20	0.75**	0.55**			1	0.17	0.26
Cu	0.56**	-0.80**	-0.33*	-0.98**	-0.81**	0.09	0.22	0.93**	0.26				1	0.44*
Al	-0.43*	0.91*	-0.72**	0.08	-0.62**	-0.06	0.31*	-0.27	0.01					1
RUS														
Fe	0.98**	0.60**	0.58**	-0.89**	-0.99**	-0.14	-0.20	0.87**	0.59**	1	0.52**	0.54**	0.59**	0.68**
Mn	0.99**	0.91**	-0.98**	-0.49**	-0.21	0.27	0.26	0.66**	-0.04		1	0.67**	0.16	0.28
Zn	-0.45**	-0.89**	0.55**	-0.96**	-0.93**	-0.04	-0.21	-0.53**	0.71**			1	-0.17	-0.14
Cu	-0.60**	0.32*	-0.60**	0.81**	-0.23	-0.08	-0.61**	-0.06	0.01				1	0.24
Al	0.98**	-0.62**	-0.93**	-0.58**	-0.76**	-0.34*	0.96*	0.28	0.59**					1

RFS: Rainy season footslope soils; DFS: Dry season footslope soils; RMS: rainy season midslope soils; DMS: dry season midslope soils; RUS: rainy season upslope soils; DUS: dry season upslope soils; \*\*Significant at the 0.01 level; \*Significant at the 0.05 level.

### 3.6. Micronutrients Intake Rates

The daily intake of metals was higher in children than in adults for the same landscape position and season (Figure 7). In adults, the daily intake of Fe was low for all cases, while in children Fe was low only in the rainy season at upslope and midslope.

In adults, based on position, except for DMV and DUV, there was no significant difference between the daily intake rates of Fe in adults. However, Fe contents varied significantly ( $P < 0.05$ ) between seasons (Figure 7a). Mn

intake rates were not significantly different among positions but were all significantly different among seasons, apart from DFV and DMV. For Zn, only RUV and RMV did not vary significantly from the rest of the vegetables based on positions while season-wise, all the daily intake rates were significantly different among seasons. The daily intake rates of Cu at footslope were significantly different from the rest of the positions. Season-wise, only the midslope and the upslope daily intake rates varied significantly among seasons.

Table 3. Correlation coefficients (r) among micronutrients in soil and vegetable for the different sites and seasons

