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Dynamics of Micronutrients (Fe+3, Cu+2, Zn+2 and Mn+2) Transfer between Soils and Spicery Plants grown in Different Soil Environments

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ABSTRACT

Micronutrients dynamics between the concentration in shale (SH) and coastal plain sand (CPS) derived soils and that of plants were evaluated as indices of uptake of micronutrients by different vegetable plant spices. The transfer coefficient (TC) is the micronutrients concentration in plant tissues aboveground divided by the micronutrient concentration of soil. The micronutrients content in leaves as well as total available content in soil in which those plants were grown were analyzed and measured by AAS. The results showed that, the soils were generally strongly acidic (pH 4.68), with soil textures which were dominated by sandy loam and sandy clay loam. The content of total organic carbon (TOC) at 14.01 g kg-1 and cation exchange capacity (CEC) of 6.64 cmol kg-1 of the soils were low. Total micronutrient content and the coca-cola extractable-fraction in soils were equally low and below the critical values for plant growth. This was in agreement with the amount of micronutrients present in the leaf tissue. Between the soil types, soils of SH had higher percent of Zn transfer coefficients (85.05%), while CPS soils had higher percent of Fe transfer coefficients (94.65 %) in plant tissues. Among the plant species, Cent leaf has the highest percent transfer coefficient (31.10 %), while Turmeric has the lowest percent transfer coefficient (25.75 %). Higher TC values show relatively greater efficiency of plants to absorb metals whereas low percent coefficients reflect the strong sorption of micronutrients to the soil colloids. A strong relationship between the extractable data and the soil-plant transfer coefficients suggests an appropriate dynamics of micronutrients from soils to plants.

Keywords: *Coca-cola extraction, micronutrients, plant species, soil type, transfer coefficient, uptake.*

INTRODUCTION

Iron, copper, zinc and manganese are micronutrients with known essential functions for plants (Zekri and Obreza, 2009). They are, however, readily absorbed by plant roots and translocated to above-ground plant parts (Marschner, 2012). The deficiencies of these nutrient elements in soil can severely impair crops performance and are currently recognized as the most important nutritional problem in the food crop production (WHO, 2004). Deficiencies lead to micronutrients malnutrition or "Hidden Hunger" which have been considered as a massive and growing public health problem among poor people in the developing nations (Welch and Graham, 2004; FAO, IFAD, WFP, 2014). "Hidden hunger" is a form of malnutrition occurring when intake of vitamins and minerals is too low to sustain good health and development in children and maintenance of normal physical and mental functions in adults (FAO, 2013). Micronutrient concentrations are typically known to be higher in the plant leaves than in fruits or storage organs (WHO, 2004; Kabata-Pendias, 2011). The uptake of these nutrient elements by plant increases proportionally to increasing soil micronutrients cations when, the soil contains substantial concentration in soil solution (Chizzola *et al.*, 2003) though can be affected by the presence of major nutrients due to either negative (antagonistic) or positive (synergistic) interactions.

Soil-plant transfer system of essential nutrient cations is a part of the nutrient dynamics of chemical elements in a natural agro-ecological environment (Li *et al.*, 2010; Thompson and Goyne, 2012). The transfer factor (TF) is the ratio of nutrient concentration in the plant to that in the soil and is also, the slope of the proportional line between plant and the soil content of the elements. The transfer factor is an indication of the plant species ability or tendency to absorb a certain element from the soil (Taha *et al*., 2013; Moralejo and Acebal, 2014).

The amounts of exchangeable micronutrients cations in soil can be related to their concentrations in soil solution (Gaya and Ikechukwu, 2016). Previous studies noted that TF ranged between 0.01 and 0.3 for some selected data (Taha *et al*., 2013; Moralejo and Acebal, 2014). Dry matter-based concentration ratios indicate that leafy vegetables have higher concentrations than storage organs or fruits (Li *et al*., 2010). The TF concept suggests that plant micronutrients can be properly predicted from the availability in soil (Chizzola *et al.*, 2003; Thompson and Goyne, 2012).

