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Investigations on the nutritional status of *Hevea brasiliensis* plantations in the humid forest zone of Cameroon Part 1: Micronutrient status and distribution in soils

Untersuchungen zum Nährstoffstatus von *Hevea brasiliensis*-Plantagen in der Feuchtwald-Zone von Kamerun
Teil 1: Mikronährstoffstatus und -verteilung in Böden

Abstract

Micronutrients are very essential for plant growth. To make statements about the optimum micronutrient supply for *Hevea brasiliensis*, the micronutrient concentrations of selected soils in Cameroon under *Hevea brasiliensis* cultivation were studied. A total of 130 soil samples from plantations were collected and analyzed for their AAAc-EDTA-extractable micronutrient concentrations, pH and soil organic carbon. 62% of the sampled sites were deficient in extractable Zn, 15% in extractable Fe and 10% in extractable Cu. This shows that one main focus should be on a sufficient Zn-nutrition. AAAC-EDTA-extractable concentrations of Mn, Fe, Cu and Zn in the soils varied from 0.3 to 128, 14 to 235, 0.49 to 24 and from 0.3 to 12 mg/kg. Considering their mean values, the order of abundance of the micronutrients was Fe > Mn > Cu > Zn. Simple correlation analysis revealed that the AAAc-EDTA-extractable Cu- and Fe-amounts are significantly and positively correlated with soil organic carbon. There also was a positive correlation between AAAc-EDTA-extractable Cu, Mn and Zn with the pH-value of the soil and between Zn and Cu and Fe.

Key words: Micronutrients, *Hevea brasiliensis*, organic carbon, pH, AAAc-EDTA-extraction, plant nutrition

Zusammenfassung

Mikronährstoffe sind essentiell für das Wachstum von Pflanzen. Um Aussagen über die optimale Mikronährstoffversorgung von *Hevea brasiliensis* treffen zu können, wurden Mikronährstoffkonzentrationen ausgewählter Böden in Kamerun unter *Hevea brasiliensis*-Plantagen untersucht. Insgesamt wurden 130 Bodenproben auf ihre AAAc-EDTA-extrahierbaren Mikronährstoffkonzentrationen, sowie pH-Wert und organische C-Gehalte hin analysiert. 62% der beprobten Standorte wiesen Mängel an extrahierbarem Zn auf, 15% an extrahierbarem Fe und 10% an extrahierbarem Cu. Dies zeigt, dass ein Hauptaugenmerk auf eine ausreichende Zn-Versorgung gerichtet werden sollte. AAAc-EDTA-extrahierbare Konzentrationen an Mn, Fe, Cu und Zn in den Böden variierten zwischen 0,3-128, 14-235, 0,49-24 und 0,3-12 mg/kg. Bezogen auf die mittleren Gehalte war die Reihenfolge der Konzentrationen wie folgt: Fe > Mn > Cu > Zn. Die Korrelationsanalyse zeigte, dass die AAAc- EDTA-extrahierbaren Cu- und Fe-Gehalte signifikant positiv mit den Gehalten an organischem C korrelierten. Darüber hinaus war eine positive Korrelation der AAAc-EDTA-extrahierbaren Cu-, Mn- und Zn-Gehalte mit dem Boden-pH sowie zwischen Zn, Cu und Fe zu beobachten.

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Stichwörter: Mikronährstoffe, *Hevea brasiliensis*, organischer Kohlenstoff, pH, AAAc-EDTA-Extraktion, Pflanzenernährung

