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The Status of Micronutrient and Sulphur in Some Plantation Crops of Different Ages in an Alfisol in Southern Nigeria

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ABSTRACT

A study was conducted to assess the micronutrient and sulphur status of soils and leaf under old and young cocoa, coffee and cashew plantations at Uhonmora, Edo State, Nigeria. Soil samples were collected from each of the six plantation and the samples were analyzed using standard procedures for sand, silt, clay, pH (H_2O), organic matter, Fe, Cu, Zn, Mn and SO_4 contents while the leaf samples were analyzed for Fe, Cu, Zn, Mn and SO_4 contents. Data was subjected to ANOVA and correlation study. Results showed that the silt + clay values range from 143 - 246 g kg^{-1} soil, which falls below 320 g kg^{-1} soil considered optimal for better water retention for most tree crops. Organic matter content was highest (6.36 g kg^{-1}) in the old cashew plantation and was significantly different ($p \leq 0.05$) from the other plantations. Copper, Fe and SO_4 contents were higher in the soil than in the leaves. Manganese and Zn contents were higher in the leaves than in the soil. The old and young cocoa plantations were similar in Zn, Mn and $S0_4$ contents. Leaf Fe content for the young cashew plants was too low compared to the critical level in the region. However, there were significant differences ($p \leq 0.05$) in micronutrient status between the young and old plantations as this was observed in all the plantations studied. Correlation studies revealed that there was strong relationship between leaf micronutrient and soil micronutrient. In the young cocoa plantation there was correlation between leaf Fe and soil Cu ($r = 0.90$, $p \leq 0.05$), leaf Fe and soil Zn ($r = 0.98$, $p \leq 0.05$). In the old cocoa plantation, there was correlation between leaf Mn and soil Mn ($r = 0.94$, $p \leq 0.05$) ; leaf Mn and soil SO_4 ($r = 0.99$, $p \leq 0.05$). In the young coffee plantation foliar Fe correlated with soil Fe ($r = 0.99$, $p \leq 0.05$); leaf Fe and soil Mn ($r = 0.97$, $p \leq 0.05$). In the old coffee plantation leaf Cu negatively correlated with soil Mn ($r = -0.97$, $p \leq 0.05$); leaf Fe with soil Mn ($r = 0.97$, $p \leq 0.05$). In the young cashew plantation there was correlation between soil Fe and foliar Zn ($r = 1.00$, $p \leq 0.05$); soil Zn and foliar Fe ($r = 1.00$, $p \leq 0.05$) while in the old cashew plantation there was correlation between leaf Fe and soil Cu ($r=0.95$, $p \leq 0.05$); soil Mn correlated with foliar Zn ($r=0.99$, $p \leq 0.05$). Soil SO_4 correlated ($r= 0.94$, $p \leq 0.05$) with foliar Mn.
The old and young cocoa plantations will need Zn, Mn and SO_4 containing fertilizers to meet their requirements for cocoa. It was also detected that there was no severe micronutrients deficiency in the coffee and cashew, when mean values for both soil and leaves samples were taken into consideration.

Keywords: Alfisol,different ages, leaf nutrient content, micronutrient, plantation crops, soil nutrient content, soil fertility management

INTRODUCTION

Micronutrient deficiencies can become one of the major constraints in sustaining crop production in the present day exploitative arable agriculture and even so in plantation crops. It is well known that micronutrients availability are influenced by their distribution in the soil as well as other soil characteristics. Cocoa (*Theobroma cacao*), coffee (*Coffea arabica)* and cashew (*Anacardium occidentale* L.) are crops of economic importance in Nigeria (Famaye *et al*. 2012). Most of the cocoa, coffee and cashew plantations are on small holdings of less than one hectare and are managed by very old men and women on self ownership or as tenant farmers established for than three decades (Adegeye 2000). According to Agricultural Export and Commodity Report (2013) the total area cultivated in Nigeria for cocoa is 1,363,000 hectares, coffee is 54,000 hectares and cashew is 120,000 hectares.

Based on this effort are being geared towards rehabilitation of old, abandoned and moribund cocoa, cashew and cashew farms as well as opening up of new plantations.