Approaches have been developed to increase Fe, Mn, Zn and Cu uptake by roots, and transfer to edible plant portions for absorption by humans from plant food sources (Zekri and Obreza, 2009; Yuanmei and Zhang, 2010). However, studies show that TF values vary with soil parent materials (Moralejo and Acebal, 2014). The variability in the nutrients availability across soil types often overrules the variability in crop micronutrients due to difference in soil concentrations yielding insignificant correlations between the metals content in the crop and the soil (Taha *et al*., 2013).

However, soil tests are an alternative way to predict the crop micronutrient concentrations. Various one-step extraction methods are frequently used to assess bioavailability because of their simplicity and ease of operation. Coca-cola solution is, believed to extract potentially mobile portions of Cu, Zn, Mn and Fe content in soil (Schnug *et al.*, 2001). It is often observed that the concentration in soil solution or the micronutrient concentrations in acid extracts of soil (Coca-Cola extracts) is better predictors for crop micronutrients than total soil micronutrients (Schnug *et al.*, 2001; Eteng *et al.*, 2014). This suggests that Cu, Fe, Mn and Zn availability is linked with their mobility. However, sometimes the mobility and plant availability do not always go hand in hand. The plant ability to take up micronutrients from the soil may be evaluated by determining the ratio of the total element concentration in the plant to the total element concentration in soil, and this ratio is called “transfer coefficient” (Moralejo and Acebal, 2014; Gaya and Ikechukwu, 2016).

Vegetable plant spices such as ginger (*Zingiber officinale*), mungbean (*Vigna radiata Wilczek*), garlic (*Allium sativum*), curry (*Murraya koenigii*), cent- leaf (*Ocimum gratissimum*), pepper (*Capsicum annum*) and turmeric (Gaya and Ikechukwu, 2016) are an important source of micronutrients in human’s diet (Moralejo and Acebal, 2014), which are grown everywhere in soils of Southeastern Nigeria. They constitute essential diet components by contributing protein, vitamins, iron, calcium and other nutrients, which are usually in short supply. They also act as buffering agents for acidic substances produced during the digestion process. These crops have great economic importance, especially as spies, aromatic, medicinal plants (Chizzola *et al.*, 2003) and increased awareness of their nutritional and healing characteristics.

These crops need good mineral nutrition for optimum growth and sustainable production (Yuanmei and Zhang, 2010; Marschner, 2012). Nigerians are prone to spicy foods which lends them to the associated results (Chizzola *et al.*, 2003; Gaya and Ikechukwu, 2016). Previously, the levels of Cu, Fe and Zn have been determined in some Nigerian vegetable spices (Iwegbue *et al.*, 2011). The contents of available micronutrients (Cu, Zn, Mn and Fe) together with their uptake by plants were determined together in soils, where the spice plants were grown. The purpose of the study was to evaluate the contents of the micronutrients (Cu, Zn, Mn and Fe) in the plant samples, the Coca-cola-extractable amounts in the soils, and the soil-plant transfer coefficients in these agricultural soils.

MATERIALS AND METHODS

The study area falls within the humid tropical zone of southeastern Nigeria, characterized by tropical wet season from the months of May to October and dry season from the months of November to April. The mean annual rainfall in 2017/2018 was 2650 mm, characterized with an average rainfall of 187.75 mm, distributed in a bimodal pattern, starting appreciably in May with peaks in July and in October. During the first two months of the raining season up to the end of September, the rain comes as violet thunderstorms. The monthly temperatures were high and changed only slightly during each year, being generally highest in the month of February to April. The monthly temperatures ranged from 25 to 33°C with a mean of 27.45° C. Temperature rarely falls below 21°C except during the 'harmattan' weather (December to January). The relative humidity was highest (89.07 %) at the peak of rains (July and October) and lowest (41.79 %) during the dry seasons (January to March) period. The sunshine duration of the experimental area in 2018 was highest in the months of February, April, November and December, with maximum sunshine duration which ranged from 5.08 -5.97 hrs/day. The lowest sun shine duration was recorded in the months of July, August, September and October; with minimum unshine duration which ranged from 2.27 -3.3.48 hrs/day.