Introduction

Micronutrients such as Fe, Mn, Zn and Cu belong to the group of "transition elements" of the periodic table and are usually relatively low in abundance in soils. Nevertheless, they play key roles in the growth and development of crop plants (Mustapha et al., 2010). Micronutrients are involved in various enzymes and other physiologically active molecules. Thus, they are essential for processes such as gene expression, biosynthesis of proteins, nucleic acids, growth substances, chlorophyll and secondary metabolites and for the metabolism of carbohydrates and lipids as well as stress tolerance (Rengel, 2003). Although micronutrients are needed in smaller quantities than macronutrients, a deficient supply will make it impossible to obtain maximum yields, even if the supply of the macronutrients is balanced and high yielding varieties are grown (Yadav, 2011). With the cultivation of high yielding varieties, high amounts of macro- and micronutrients are removed from the soil. The continuous use of mineral N- and P-fertilizers in the intensive cropping system with a reduced application of manures results in the quick depletion of micronutrients from soils (Dhane and Shukla, 1995). Since mineral NPK fertilizers are most commonly used in rubber plantations in Cameroon (Chuba and Gobina, 2007), the soils of these farms are prone to micronutrient deficiencies. Soil reserves of micronutrients are supposed to be sufficient for the complete growth period of the plant, thus, micronutrients are not regularly applied as fertilizers. To understand the inherent capacity of the soil to supply micronutrients to the plants, knowledge of the status of micronutrients and their interrelationship with soil parameters is helpful (Sharma and Chaudhary, 2007). Besides soil characteristics, the land use pattern has also a strong influence on the nutrient level in the soil (Venkastesh et al., 2003). A continuous cultivation of soils under particular land use systems may have an effect on their physic-chemical properties which may in turn influence the amount of extractable micronutrients and their plant availability. So the determination of these properties along with the micronutrients status of a particular land use system is important (Yadav, 2011). Results of a study on the micronutrient status of soils under legume crops in an arid region of western Rajasthan, India indicated that soil pH and organic carbon are the main soil characteristics which control the micronutrient availability (Yadav, 2011). However, the investigation of the distribution of available micronutrients in relation to the soil characteristics in Hissar; Haryana (India), showed that only the organic carbon content was significantly correlated with the distribution of the available amounts of all four micronutrients (Bassirani et al., 2011). To determine whether a soil can supply adequate amounts of available micronutrients for optimal crop production or whether nutrient deficiencies are to be expected soil tests are applied. To date, there is no information available on the micronutrient status of soils under *Hevea* in Cameroon. Therefore the aim of this study was to generate information regarding the AAAc-EDTA-extractable micronutrient status in soils under *Hevea brasiliensis* in Cameroon and to relate these concentrations to the pH-value and organic carbon content of the soils.

Materials and Methods

The study area

95 composite topsoil samples were collected from 11 rubber estates belonging to the Cameroon Development Corporation of Cameroon which lies between latitude 4° 05′- 4° 42′ N and longitude 9° 22′- 9°40′ E. 35 samples were collected from the Société Forestiere Agricole du Cameroon (SAFACAM) rubber estate which lies between latitude 3° 46′- 3°51′ N and longitude 9° 7′- 9°9′E (Fig. 1). The climate of the study site is characterized by temperatures between 25 °C and 28 °C and seasonal rainfall ranging from 700–1250 mm. The choice of the number of samples per estate was conditioned by the field size, and the age of the plantation. The estates and their corresponding number of samples were; Meanja – 8, Malende – 7, Matouke – 9, Kompina – 5,Tombel – 2, Mbonge – 9, Mukonje – 15, Sonne – 12, Misellele – 16, Likomba – 8, Penda Mboko – 4, SAFACAM-Dizangue – 35 samples.

Soil sampling and analysis

Sample collection involved removal of surface organic debris and augering to a depth of 0–15 cm. Each sample consisted of at least 10 sub-samples from the entire sampled area. The collected soil samples were air-dried and then passed through a 2-mm sieve.

The determination of total carbon concentration was done by dry oxidation at 1,200 °C using the vario MAX CNS Element Analyzer. To obtain the organic matter content of the soil, the determined total carbon concentration was multiplied with the conversion factor 1.724. The pH was measured by using a pH-meter with a glass electrode in a suspension of 1:2.5 soil and 0.01 M $CaCl_2$ (DINISO, 2005).

The extractable micronutrient-concentration was determined by inductively coupled plasma optical emission spectrometry (ICP – OES) following the extraction with acidic ammonium acetate – EDTA (Lakanen and Erviö, 1971).

Statistical Analysis

The maximum, minimum and mean values of the soil properties were computed as well as an analysis of variance (ANOVA) to show the variations between estates. The relationship between various soil properties and micronutrients was established by using the simple correlation procedure of the JMP 5 software (SAS, 2002). The coefficients of correlations characterizing the inten-