Most soils under cocoa, coffee and cashew production in Nigeria are marginal to moderately suitable in fertility status (Egbe *et al*. 1989). Soils under these plantations therefore require good cultural and fertilizer management techniques to achieve optimum crop production on sustainable basis. Due to inadequate quantity of fertilizer supply and the high procurement cost (Agbede and Kalu 1995), most farmers do not use fertilizer (Iremiren 1989) and the farms therefore depend on native soil nutrient supply. Over the years research efforts have indicated that there were short supply of N, P, K and Mg on soils under cocoa, coffee and cashew plantation resulting from nutrient mining from harvests of cocoa pods, coffee berries and cashew apple and nuts, which subsequently resulted in nutrient deficiency symptoms and low yields (Mamani-Pati *et al*. 2012; Ipinmoroti and Ogeh 2014). The soil nutrient factor has therefore been found to be very important in the production of cocoa, coffee and cashew in Nigeria (Ipinmoroti *et al*. 2011; Ipinmoroti and Akanbi 2012). The evaluation of the soil physical suitability and constant monitoring of soil and leaf nutrient status have been advocated, to ensure appropriate farm management and optimal fertilizer usage for profitable arable and tree crop production in Nigeria (Egbe *et al*. 1989).

Nath (2013) observed that the concentration of nutrients element of tea leaf were related with the soil environment and that fresh tea leaf had a mineral content which might vary depending on the earth structure on which it was grown, maintenance and fertilizing. Based on this it also became necessary to investigate the micronutrient status of plantation crops like cocoa, coffee and cashew which are of economic importance in Nigeria. Hence this investigation was conducted to assess the micronutrient status of old and young plots of cocoa, coffee and cashew in Cocoa Research Institute of Nigeria (CRIN) experimental station at Uhonmora, Edo State, Nigeria. The objective of this work was to know the status and availability of micronutrients for sustainable crop production and the relationship between the nutrient content of the soil anf the leaves in cocoa, cashew and coffee.

MATERIALS AND METHODS

Six plots which combined between crops and crops ages were made up of (1) a very old cocoa plot established in 1949, (2) a juvenile cocoa plot established in 2012, (3) old coffee plots established in 1996, (4) a young coffee plot established in 2007, (5) a old cashew plot established in 1971 and (6) a juvenile cashew plot established in 2011 at CRIN Uhonmora Station (6^{O} 53^{I}N and 5^{O} 58^{I}E). Each plot of 1.0 ha were demarcated into 4 sub-plots of 0.25 ha size and soil samples were collected using random sampling technique. Soil samples were collected from 0-30 cm soil depths from each sub plot using soil auger. Leaf samples for each of the crops (Cocoa, coffee and cashew) were collected from the fourth leaf of the branches of the four adjacent trees next to the point of soil sample collections giving a total of 10 leaves per crop.

The soil samples were air dried, sieved through 2 mm sieve and the 10 samples per sub-plot were thoroughly mixed to form a uniform composite sample. Four composite samples were obtained per plot to give a total of 24 composite samples for the 6 plots. The composite samples were analyzed for sand, silt, clay, pH (H_2O), EC, Fe, Cu, Zn, Mn and $SO_4^{=}$ contents. Soil particle size distribution was determined by hydrometer method, while the soil pH was in soil/water ratio of 1:2.5 and read with electronic pH-meter. The electrical conductivity was determined in 1:2 soil/water ratio using conductivity bridge (Rhoades 1982). The soil micronutients – Cu, Zn, Mn, S and Fe were determined after extraction of the soils with 0.1*N* HCl and the filtrate read on a Perkin-Elmer Atomic Absorption Spectrophotometer. Leaf samples were analyzed for Fe, Cu, Zn, Mn and SO_4 contents using IITA (1979) procedure before they were read through AAS Soil and leaf nutrient contents results were compared across the plots with the corresponding soil and leaf nutrient critical values for appropriate nutrient addition needs to the soil and uptake by leaves for continuous optimal and sustainable cocoa, coffee and cashew production.

RESULTS AND DISCUSSION

Soil pH and Particle Size Analysis

The soils of the plantations varied in their sand, silt and clay contents. The soil contents had a sand range of 757-857 g kg^{-1}, silt ranged from 111-191 g kg^{-1} and clay ranged from 32-52 g kg^{-1} (Table 1). The silt + clay values range from 143-246 g kg^{-1} soil, which falls below 320 g kg^{-1} soil considered optimal for better water retention for most tree crops (Egbe *et al*. 1989). This indicated that the soils might not retain and supplied sufficient water to meet the needs of the plantation crops without irrigation, especially over a long period of dry season. Sufficient water supply, most importantly during flower and fruit settings for the crops would be necessary at this critical point. The failure of water supply at such a time would lead to flower and fruit abortions with resultant low fruit yield. The plantation soils could be better managed by making sure that plantation canopies were covered by not allowing missing stands, while the plantation floor was

Table 1. Mean soil pH and some soil physical properties of the plantations.