Soil and Plant Sample Locations

The soils and plants samples used for the study were collected in October, 2017 from different Institutional Research Farms (Table 1). Six vegetable spices (Table 2) were collected from eight agriculture soil sampling sites from two soil parent materials. Surface soils (0 - 20 cm) representing shale and coastal plain sand derived soils were used for the study. The experimental soils were mainly of Alfisol and Ultisol for shale and coastal plain and are classified as Udic Haplustalfs and Typic Paleudults, respectively.

Table1. *Sample sites and Soil parent materials*

Soil parent materials	Sample sites	Institutional location	Code
Shale derived soils (SH)	Ishiagu	Federal College of Agriculture, Ishiagu	FCA
	Afikpo	Federal Polytechnic, Uwana	Fed Poly
	Bende	Cocoa Research Institute Nigeria	CRIN
	Uturu	Abia State University	ABSU
Coastal plain sands derived soils (CPS)	Amakama	National Cereal Research Institute, Amakama	NCRI
	Umudike 1	National Root Crop Research Institute, Umudike	NRCRI
	Umudike 2	Micheal Okpara University of Agriculture, Uumudike	MOUAU
	Ahiaeke	Federal Soil Science Laboratory, Abia State	FSSL

Table2. *Description of the spices samples analyzed*

Commom name	Scientific name	Spice group	Plant parts sampled
Cent leaf	*Ocimum gratissimum*	Leaf	Leaf
Curry leaf	*Murraya koenigii*	Leaf	Leaf
Garlic	*Allium sativum*	Bulb	Leaf
Ginger	*Zingiber officinale*	Rhizome	Leaf
Pepper	*Capsicum annum*	Fruit	Leaf
Turmeric	*Curcuma longa Linn*	Rhizome	Leaf

Soil Samples Preparation and Analysis

On each sampling site, 8 samples of topsoil (0 - 20 cm) were taken randomly on an area of about 1.0 ha and bulked to form a composite topsoil sample. The soil samples were air-dried at room temperature, ground and screened through a 2 mm stainless steel sieve to obtain a < 2 mm size fraction. Particle size distributions were determined using the hydrometer method (Gee and Bauder, 1986). Soil pH was determined in a 1:2.5 soil: $CaCl_2$ suspension using a glass pH electrode pH meter (Thomas, 1996). Total organic carbon (TOC) was measured by dry combustion using (Nelson and Sommers, 1996). Cation exchange capacity (CEC) of each soil sample was obtained by extracting the samples with 1 mol·L^{-1} NH4OAc at pH 7 (Sumner and Miller, 1996). All the reagents were commercial products of the highest available purity.

Plant Sampling Procedure

For each of the plant spices, four mature plants were selected where the soils samples were collected. Plant samples were collected together with soil samples. In each tagged plant, adult leaves (third and fourth) with a healthy appearance were collected and pooled. No plant presented deficiency symptoms. Leaf samples were separated, carefully rinsed in distilled water, air-dried, cut in small pieces, sieved through a 2 mm sieve and ground to fine powder prior to performing the analysis. A total of three pooled leaf samples were analyzed for each plant species.

Soil and Plant Tissue Analysis and Procedures

The elemental analyses of soils and plants were determined using tri-acid digestion. Total concentrations of Cu, Zn, Mn and Fe in soil samples were determined by the decomposition of 0.5 g sample of finely ground soil (< 2 mm fraction) with tri-acid mixture of HNO_3 (70%) + $HClO_4$ (70%) + H_2SO_4 (48%) at about 200˚C (1:2:1 ratio) (Hossner, 1996). The mixture was swirled gently and digested for fifteen minutes as reported by Shuman (1991)**.** The mixture was allowed to cool and diluted to 50 cm^3, heated gently and the extracts were then filtered through Whatman filter paper (No. 42).

The available content of Cu, Zn, Mn and Fe in soil samples was determined after extraction with Coca-cola. 10.0 g air dried soil samples were weighed and transferred into 100-mL polyethylene bottles, 50 mL genuine Coca Cola® solution, was added at a soil-solution ratio (1:10) and shaking in a horizontal shaker at 150 rpm for 1 h at room temperature. After extraction, soil-Coca-cola suspensions were centrifuged for 15 min at 3500 rpm, and then, filtered through a Whatman filter paper (No. 42) into a 50 ml volumetric flask and made up to the mark with distilled water. The supernatants were used for analysis by quantitative determination by AAS.