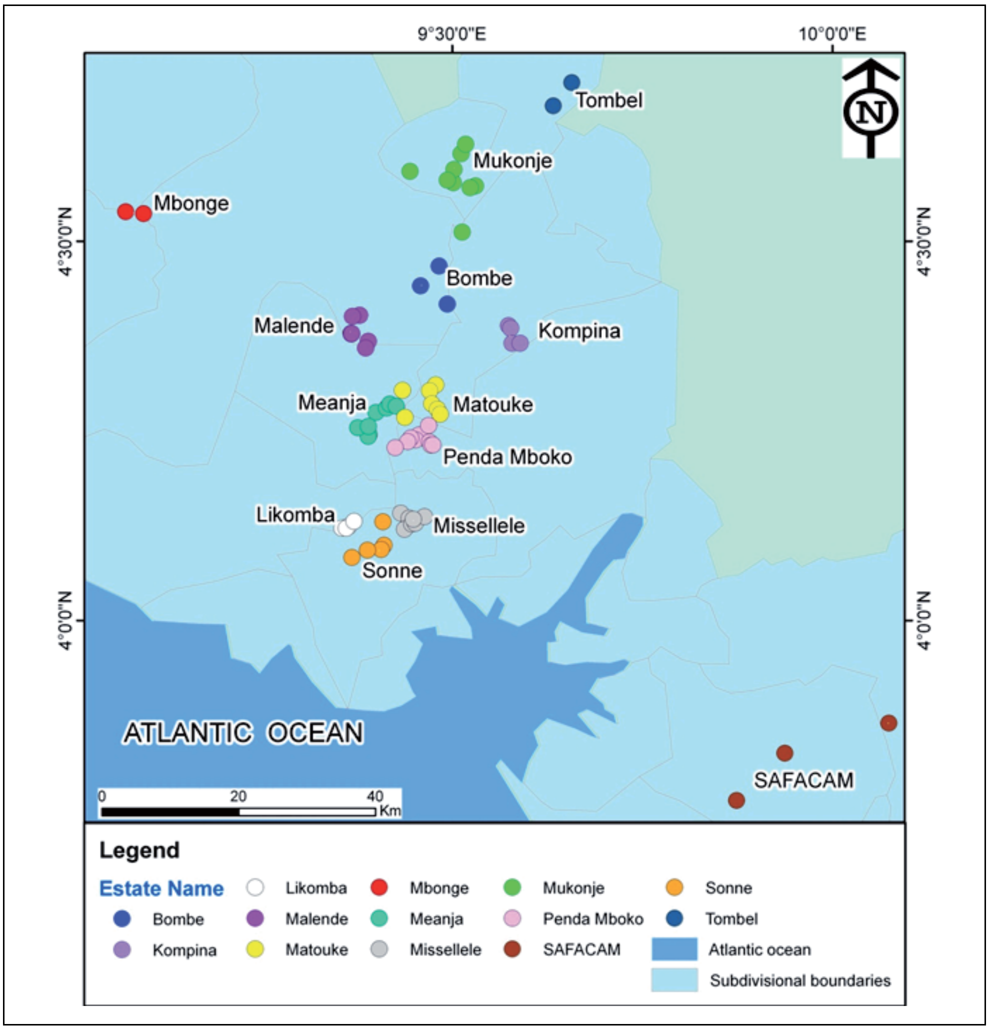

Fig. 1. Map of Cameroon showing the sampled sites.

sity of the linear relationships between all discrete data were performed. These relationships were further analyzed using the principal component analysis technique (Onywere et al., 2000). Principal component bands (PC's) were produced using correlation matrices. The PC's represent linear combinations along orthogonal axes featuring the direction of maximum variance (PC1) where most spread in the scatter plots were observed, while the other axis (PC2) described the variance of the rest of the data.

Results and Discussion

Soil Nutrient Status

The minimum, maximum and mean values of the micronutrient concentrations and soil properties of the samples are presented in Tab. 1. The results show that all the soil sites were acidic in nature (maximum pH < 6) with organic carbon ranging from 0.9 to 14% with a mean of 3%. The Cu content ranged between 0.49 mg/kg and 24 mg/kg with a mean of 2.3 mg/kg. For the interpretation of the results of this study we shall consider that 1 mg/kg = 1 mg/L = 1 ppm. The deficiency limit for AAAc-EDTA extracted Cu according to an international study was 0.8–1 mg/L (Sillanpää, 1982). Following this limit, Cu was relatively available on the investigated sites with just 10% of them being deficient. The mean Zn (1.7 mg/kg) content of the soils in the study area was higher than the 1–1.5 mg/L range which is considered to reflect deficiency when acidic ammonium acetate + EDTA is used for extraction (Sillanpää, 1982). However, considering this limit, 62% of the sampled sites can be characterized as being Zn-deficient. The high percentage of Zn-deficient sites is in accordance with the results of Cakmak (2008) who found out that as regards agriculture, Zn-deficiency is the most widespread soil micronutrient deficiency in the world. Furthermore, the results of this study are also in agreement with previous findings that absolute Zn contents tend to be low in highly weathered acid tropical soils (Gupta, 2005). Shorrocks (1964) observed temporal Zn deficiency in *Hevea* plantations and explained that it was due to P fertilization. As explained by Bolland et al., 1977, Zn deficiency caused by high P is due to the fact that P addition enhances Zn adsorption on Fe and Al oxides, making it less bioavailable. Mn had a mean of 14 mg/kg which shows that the soils were well supplied when the limit of < 2 mg/L for