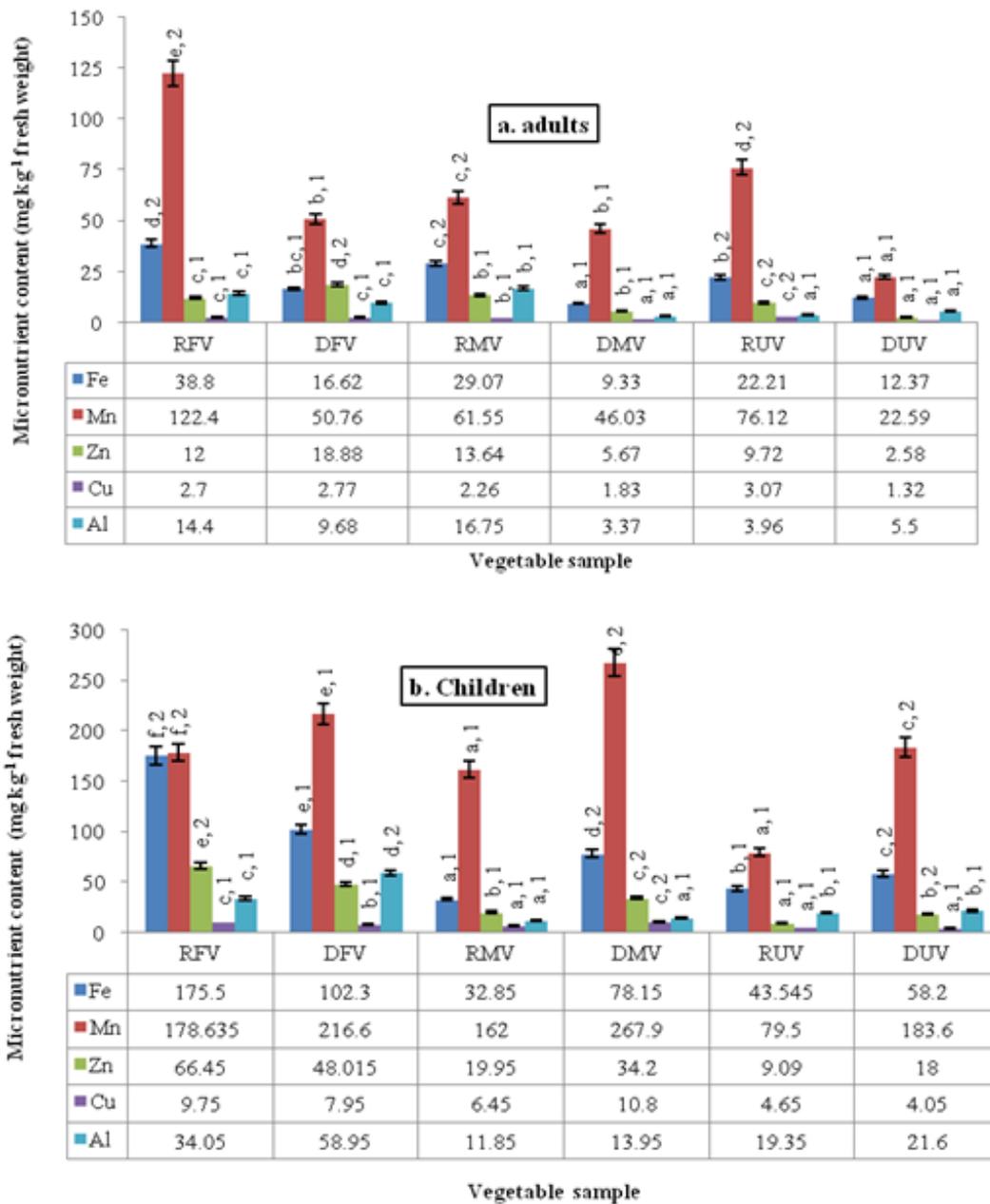
	Micronutrients	Fe	Mn	Zn	Cu	Al
<b>RFS</b>						
<b>RFV</b>	Fe	-0.61**	-0.89*	-0.23	-0.72**	-0.89**
	Mn		0.64**	0.16	0.21	0.78**
	Zn			0.91**	-0.12	0.54**
	Cu				0.65**	0.62**
	Al					0.17
<b>DFS</b>						
<b>DFV</b>	Fe	-0.67**	0.16	-0.61**	0.32*	0.23
	Mn	0.06	-0.66**	0.14	0.56**	0.61**
	Zn		-0.56**	0.22	-0.29	-0.43*
	Cu				0.85*	-0.53**
	Al					0.11
<b>RMS</b>						
<b>RMV</b>	Fe	0.16	-0.79*	0.69**	0.55**	-0.68**
	Mn		0.76*	0.32*	0.60**	0.48**
	Zn			0.64**	0.39*	-0.70**
	Cu				0.93**	0.90**
	Al					-0.41*
<b>DMS</b>						
<b>RUV</b>	Fe	-0.81**	0.14	0.45**	-0.87**	0.29
	Mn		0.89**	0.34*	0.64**	0.66**
	Zn			0.95**	-0.22	-0.34*
	Cu				0.66**	0.89**
	Al					-0.87**
<b>DUS</b>						
<b>DUV</b>	Fe	-0.88**	-0.73**	-0.10	-0.86**	-0.16
	Mn		0.32*	0.60**	0.21	-0.20
	Zn			0.22	0.67**	0.32*
	Cu				0.71**	0.22
	Al					-0.49**
<b>RUS</b>						
<b>RUV</b>	Fe	-0.53**	-0.83**	0.03	-0.52**	-0.42*
	Mn		0.54**	-0.05	0.82**	0.59**
	Zn			-0.41*	0.59**	-0.21
	Cu				0.08	-0.24
	Al					-0.72**

RMS: rainy season midslope soils; DMS: dry season midslope soils; RUS: rainy season upslope soils; DUS: dry season upslope soils; RFV: Rainy season footslope vegetables; DFV: Dry season footslope vegetables; RMV: rainy season midslope vegetables; RUV: rainy season upslope vegetables; DUV: dry season upslope vegetables.

In Children, all the daily intake rates of Fe and Mn were significantly different among positions. Season-wise, all the intake rates were significant different between seasons and topographic positions (Figure 7b).

For Zn, apart from DUV and RMV, all other daily intake rates were significantly different among positions but all the values were significantly different among seasons within each topographic position.

For Cu, DUV, RUV and RMV did not vary significantly unlike the rest of the daily metal intake rates. Within each topographic position, footslope and midslope values were significantly different among seasons. Finally, the daily intake rates of Al varied significantly between topographic positions but only footslope showed a seasonal significant variation ( $P < 0.05$ ).