Soil properties	Cocoa		Coffee		Cashew	
	Young	Old	Young	Old	Young	Old
pH (g kg^{-1})	6.5	6.9	5.8	5.9	6.1	5.1
Sand (g kg^{-1})	827	857	757	837	817	842
Silt (g kg^{-1})	141	111	191	126	141	116
Clay (g kg^{-1})	32	32	52	37	42	42

covered with leaf litter falls to serve as preventive measures against loss of soil water through evaporation (Loria 1999; Ogunlade and Iloyanomon 2009).

Soil Micronutrients and Sulphur Contents

There were significant differences ($p \leq .05$) for soil Fe, Cu, Mn, Zn and SO_4^- at different ages in all the plantations except in the young and old cocoa plantation where there was no significant difference in soil Mn, Zn and SO_4^- and also for soil Mn in young and old coffee plantation as indicated in Table 2. Soil Mn content at the plantations was between 3.90-5.41 mg kg^{-1}. The lowest value was found at young cashew plot and highest one at old cashew plot. Soil Cu content was 0.77-2.14 mg kg^{-1} soil. The least value (0.77 mg kg^{-1}) was obtained for both old coffee and young cashew plantations. This low value which was relatively higher compared to other plantations indicated that great amount of Cu have been exploited from the plantations over the years through berry harvest for the coffee plantation and through previous arable crop harvest for the young cashew plantation. This suggests the need for replenishment of the soils in Cu content to meet requirement of the plantations for Cu in order to checkmate the possibility of nutritional deficiency symptoms on the crops.

Soil Fe contents varied from 30.6-450.6 mg kg^{-1} soil. The values were very low for old cocoa (30.6 mg kg^{-1}) and young cashew (47.6 mg kg^{-1}) and very high for old cashew (450.6 mg kg^{-1}) and young cocoa (427.6 mg kg^{-1}). Except for cocoa plantation, soil Fe level was higher for old plantations compared to young ones. The very low level obtained for young cashew was a result of previous type of land use, while that of old cocoa must have been due to plant removal over the years through harvest of cocoa pods.

Soil Zn content ranged from 15-38.8 mg kg^{-1} (Table3). The coffee plantation had the lowest soil Zn values compared to cocoa and cashew plantations. The values were generally higher at soils of old plantations compared to young plantations. This indicated a built-up in the soil Zn contents with age of the plantations, while it was similar for both old and young cocoa plantations. Soil Mn contents ranged from 3.90-5.41 mg kg^{-1}, while the values were higher at older plantations for coffee and cashew but it was lower at old cocoa plantation compared to young cocoa plot.

Higher content of soil Fe, Cu, Zn and Mn was observed in this study and could be attributed to the chelating of organic compounds released during decomposition of organic matter (Singh *et al.* 1990). Katyal and Vlek (1985) also observed that soil copper availability increased with fineness of soil texture which may also be a likely reason for soil copper availability in this study. There were significant differences ($p \leq .05$) in micronutrient status between the young and old plantations as this was observed in all the plantations studied. There were significant differences ($p \leq .05$) in organic matter content between the plantations. The highest OM content was recorded in old cashew plantation. This may be attributed to influence of age in organic matter accumulation from prunes, plant residues (of the diverse vegetation under the plantation's canopy) crop remains and leaf litter over the years. The crop had certainly grown old, but the impact of the plantation on the fertility of the soil was positive which could contribute to improvement on the soil quality for the tree crop production.

The low values for Cu in old and young coffee plantations contents indicated that the coffee plantations would need application of Cu containing fertilizers to be able to meet coffee crop needs for the nutrients in order to have a sustainable coffee production on the plantations compared to cocoa and cashew plantations with relative built-up of nutrients in the soils with age of the plantations. Adequate level of Zn in the soils indicated that it would not be source of nutritional problem in the plantation. Soil Mn and Zn increased with age across the plantations

Plant Micronutrients and Sulphur Contents

There were significant differences ($p \leq .05$) for Fe, Cu, Mn, Zn and SO_4 at different ages in leaf nutrient content for all plantations except Cu at young

Table 2. Organic matter, sulphur and micronutrient contents of soils in cocoa, cashew and coffee plantation.