Tab. 1. Basic statistics of soil properties and micronutrients

Element	Mean	Min	Max	Std Dev
% organic C	3	1	14	1.6
pH	4.3	3.7	5.7	0.5
Cu mg/kg	2.3	0.5	23.7	2.2
Fe mg/kg	61	14	235	32
Mn mg/kg	13.5	0.3	128.3	16.8
Mo mg/kg	0.01	0.0	0.04	0.01
Zn mg/kg	1.7	0.3	12.1	1.5

Min = Minimum, Max = Maximum, Std Dev = standard deviation

Mn-deficiency after extraction with DTPA is considered (SILLANPÄÄ, 1982). Due to the lack of critical values of Mn extracted by AAAc-EDTA, we compared our obtained value to the DTPA value. The mean value of Fe (61 mg/kg) obtained in this study was by far greater than the deficiency range of 30–35 mg/L (SILLANPÄÄ, 1982). This shows that most of the fields were well supplied with Fe. The order of abundance of the micronutrients was Fe > Mn > Cu > Zn, considering their mean values. In nature, Fe is one of the most abundant elements in the earth crust (LANDON, 1984).

Spatial Distribution of Organic Carbon, pH and Micronutrients

Due to the fact that the classification of estates varied with the nutrient in question (Tab. 2), a principal component analysis was carried out to better understand the grouping of estates based on the composition of their soils (Fig. 2). The eventual grouping of estates will help in formulating fertilizer recommendation packages since estates grouped together will be offered similar recommendations. The first two principal components (F1 and F2) accounted for over 83% of the total variation. This shows that those components could be used to analyse the data without loss of substantial information. C org and Cu contributed most (21%) each to F1 while Mo contributed most to F2 (37%). The estates were grouped into three broad groups, with Tombel and SAFACAM being at the extremes. SAFACAM soils are old sedimentary soils while Tombel soils are old volcanic soils. The soils of the rest of the estates were a mixture of sandy, young volcanic and young sedimentary soils (HOF et al., 1985). There was a significant variation in the soil parameters which could be attributed to the variation in the base rock in the areas because changes in soil physiography have a strong influence on micronutrient distribution (VERMA et al., 2005).

The variation of the amount of extractable soil micronutrients on the different sites shows that for effective fertilization, site specific fertilizer recommendations must be carried out. Hence, estates with similar soil properties will receive similar fertilizer recommendations. Site-specific micronutrient application can help to increase yields of *Hevea brasiliensis* by adding those nutrients which were identified as being deficient.

Correlation studies

Simple linear correlation studies of AAAc-EDTA extractable Fe, Cu, Zn and Mn, pH and organic carbon are shown in Tab. 3. All the investigated micronutrients were influenced by the soil environment.

Weak but significant positive correlations were obtained between soil organic matter and the soil cations, Cu (r = 0.3) and Fe (r = 0.2). NAZIF et al. (2006) also found positive correlations between extractable Cu and soil

Tab. 2. Overall soil pH, organic carbon and micronutrients of some estates planted to rubber