RFV: Rainy season footslope vegetables; DFV: Dry season footslope vegetables; RMV: rainy season midslope vegetables; DMV: dry season midslope vegetables; RUV: rainy season upslope vegetables; DUV: dry season upslope vegetables. Between topographic positions, bars with same shades, followed by different letters are significantly different at  $P < 0.05$ ; within topographic positions (between seasons), bars with the same shade followed by different numbers are significantly different at  $p < 0.05$  for different seasons).

Figure 7. Average daily intake of micronutrients through vegetable consumption in Bafut (a) adults; (b) children

## 4. Discussions

### 4.1. Soil Properties along the Soil Catena

All the studied soils revealed a uniform particle density in all topographic positions, but porosity was slightly lower for the footslope soils. This could be due to lateral migration and accumulation of fine clayey materials at the lower positions leading to an increase in bulk density of the soils. The studied soils revealed a silt/clay ratio above 0.15 or 0.20 indicating that the soils are relatively young with high degree of weathering potential, respectively [60,61,62,63,64]. The pH values were globally below 5 revealing very acidic soils [7]. Leaching of bases under high rainfall and

warm temperature, typical of tropical ecosystems, is the primary cause of soil acidic reactions [65]. The OC contents were very high in all the soils and decreased with increased slope with lowest values recorded at mid-slope and results matched the findings of [2,4,64]. Soil texture has a strong influence on soil's ability to store and amass soil organic carbon [65]. The exchangeable cations were higher at the footslope than the upper positions. This might imply leaching from the upper landscape positions and deposition at the footslope [65]. Also, the basic cations were higher in the dry season compared to the rainy season at different positions and these agrees with abundant rainfall in the rainy season that leaches upper landscapes and enriches the lower positions with basic cations [66].

## 4.2. Micronutrient Concentrations of Soils along the Soil Catena

The Fe contents were high for all the positions and seasons according to [59], and fell within the permissible range of agricultural soils [72] as well as above the critical limits for plant growth [73]. The Fe contents of soil usually range between 200 mg kg<sup>-1</sup> and 100 000 mg kg<sup>-1</sup> [74]. Apart from the upslope rainy season soils in Bafut, all soil Fe levels were higher than the 21.4-58.9 mg kg<sup>-1</sup> reported for some contaminated soils in Jos (Nigeria) by [75] but lower than Fe contents documented for vegetable soils of the Cameroon inland valleys of the Nkoup River in Foubot [29] and Mezam River in Bamenda [25]. Fe availability under stress conditions in some soils is enhanced through the production of organic chelating agents by microorganisms [76]. Fe deficiency is common in neutral to alkaline soils [77]. The high Fe concentration of the Bafut soils might therefore be related to their acidic nature, conditions favorable for Fe accumulation. The main sources of Fe are probably the parent rocks, iron pipes, waste can containers and rusted iron rods commonly dumped into nature following rapid population growth in the Bafut Sub-division as well as Fe present in irrigation water [78]. Fe deficiency, thus, is not likely to occur on vegetables grown on these soils.

Mn was the most concentrated micronutrient in the *S. scabrum*, ranging between 53 and 178.6 mg kg<sup>-1</sup>. The highest contents were observed for DMV while the lowest ones were shown by the RUV implying a possibly higher Mn absorption in the dry season compared to the rainy season. Apart from RUV, the Mn contents of the rest of the vegetables did not vary significantly site-wise. Between seasons, the Mn contents were significantly different for all the sites revealing that seasonal changes play a vital role on Mn availability and absorption. These values were however within the intervals required for normal plant growth [79], but fell far below the toxicity level in plants [80] indicating a normal plant growth. Generally, the concentration of Mn in soil covers a particularly wide range, from as little as 20 mg kg<sup>-1</sup> to well over 3000 mg kg<sup>-1</sup> [74]. The lowest limits are typical of severely leached acid soils meanwhile Mn toxicities are common in unleached acid soils and waterlogged conditions; severe Mn deficiency is common in alkaline and calcareous soils [10,77]. Soil pH is therefore one of the main factors determining Mn availability in soils [65]. A pH value below 6.0 favours Mn reduction and formation of the more available divalent ion (Mn<sup>2+</sup>); a higher pH favours Mn oxidation to Mn<sup>4+</sup> ion, forming the insoluble oxides like MnO<sub>2</sub>, Mn<sub>2</sub>O<sub>3</sub> and Mn<sub>3</sub>O<sub>4</sub> [65,74]. The high Mn contents of vegetables recorded in the present study could be related to the soil acidic pH [81].