Wet digestion is commonly employed for the preparation of samples of vegetable materials (Wieteska *et al.*, 1996). Total concentrations of Cu, Fe, Mn and Zn in plant samples were determined after decomposition by tri-acid mixture of sulphuric acid (H_2SO_4) (70%) + nitric acid (HNO_3) (65%) + perchloric acid ($HClO_4$) (40%), (1:2:1 ratios) in an open system at 200˚C (Wieteska *et al.*, 1996). A blank digestion solution was made for comparison. The Cu, Zn, Mn and Fe contents in soil and leaf samples were determined by atomic absorption spectrophotometer (AAS) in an air-acetylene flame using PG-Model AA-500.

Determination of Transfer Coefficient

Metal concentration in the extracts of soils and plants were calculated on the basis of dry weight. The plant transfer coefficient (TC) was calculated as follows:

$$\mathbf{TC = C_{plant}/C_{Soil} \times 100}$$

Where:

C_{plant} = concentration micronutrient in plants extracts

C_{soil} = concentration micronutrient in soils, respectively

Data Analysis

All data are presented as mean values of triplicate experiments. Statistical analysis of the data was carried out using analysis of variance (ANOVA). Significant means were separated using Fisher's Least Significant Different were appropriate at $P<0.05$ (two-tailed). The statistical analysis was performed using PASW Statistics software, version 18 for Window 10.

Results and Discussions

Physical and Chemical Properties of the Soil Samples used for the Study

Some relevant physical and chemical properties of the studied soils are presented in Table 3. The soil texture of the two soil parent materials ranged from loam to sandy clay loam. In general the soils have low clay content, so they tend to be permeable. The pH values of the soils ranged from 4.23 to5.67 and from 3.68 to 5.11 with mean values of 4.83 and 4.52 for soils of Shale and coastal plain sands, respectively. The pH values suggest that the soils are strongly acidic. The values have no regular trend with location. The soil pH determined in $CaCl_2$ was more acidic in soils of Shale than in soils of Coastal plain sands. The effect of pH value below 6 in increasing metal ion activities in soil can be attributed to the decrease in pH dependent surface charge on oxides of Fe, Al and Mn, chelating by organics of metal hydroxide (Zekri and Obreza, 2009). Total Organic Carbon (TOC) ranged from 8.81-20.54 gkg^{-1} and from 6.56 – 18.65 gkg^{-1} with mean values of 15.24 and 12.78 gkg^{-1} for soils of Shale and coastal plain sands, respectively. The amount of Total Organic Carbon recorded in this study is suggestive of degradation or presence of degradable and compostable materials in the soils. The total organic carbon was higher in Shale than in soils of Coastal plain sands (Table 3). The Cation Exchange Capacity values of the soils ranged from (cmol/kg) 3.67-7.94 $cmolkg^{-1}$ and from 5.53- 9.59 $cmolkg^{-1}$ with mean values of 5.84 and 7.43 $cmolkg^{-1}$ for soils of Shale and coastal plain sands, respectively. Both organic and inorganic colloids possess cation exchange capacity that contributes to the overall cation exchange of the soil. The low values observed in this study may be attributed to the fact that organic colloids may coat inorganic surfaces and hold particles together, making the net cation exchange capacity value lower than what might be predicted if the organic and inorganic contributions were strictly additive (Sillanpaa, 1990; Thompson and Goyne, 2012).

Table3. *Physical and chemical properties of the soil samples from shale and coastal plain sands*

Sample site	Particle size distribution			Texture	Chemical property		
	Sand	Silt	Clay		pH ($CaCl_2$)	TOC gkg^{-1}	CEC $cmolkg^{-1}$
	←	gkg^{-1}	→				
Shale derived soil							
Ishiagu – FCA	562.65	206.55	230.80	Sandy clay loam	4.23	14.16	5.51
Afikpo – Fed Poly	501.28	305.02	193.70	Loam	4.65	17.43	6.22
Bende – CRIN	515.37	292.12	202.51	Sandy loam	4.78	20.54	7.94
Uturu- ABSU	604.92	167.23	227.85	Sandy clay loam	5.67	8.81	3.67
Mean	546.06	242.73	213.22	Sandy clay loam	4.83	15.24	5.84
Coastal plain sand derived soil							
Amakama – NCRI	781.14	113.55	105.31	Sandy loam	5.11	9.43	6.33
Umudike 1– NRCRI	580.15	317.39	102.46	Sandy loam	4.93	16.54	8.28
Umudike 2–MOUAU	657.83	136.05	206.12	Sandy clay loam	3.68	18.65	5.53
Ahiaeke - FSSL	685.35	216.9	97.75	Sandy loam	4.36	6.52	9.59
Mean	676.12	195.97	127.91	Sandy loam	4.52	12.78	7.43