Estate	pH		OC (%)		Cu (mg/kg)		Zn (mg/kg)		Mn (mg/kg)		Fe (mg/kg)	
Kompina	3.7	e	3.4	a	1.8	b	1.1	d	14.4	b	26.0	e
Mukonje	4.4	c	2.5	b	2.8	b	1.4	c	15.3	b	59.7	d
Sonne	4.4	c	2.1	b	2.6	b	2.0	b	16.5	b	65.3	b
Mbonge	4.9	b	2.0	b	3.2	b	1.9	c	27.3	a	79.6	b
Tombel	5.4	a	1.7	bc	13.2	a	3.5	a	10.2	c	107.0	a
Dizangue I	3.9	e	1.9	b	1.3	d	0.8	d	2.0	d	78.2	b
Penda Mboko	4.9	b	1.6	bc	2.1	bc	2.2	b	22.9	a	40.7	d
Likomba	4.3	c	1.5	c	2.5	bc	1.9	c	14.9	b	48.9	d
Meanja	5.2	a	1.5	c	2.5	bc	3.9	a	14.2	b	46.0	d
Missellele	4.2	c	1.5	c	2.4	bc	2.6	b	14.6	b	64.9	c
Dizangue II	4.3	c	1.5	c	1.6	d	0.7	d	0.8	d	79.3	b
Matouke	4.0	d	1.0	d	1.3	d	0.	d	27.9	a	31.8	e
Malende	4.2	c	1.0	d	2.1	bc	2.4	b	10.7	c	42.4	d

Mean values of estates followed by the same letters in a column were not significantly different ($P \leq 0.01$)

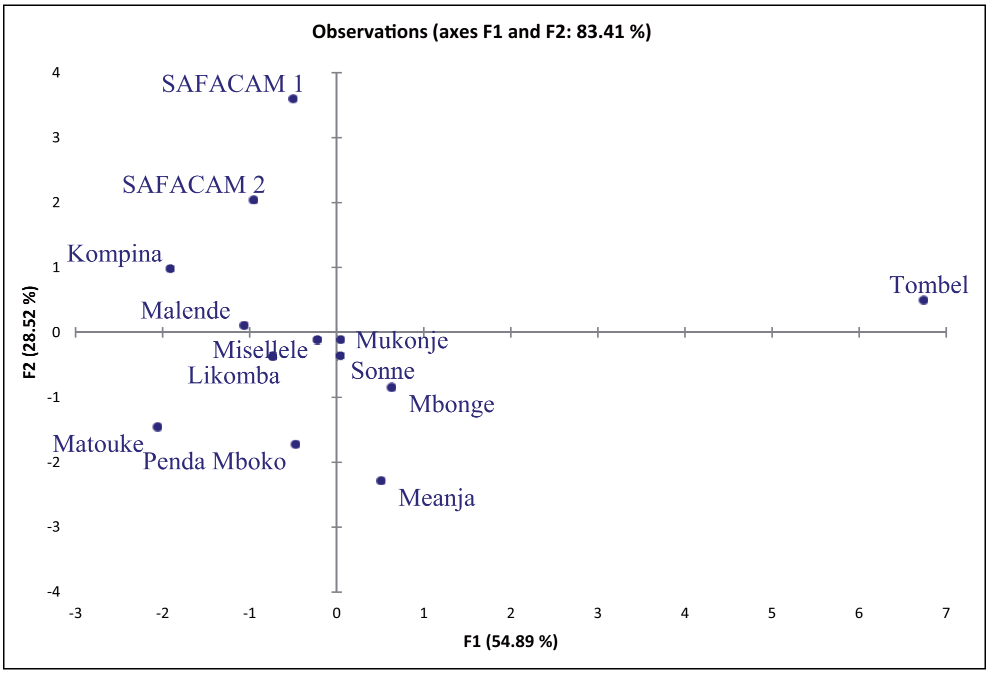

Fig. 2. Spatial distribution of fields sampled following a principal component analysis.

Tab. 3. Correlation coefficients (r) between micronutrients and soil physical and chemical properties

Soil Property	Cu		Fe		Mn		Zn	
	r-value	p-value	r-value	p-value	r-value	p-value	r-value	p-value
Organic carbon	0.306	0.001**	0.178	0.041*	−0.013	0.882	0.079	0.397
pH	0.287	0.001**	−0.038	0.666	0.293	0.001**	0.397	000**
Fe	0.349	0.000**						
Mn	0.018	0.084	−0.153	0.083				
Zn	0.365	0.000**	0.011	0.900	0.128	0.149		