The mean soil Zn contents in all the topographic positions were high based on the critical values of [59]. Generally, in most of the positions, Zn was irregularly distributed in others. It was below the permissible range for agricultural soils [72] and generally above the critical levels recommended for agriculture [73]. Similar results have been documented [2,4,6]. Certain soil conditions might reduce Zn availability, notably high pH as the solubility of Zn decreases with increase pH [10]. Thus, a high incidence of Zn deficiency often occurs on

calcareous or limed soils while excessive levels are common on very acid soils (< pH 5.0) or in areas where zinc-enriched municipal sewage sludge or industrial waste have been added to cropland as soil amendment [27,77].

The Cu contents in the Bafut soils were medium to high [59], fell below the permissible range for agricultural soils [72] and below the critical levels for agricultural soils [73]. These results are similar to those reported by [34]. *S. scabrum* is particularly sensitive to Cu deficiencies [82]. Soils derived from basic rocks usually show low Cu contents whereas acid rocks favour Cu availability [74]. Factors affecting the soils ability to provide Cu to plants include pH, humus content and proportion of sand to clay [65]. Cu deficiency is most common on highly calcareous soils as well as in sandy soils with low organic matter contents [82]. These findings are consistent with those of the studied area. High contents of other metals Fe, Mg and Al in soil can induce Cu deficiency due to ionic balance effect [10,74].

The Al concentrations of the soils were very high and this was unfailingly related to the soil's strong acidity [52]. However, the Al toxicity of Kamprath [53] fell within the moderate range indicating that Al tolerant plants could grow on such soils. In such acid soils, the Al concentration increases drastically, becomes toxic and disturbs root growth and functions. Soil pH is the most important factor that influences the form of Al present in soils [84-89].

Soil pH(H<sub>2</sub>O) values below 5.5 are accompanied by numerous phenomena, such as increased abundance of Al and Mn, reduced amounts of basic cations, reduced solubility of phosphorous and molybdenum and the inhibited root growth [10]. Significantly high clay contents and available phosphorus might increase risk of Al toxicity at low pH [10]. At low pH, organic matter could buffer Al toxicity by forming chelates with it, thus reducing excess Al from being taken up by plants [86,87,88]. However, in the present study, despite the highest pH, clay contents, exchangeable cations and CEC of the footslope soils, they showed the highest Al concentrations. This might be due to site-specific features responsible and a possible migration of excess Al from the upper landscapes to the valleys [10]. These Al concentrations are higher than those reported elsewhere by [89], perhaps because of the acidic pH of the Bafut soils which could be stimulating dissolution of Al species. These high values are typical of volcanic soils where Al commonly forms complexes with organic material to leading to an increase in its stability [65]. The acidic character of Bafut soil might be influenced by several agricultural practices conducted by farmers.

The Fe/Mn ratios were greater than 2.5 for all the midslope soils but less than 1.5 for all footslope soils, no matter the season. This revealed a potential Fe toxicity to plants in the midslope and a potential Mn toxicity to plants at the footslope [10]. For the upslope soils, the Fe/Mn ratios fell between 1.5 and 2, indicating that none of the two micronutrients were toxic to plants at this landscape position [10]. This Fe/Mn trend from upslope to footslope could be directly linked to soil controlling factors which are both intrinsic (clayey to heavy clayey texture, relative humidity, mediocre porosity, acidic pH, high organic matter content, degree of slaking, structural

stability, etc) and extrinsic (high precipitation, temperature, gradient of slope, etc). These factors influence the solubility and mobility of soil micronutrients and subsequent availability for plants absorption [90].