Total Content of the Micronutrients in Soils and Plant Materials from Different Soil Type

Total content of the micronutrients in the surface soils and leaves are given in Table 4. Total concentrations of the metals in leaf and soil samples followed the order: Fe > Mn > Zn > Cu for soils of Shale and Zn > Fe > Mn > Cu for soils of coastal plain sand. The obtained values were similar to those of the chemical composition obtained by Eteng *et al* (2014) from soils of south-eastern, Nigeria and the levels fell within the range found for other agriculture soils of different regions of the world (Moralejo and Acebal, 2014; Gaya and Ikechukwu, 2016), thus the critical values for plant growth were not exceeded (Sillanpaa, 1990; Kabata-Pendias, 2011). The analysis of the plant materials, as well as the soil samples, showed that high concentrations of the micronutrients were resident in the soil, since soils play an important role in the accumulation and availability of essential nutrient elements for plant uptake. General, the chemical composition of the leaves are a reflection of the elemental composition of the growth media. Normally, ranges of trace element concentrations for the mature leaf tissue are generally approximations. In this study, all the microelements (Cu, Zn, Mn and Fe) assessed in the leaf samples were within the maximum permissible limits (WHO, 2004; Maleki, 2008; Zekri and Obreza, 2009). Likewise, the total concentration of the micronutrients in soil was equally within the maximum allowable concentration reported in the literature (Sillanpaa, 1990; Kabata-Pendias, 2011).

Table4. *Total micronutrients in soils and plant samples of shale and coastal plain sands*

Location	Sample	Shale derived soils				Location	Sample	Coastal plain sand derived soil			
		Fe	Cu	Zn	Mn			Fe	Cu	Zn	Mn
Concentration of micronutrients ($mgkg^{-1}$)											
Ishiagu – FCA	Soil	103.38	51.56	78.41	86.21	Amakama – NCRI	Soil	77.36	33.73	73.45	61.24
	Turmeric	11.79	13.31	24.04	8.87		Garlic	47.11	8.86	17.24	30.46
	Curry leaf	12.53	7.63	37.47	10.16		Turmeric	38.87	5.33	15.76	24.13
	Pepper	9.16	5.46	41.11	10.85		Cent leaf	35.79	6.86	32.78	45.75
Afikpo – Fed Poly	Soil	115.19	62.54	61.19	71.03	**Umudike 1 – NRCRI**	Soil	66.92	41.16	82.87	24.09
	Turmeric	11.23	6.41	35.89	8.21		Ginger	47.03	11.73	7.72	13.43
	Ginger	9.66	4.96	38.09	7.05		Pepper	32.27	5.68	21.75	9.58
	Cent leaf	7.26	4.35	44.12	7.26		Curry leaf	36.29	6.46	5.11	6.56
Bende – CRIN	Soil	91.38	73.34	58.57	82.87	**Umudike 2 –MOUAU**	Soil	59.63	61.33	78.05	62.12
	Ginger	7.13	6.46	35.17	7.1 8		Turmeric	31.11	7.76	18.09	17.78
	Garlic	8.18	8.24	28.32	4.23		Cent leaf	29.21	4.86	13.44	11.16
	Curry leaf	9.12	5.44	26.91	9.26		Ginger	33.13	8.64	8.07	7.39

Uturu-ABSU	Soil	84.31	43.11	78.13	99.65	**Ahiaeke - FSSL**	Soil	43.36	43.05	63.45	57.32
	Garlic	6.19	16.16	54.66	5.98		Pepper	31.63	7.55	12.97	13.06
	Cent leaf	16.54	8.76	66.45	11.78		Curry leaf	41.04	8.21	7.77	18.62
	Pepper	6.65	11.16	53.22	6.43		Garlic	33.5	3.03	8.29	9.61