** significant at 1% alpha level

organic matter. The positive correlation between soil Fe and organic matter is similar to what was obtained by VERMA et al. (2005) and is in agreement with LANDON (1984) who said that one of the factors that contribute to Fe deficiency in plants is low soil organic matter. The relationship between organic matter and the soil cations Zn and Mn was respectively positive and negative but non-significant. The positive relationship between Zn and organic matter is similar to what was obtained by VERMA et al. (2005), however, he found highly significant correlations. The positive correlation between soil cations and organic matter shows that the micronutrients become more available with an increase in organic matter content. This might be ascribed to the greater availability of chelating agents generated from organic matter. The organic chelating agents extract micronutrient cations from pools and make them more bioavailable. For instance organic matter improves Fe availability by combining with iron, thereby reducing chemical fixation or precipitation of Fe as ferric hydroxide (KUMAR and BABEL, 2011). These results were similar to the findings of BASSIRANI et al. (2011) who found that soil cations like Zn, Cu and Fe have significant positive correlations with soil organic carbon. However, the tendency towards a negative correlation between soil available Mn and organic carbon observed in this study did not agree with the results of BASSIRANI et al. (2011). A negative correlation may be due to the formation of organic complexes between organic matter and Mn, reducing the bioavailability of this micronutrient. In addition, this finding suggests that some other soil factors like poor aeration decreased Mn^{2+} stability and thus influenced its solubility/bioavailability (LANDON, 1984). Similarly, a negative relationship between soil organic matter and soil Fe were observed by VERMA et al. (2005). The significant correlations between soil organic carbon and extractable micronutrients observed in this study underline the important role of soil organic matter in enhancing the amount of plant available micronutrients in the soil. The presence of both positive and negative correlations indicates that soil organic carbon does not only mobilize micro-elements but immobilizes them as well (JIANG et al., 2009). The increase in EDTA-extractable Cu with increasing soil organic carbon can be attributed to the formation of highly stable Cu-humate complexes (mobilization), which are dissolved to a large degree in soils with higher organic matter level (DI PALMA et al., 2007). In fact the soil organic matter is one of the soils`s major components which chelates and retains micronutrients in soils against leaching and loss (ABDUL and IMTIAZ, 1999).

The soil pH was negatively but non-significantly correlated with Fe content (r = −0.04). A tendency can be observed for extractable Fe, unlike the other micronutrients, to decrease with an increase in soil pH. These results were supported by YADAV (2011) who suggested that the reduced Fe-availability with increasing pH might be attributed to the conversion of Fe^{2+} to Fe^{3+} ions. The ferric ion (Fe^{3+}) compounds have low solubility in solution and so are less bioavailable (LANDON, 1984). On the other hand, weak but significant positive correlations were found between soil pH and the AAAC-EDTA extractable Cu (r = 0.3), Mn (r = 0.3) and Zn (r = 0.4). The positive correlation between extractable Zn, Mn and Cu with soil pH is in agreement with earlier findings stating that Zn, Mn and Cu are more available under acidic conditions (LANDON, 1984). Though their availability in general slowly decreases with increasing pH, no decrease could be observed in this study, because the pH range of the soils was within the acid region. The positive relationship between AAAc-EDTA extractable Cu-content in soils and soil pH is in agreement with the findings of YADAV (2011).

Soil cations Fe, Mn and Zn were positively and significantly correlated to Cu with respective r values of 0.4, 0.2 and 0.4. However, the correlation between Cu and Mn was not significant. A positive and significant correlation between Fe and Cu was also observed by YARO et al. (2002). The interaction between Cu and other micronutrients is in agreement with LANDON (1984) who confirmed that Cu availability is influenced by the presence of other micronutrients. There was a tendency toward a negative relationship between Fe and Mn and a positive one between Fe and Zn, however, these relations were not statistically significant (r = 0.2 and 0.01, respectively). Soil Zn was positively but non-significantly correlated to soil available Mn (r = 0.13).

On the other hand, positive but non-significant correlations were observed between the extractable Mn-content and available Cu and Zn. This is contrary to the observation of BASSIRANI et al. (2011) who found positive and significant correlations between Mn and available Zn as well as available Cu. This difference could be due to the fact that soils for this study were simple surface soils (0–15 cm depth) while those used in the study of BASIRINI et al., were from 10 different profiles. Keeping in mind that soil nutrient status varies with soil depth, there a bound to be such differences.

Conclusion

Except for Zn, most of the soil micronutrient concentrations were within the acceptable limits for crop growth found in literature. However, Zn was deficient in most sites sampled with up to 62% of the sites being deficient. Based on the micronutrients concentrations, pH and organic carbon contents, the estates were distributed into three broad groups which could facilitate fertilizer recommendation. There were significant correlations between micronutrients and soil pH and organic carbon as well as between the micronutrients themselves. The positive significant relationship between Zn and organic carbon indicates that Zn nutrition of the deficient farms could be improved by enhancing the soil organic matter, which will improve the ability of the soils to hold and retain micronutrients on a whole.

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