### 4.3. Vegetable Micronutrient Levels along the Soil Catena

The Fe contents in *S. scabrum* ranged from 21.9 to 68.2 mg kg<sup>-1</sup> and were the second most represented element in the vegetable samples from the studied sites after Mn. The highest Fe contents were observed for DFV and the lowest ones were shown by the RMV. These trends might be related to depletion of iron by rain water and subsequent accumulation in the footslope, which begin to precipitate during the dry season [65]. This might, thus, explain why there was a season-wise significant difference in Fe contents between the midslope and valley vegetables. Apart from dry season vegetables in upslope and valley, the remaining treatments were below the normal range required for plant growth [79], very far below the toxicity levels [80] and will therefore not pose any problems to consumers as Food [91]. The low Fe contents of *S. scabrum* compared to the soils could be due to the naturally high organic matter contents at soil surface, which at low pH, favours the formation of organo-metallic complexes with Fe, thereby blocking its uptake by plants [92]. In the footslope, the Fe contents were lower than those already documented in Ngaoundéré (North Cameroon) by [93] and [8], but very far below those reported by [25] on vegetables grown along the Mezam River in Bamenda. These metal values were also lower than those reported in Kenya and Tanzania [8] and in Nigeria [83]. The Mn contents in the Bafut *S. scabrum* were extremely high relative to values reported for some vegetables in India [15,24] and Russia [94]. Globally, the dry season *S. scabrum* showed higher Mn contents than those grown in the rainy season. The metal contents of vegetables fell within the sufficiency levels and below the toxicity levels for optimum plant growth [79] as well as within the permissible levels in food [91]. Mn and Fe are essential mineral elements for both plants and animals, and the recorded levels in this study indicate that the vegetables constitute very good sources of nutrients for the population.

The Zn concentrations of *S. scabrum* fell below the critical range for optimum plant growth [14] as well as the permissible level in food [91]. All the *S. scabrum* samples contained inadequate Zn levels [79]. These observed values were in agreement with those published by [8] and [82] but were higher than values reported by [25] on vegetables grown along the Mezam River valley in Bamenda. This Zn levels were also analogous to the 25.2-50.0 mg kg<sup>-1</sup> reported for *S. scabrum* in India [15,24], higher than values recorded on vegetables in Nigeria [95], Egypt [97] and Latin America [97]. Zn deficiency has been reported on crops growing where calcareous subsoils have been exposed by land leveling or erosion, or where subsoil is mixed with topsoil [77].

The Cu contents of *S. scabrum* were very low compared to the other metals. The footslope vegetables fell within the normal level in plant growth [79] and below the toxicity level [80], but fell within the permissible level for

human consumption [91]. For the midslope, RMV fell below the normal level in plants and RMV fell within normal level, but both were within the permissible levels in food [91]. The upslope vegetables fell below the normal level and toxicity limits [80], but fell within the permissible level in food (FAO/WHO 2001). These values were close to those reported by [93] in Ngaoundéré (North Cameroon), but higher than those of [29] for vegetables grown along the Nkoup River valley in Foubot (West Cameroon). This range fell within values for vegetables irrigated with wastewater [25]. The Cu content of most agricultural soils ranges from 2 to 100 µg/g [74,98].

Although the vegetable Al contents were far below those of the studied soils, they were extremely high compared to the permissible limit of 1.00 mg kg<sup>-1</sup> in food [91]. These results were contrary to expectations considering that the soils of the area showed low pH, high organic matter, high available phosphorus and high exchangeable Ca which are conditions that hinder Al uptake by roots. Even so, mechanisms controlling Al uptake, tolerance and toxicity are numerous and complicated due to the complex chemistry of Al according to [86]. The long-term human intake of such vegetable with high Al contents could cause problems in humans as nervous system, lungs, and kidney. Strong accumulation in humans could lead to Alzheimer's disease, Parkinson's disease, etc [91].

The metal transfer factors were above 1 for Cu and Mn in the studied soils implying a relatively higher concentration of those two metals in the vegetables compared to the soils. Zn showed a transfer factor above 1 only for the rainy season footslope soils. The rest of the horizons showed transfer rates below 1. Similar findings [25] along the Mezam river valley in Bamenda town revealed very high metal transfer factors for Zn (4.58-7.09 mg kg<sup>-1</sup> dry weight) and Cu (0.69-1.62 mg kg<sup>-1</sup> dry weight) compared to Bafut, while the Fe and Mn factors were comparable. The differences may result from vegetable irrigation with contaminated water in the Bamenda Urban Centre which leads to the deposition of excess plant micronutrients in the soils.

Most of the soil micronutrients showed strong correlations with other soil micronutrients and physicochemical characteristics. Between vegetables and soils, Mn, Zn and Cu correlated positively amongst themselves and with most of the other metals in agreement with the high transfer factors of these three micronutrients compared to Fe and Al. However, numerous redundancies were observed in soil and vegetable data correlations attributable to many causes such as site-specific biogeochemical characteristics, previous land management systems, biotic activity and small size of samples used. Amundson et al. [99] attributed such behavior of soil properties to the agriculture imprint on the critical zone. Biogeochemical processes in the critical zone affect the metal speciation thereby controlling their solubility, mobility, bioavailability and toxicity hence making their distribution in the critical zone very complex [100]. Thus, Metal ions in soil solution may undergo numerous pathways: plant uptake or retention on surfaces of minerals, natural organic matter, and microbes or leaching into groundwater or by colloid-facilitated transport, or even precipitation into solid phases or finally diffusion in porous media such as soils.