Total and Extractable Contents of Cu, Zn, Mn and Fe in Shale and Coastal Plain Sand Derived Soils

The amounts of Cu, Zn, Mn and Fe extracted using Coca-cola is shown in Table 5. Total contents are also included for easy comparisons. The Coca-cola extracted high percentage of the total micronutrients with values which ranged from 37.07-45.03 $mgkg^{-1}$ for shale soils to 12.74-14.03 $mgkg^{-1}$ for coastal plain sand soils, respectively. The amounts of metals extracted by Coca-cola from Shale soils were in the order as follow: Zn > Mn > Fe >Cu while, the metals extracted from the Coastal plain sand soils were in the order: Fe > Zn > Mn > Cu. The Coca-cola solutions extracted several chemical pools that include plant available form, exchangeable cation, labile and complexed species (Schnug *et al.*, 1996). The single extraction method with Coca-cola solution was validated by good inter-laboratory reproducibility for Cu, Zn, Mn and Fe. Moreover, this technique was readily available, economically practical, and provided quantitative results rapidly (Schnug *et al.*, 2001).

Table5. *Total and extractable contents of Cu, Zn, Mn and Fe in shale and coastal plain sand soils*

Extraction method	Shale derived soil				Extraction method	Coastal plain sand derived soil			
	Fe	Cu	Zn	Mn		Fe	Cu	Zn	Mn
←					($mgkg^{-1}$)				→
	Ishiagu					**Amakama**			
Total	103.38	51.56	78.41	86.21	Total	77.36	33.73	73.45	61.24
Coca-cola	18.06	21.95	56.47	29.83	Coca-cola	56.18	9.44	28.23	21.18
	Afikpo					**Umudike 1**			
Total	115.19	62.54	61.19	71.03	Total	66.92	41.16	82.87	24.09
Coca-cola	25.21	12.75	58.42	16.51	Coca-cola	47.82	13.29	39.57	9.85
	Bende					**Umudike 2**			
Total	91.38	73.34	58.57	82.87	Total	59.63	61.33	78.05	62.12
Coca-cola	23.94	21.76	37.93	21.36	Coca-cola	37.18	16.67	26.45	23.42
	Uturu					**Ahiaeke**			
Total	84.31	43.11	78.13	102.65	Total	43.36	43.05	63.45	57.32
Coca-cola	24.83	12.70	47.44	31.98	Coca-cola	35.76	12.82	23.64	16.89

Amounts of Extractable Cu, Zn, Mn and Fe in Shale and Coastal Plain Sands Derived Soils

The percentage amounts of extractable Fe, Cu, Zn and Mn by Coca-Cola extract are shown in Table 6. In the Shale derived soil, the mean percentage amounts of extractable for Fe, Cu, Zn and Mn were; 23.75, 30.52, 73.24 and 28.69 %, respectively. Whereas, for coastal plain sands derived soil, the percentage averages of extractable for Fe, Cu, Zn and Mn were; 72.23, 28.73, 39.33 and 43.71 %, respectively. The extraction data, evaluated as percentage of Coca-cola extractable Fe, Cu, Zn and Mn (Table 6), allowed assessing the mobility of these microelements for each examined site. Based on the extraction results from the coca-cola extraction method, it can be concluded that Zn was the most mobile and assessable micronutrient of all the studied nutrient elements in shale soils, sampled from Ishiagu, Afikpo, Bende and Uturu. Whereas, Fe was determined to be the most mobile micronutrient of all the studied nutrient elements in coastal plain sand soils, sampled from Amakama, Umudike 1, Umudike 2 and Ahiaeke. Therefore, the calculated soil-plant transfer coefficients could be compared with the extraction data of the single extraction with Coca-cola.

Zinc and iron are essential micronutrients and have very important biological functions in plant growth. Their extraction yield for the single extraction procedure was completely consistent with the soil-plant transfer coefficients obtained for all the examined sites. The increase in the content of available Zn and Fe forms in soil caused their higher concentration in plant leaves, mainly from the respective soils sampled. However, the extraction values for the single Coca-cola extraction procedure were relatively higher compared with the calculated soil-plant coefficients. The lowest extraction values were observed in soils extracted for Cu and Mn which presented rather different properties though, considered as important plant micronutrients. The calculated soil-plant transfer coefficients for individual plants and the extraction yield values were very low. This indicated that the content of phytoavailable Cu and Mn and their soil-plant mobility were very low. Similar results were reported by to the studies of Jolly *et al.* (2013), Taha *et al.*, (2013) and Moralejo and Acebal (2014).

Table6. *Extractable amounts of the micronutrients (Fe, Cu, Zn and Mn)*

Sample location	Coca-Cola-extractable micronutrients (%)			
	Fe	**Cu**	**Zn**	**Mn**
Shale derived soil				
Ishiagu	17.47	42.57	72.02	34.60
Afikpo	21.89	20.39	95.47	23.24
Bende	26.19	29.67	64.76	25.78
Uturu	29.45	29.46	60.72	31.15
Mean	**23.75**	**30.52**	**73.24**	**28.69**
Coastal plain sand derived soil				
Amakama	72.62	27.98	38.43	34.59
Umudike 1	71.46	27.18	47.75	40.89
Umudike 2	62.35	29.98	33.89	69.89
Ahiaeke	82.47	29.78	37.26	29.47
Mean	**72.23**	**28.73**	**39.33**	**43.71**

Soil-Plant Transfer Coefficient (TC)

Table 7 present the soil-plant transfer coefficients (TC) which were calculated as the ratio of the total metal concentration in the plant to the total metal concentration in the corresponding surface soil where the plant had grown in order to establish a relative sequence between Cu, Zn, Mn and Fe mobility in the different sites. The transfer coefficient values obtained indicate the potential of the plants to absorb metal ions from the soil and deploy them to their foliage (Thompson and Goyne, 2012; Taha *et al.*, 2013). Their bioaccessibility through parts of plants, mainly leaves, were significant.

The TC values for Cu, Zn, Mn and Fe for the various vegetables varied greatly between plant species, locations and soil types (Table 7). Table 6 indicates that, in shale derived soils, Zn has higher transfer coefficient for all types of vegetable spices relative to other metals and ranges from 30.66% (*Curcuma longa Linn*) to 85.05% (*Murraya koenigii*) and these were samples from Ishiagu, while in coastal plain sand derived soils, Fe has higher TC values which ranges from 46.26 % (*Ocimum gratissimum*) to 94.65 % (*Murraya koenigii*) and these were sampled from Amakama and Ahiaeke, respectively.

Ginger (*Zingiber sativum*) was found to show a higher TC (25.31 %) among the studied vegetables in shale derived soils, while Cent leaf (*Ocimum gratissimum*) was found to show a higher TC (37.31 %) in coastal plain sand soils. On the whole, Cent leaf *Ocimum gratissimum* showed the highest TC of 31.10 %, while turmeric (*Curcuma longa Linn*) has the lowest TC (25.75 %) among the studied vegetables in all the sites for both soil types.

Soil-plant transfer coefficients (TC) presented in Table 7 allowed assessing the intensity of the plant intake, phyto availability and phytoaccumulation of Cu, Zn, Mn and Fe micronutrients for each examined site which agrees with results reported by Moralejo and Acebal (2014), Gaya and Ikechukwu (2016). This result also showed that with regards to the different soil types, Zn and Fe were respectively the most phytoavailable from all the microelements tested in the study area. These metal species were significantly absorbed and accumulated by the selected plants under study which are under permissible according to Maleki, (2008) and Taha *et al*., (2013).