#### 4.4. Influence of Slope and Seasons on Soil Micronutrient Levels and Uptake by Plants and Humans

The footslope soils showed a slightly higher bulk density, lower porosity and a lower sandy fraction. Based on the silt/clay ratio, the relatively younger age of the midslope was consistent with a steep slope that favours erosions and continuous rejuvenation of the soil [65]. Soil acidity did not vary much along the slope. Organic matter content did not vary much among seasons but was highest at the footslope and least at midslope. Basic cations, sum of bases, CEC and base saturation were slightly higher at the rainy season and at the footslope but least at the midslope. Available P was higher in the dry season apart from the footslope but the lowest levels appeared in the midslope. The footslope and upslope showed a more stable structural stability compared to the midslope. Apart from soil Cu and Zn that showed higher levels at midslope, the other metals revealed a higher accumulation at the footslope and a global leaching of the midslope. All the micronutrients were highly concentrated in the dry season, apart from Al, for all topographic positions. The micronutrient concentrations of *S. scabrum* were higher in the dry seasons for all metals apart from Cu and Zn at footslope. The metal transfer factors of most of the metals in *S. Scabrum* were higher in the dry season, except for Fe at upslope, Mn at footslope and upslope, Zn at footslope and Cu at footslope and upslope. These results were concomitant with the average daily consumption rates which were highest in the dry season for most of the topographic positions in children and adults. The influence of topography and seasons on spatial variations of soil properties and bioavailability of plant nutrients has already been reported [1,3,4,10]. The results of the correlation coefficients analysis enabled to explain most of the trends from soil to plant and finally to human consumption, but not others due to the presence of numerous redundancies in data. The influence of topography and climate on the pedogenetic process has been highlighted by [65]. These factors affect plants through rate of micronutrients uptake, levels of nutrients in the vegetables and subsequent human daily intake through vegetable consumption. According to [4] slope is the main factor contributing to the transportation and accumulation of fine soil particles when soil organic matter content and structural stability are low thus contributing to upslope "cleansing" and footslope enrichment.

#### 4.5. Micronutrient Daily Intake Rates

Except for Fe and Zn in adults, most of the daily micronutrient intake rates in all topographic positions were above the recommended daily dietary allowance of the FAO/WHO [91,101] for both children and adults. The children mean daily intake was higher than that of adults and this could be linked to the relatively smaller body weight of children. This indicates excess intake of those micronutrients into the body for the inhabitants of the area calling for more attention to be taken to minimize metal contamination especially for Mn, Cu and Al in adults and all the metals in children. The approach to estimate metal intake could have presented some limitations considering

that the cooking and frying process might positively or negatively affect some of the micronutrient concentrations. The daily micronutrient intake rates were too high compared to those already reported for some African indigenous vegetables by [25,29].

### 5. Conclusion

This main objective of this work was to study the effects of different topographic positions and seasons (dry or humid) on micronutrient levels in soils and *Solanum scabrum*. The main results revealed that the micronutrient levels were lowest for the midslope soils in relation to its steeper gradient that affects downwards migration of matter. Zn and Cu were below the recommended range for agricultural soils, while Al fell far above in relation to the strongly acidic pH. In *S. scabrum*, micronutrients appeared as Mn>Fe>Zn>Al>Cu. Globally, vegetable metals levels were higher in the dry season for all positions. Except for Al, all metals were below permissible and toxicity levels in food, while only Fe, Mn and Zn were above recommended range for normal plant growth. Metal transfer factors, apart from midslope, were higher in the dry season. Only Mn and Zn for all positions and seasons as well as Zn at footslope, were above 1. The micronutrient levels in soils and vegetables were generally higher in the dry seasons for all positions. Micronutrient daily intake rates were higher in the dry season for all positions but lowest in the midslope for all seasons. Except Fe and Zn in adults, metal levels were above the recommended daily dietary intake indicating excess micronutrients intake by the inhabitants. Overall, a combination of steep slope and humid season reduces soil micronutrient level, limit uptake by vegetables and hence reduce mean daily intake in humans.

### Competing Interests

The authors declare no conflict of interests.

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