Higher percentage transfer coefficient (TC) is relatively an indication of poor retention of the micronutrients in soils or greater efficiency of plants to absorb micronutrients whereas, low coefficients reflect the strong sorption of the micronutrients to the soil colloids (Shuman, 1991; Taha *et al*., 2013). The results presented in Table 7 are in agreement with other reports (Kabata-Pendias (2011), Jolly *et al*., (2013), Moralejo and Acebal (2014), Gaya and Ikechukwu (2016**)**. This study is in line with

Taha *et al*., 2013) who pointed out that, the plant ability to uptake micronutrients from soil solutions preferably in exchangeable forms. Accordingly, Nkansah and Opoku (2011) and Jolly *et al.* (2013), observed that this is a convenient device to express the relative ease with which elements in soils are taken up above ground tissues by plants. The TC values as presented on Table 7 affirmed the degree of the micronutrients transfer and accumulation in the plant species (Iwegbue *et al.*, 2011; Nkansah and Opoku (2011); Thompson and Goyne, 2012; Jolly *et al.*, 2013). Comparatively, Zn^{+2} and Fe^{+3} cautions were characterized by the highest soil-plant transfer coefficients (normalized for 100%) in different soils and the highest phytoaccumulation of all the microelements in the study area. The percent transfer coefficient for shale derived soils were the order of Zn > Cu > Fe ≥ Mn while, the percent transfer coefficient of the metals in all the sites under coastal plain sand derived soil were in the trend of Fe > Mn > Zn > Cu. The transfer factor is an indication of the plant species ability (Maleki, 2008; Jolly *et al.*, 2013) or tendency to uptake a certain element from the soil (Moralejo and Acebal, 2014, Gaya and Ikechukwu, 2016).

Table7. *Soil-plant transfer coefficients from soils of different parent materials for selected vegetable spices*

Plant sample	Shale derived soil				Plant sample	Coastal plain sand derived soil			
	Fe	Cu	Zn	Mn		Fe	Cu	Zn	Mn
Micronutrients transfer coefficient (%)									
Ishiagu – FCA					**Amakama – NCRI**				
Turmeric	11.40	25.81	30.66	10.29	Garlic	60.89	26.27	23.47	49.74
Curry leaf	12.12	14.79	85.05	11.78	Turmeric	50.25	15.80	21.46	39.40
Pepper	8.86	10.59	52.43	10.22	Cent leaf	46.26	20.34	44.62	74.71
Afikpo – Fed Poly					**Umudike 1 – NRCRI**				
Turmeric	9.75	10.24	58.65	11.56	Ginger	70.28	28.49	9.32	55.75
Ginger	8.38	7.93	62.24	9.93	Pepper	48.22	13.79	26.25	39.77
Cent leaf	6.30	6.96	72.10	12.58	Curry leaf	54.23	15.69	6.17	27.23
Bende – CRIN					**Umudike 2 – MOUAU**				
Ginger	7.80	37.49	60.05	8.66	Turmeric	52.17	12.65	23.18	28.62
Garlic	8.95	11.23	48.35	5.10	Cent leaf	58.98	19.92	17.22	27.97
Curry leaf	9.98	7.42	45.95	11.17	Ginger	55.56	14.09	10.34	11.89
Uturu- ABSU					**Ahiaeke - FSS**				
Garlic	7.34	8.81	69.96	6.01	Pepper	72.95	17.54	20.44	22.78
Cent leaf	19.62	20.32	47.79	11.82	Curry leaf	94.65	19.07	12.25	32.48
Pepper	7.89	25.89	68.12	6.45	Garlic	77.26	7.04	13.07	16.77

CONCLUSION

This study demonstrated that, soil-plant transfer coefficients allowed for the assessment of nutrients' plant intake, through phyto availability and phytoaccumulation of micronutrients (Fe, Cu, Zn, and Mn) for each experimental site. Amongst the micronutrients Zn^{+2} and Fe^{+3} cautions were characterized by the highest soil-plant transfer coefficients (normalized for 100%) for SH and CPS soils and the highest phytoaccumulation of all the microelements in the study site. In all the experimental sites, the percent transfer coefficient (TC) for the two soils were in the order: Zn > Fe > Mn > Cu with, percent transfer coefficient values: 38.71%, 35.84%, 22.61% and 16.59%, respectively. Therefore, the calculated soil-plant transfer coefficients could be compared with the extraction yield data of the single extraction with Coca-Cola. The transfer factor is an indication of the plant species ability or tendency to uptake a certain element from the soil. Based on the extraction results from the single extraction procedure, it can be concluded that Zn and Fe were the most mobile micronutrient elements in shale and coastal plain sand derived soils. The results of this study can be useful to predict qualitative micronutrient transfer mobility in similar soil-plant systems in different regions of the world.

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