Soil Nutrients	Cocoa		Coffee		Cashew	
	Young	Old	Young	Old	Young	Old
Organic Matter (g kg^{-1})	4.8b	2.7c	4.7b	2.3c	1.38d	6.36a
Fe (mg kg^{-1})	407.6b	30.6f	199.9d	291.2c	47.6e	450.6a
Cu (mg kg^{-1})	1.68b	1.99ba	1.61b	0.77c	0.77c	2.14a
Zn (mg kg^{-1})	32.43a	32.43a	15.69c	24.58b	27.20ba	38.18a
Mn (mg kg^{-1})	4.68ba	4.07b	3.94c	4.50ba	3.90c	5.41a
$SO_4^{=}$ (mg kg^{-1})	1753.3b	1753.9b	1570.5c	1780.9b	1869.2ba	1931.3a

Means followed by the same letter in a row are not significantly different from each other by Duncan Multiple Range Test (DMRT) ($p \leq 0.05$).

Table 3. Micronutrients and sulphur contents of leaves in cocoa, cashew and coffee plants.

Leaf Nutrients	Cocoa		Coffee		Cashew	
	Young	Old	Young	Old	Young	Old
Fe (mg kg^{-1})	126.6b	200.3a	117.0b	209.5a	42.6c	132.5b
Cu (mg kg^{-1})	0.92a	0.81a	0.77a	0.08c	0.31b	0.77a
Zn (mg kg^{-1})	324.3ab	303.4ba	235.4b	465.5a	256.3b	162.1c
Mn (mg kg^{-1})	31.6b	42.0a	40.3a	39.4a	33.3b	35.1ba
SO_4 (mg kg^{-1})	489.9ba	388.1b	381.9b	538.2a	505.4ba	524.4ab

Means followed by the same letter in a row are not significantly different from each other by Duncan Multiple Range Test (DMRT) ($p \leq 0.05$).

and old cocoa plantation and Mn at young and old coffee plantation were not significantly different. The leaf nutrient contents varied across the plantations (Table 3). The leaf Fe contents (42.6 mg kg^{-1}) at young cashew plants was the lowest while that at coffee (209.5 mg kg^{-1}) was highest compared to other plantation. The values were higher at older plants compared to younger plants. Plant Fe contents of young cashew plants were too low and need to be applied through foliar application. Plant Cu content (0.08-0.92 mg kg^{-1}) was too low for old coffee plants, while for young coffee plants it was adequate. Plant Zn, Mn and SO_4 values of 162.1-465.7, 31.6-42.0 and 381.9 - 538.2 mg kg^{-1} respectively were high enough to meet nutrient requirements of each of the crops and there would be no need for their fertilizer application.

The adequate levels of soil Mn and Zn were reflected at high plant nutrient content.

Correlation between leaf micronutrients and soil parameters at young and old cocoa, coffee and cashew plantations:

***Young Cocoa plantations*:**

At young (1 years old) cocoa plantation, there was a correlation between leaf Fe, Cu, Zn, Mn and SO_4 and soil sand fraction ($r = 0.99$, $p \leq 0.05$), leaf Fe and soil Cu ($r = 0.90$, $p \leq 0.05$), leaf Fe and soil Zn ($r = 0.98$, $p \leq 0.05$), leaf Cu and soil sand fraction ($r = 0.90$, $p \leq 0.05$).

There was also a correlation between soil Fe and soil Zn ($r = 0.90$, $p \leq 0.05$), soil Fe and soil Mn ($r = 0.97$, $p \leq 0.05$), soil Fe and soil SO_4 ($r = 0.94$, $p \leq 0.05$), soil Zn with soil Mn ($r = 0.99$, $p \leq 0.05$)

Old Cocoa plantation:

At old cocoa plantation (46 years old), there was a correlation between leaf Mn and soil Mn ($r = 0.94$, $p \leq 0.05$), leaf Mn and soil SO_4 ($r = 0.99$, $p \leq 0.05$), leaf Fe with soil SO_4 ($r = 0.97$, $p \leq 0.05$), leaf Cu and soil SO_4 ($r = 0.99$, $p \leq 0.05$)

There was a correlation between soil OM with soil Cu ($r = 0.98$, $p \leq 0.05$); soil clay fraction with soil Zn ($r = 0.99$, $p \leq 0.05$); soil Mn and soil SO_4 ($r = 0.95$, $p \leq 0.05$)

Young coffee plantations:

At young coffee plantation (5 years old), there was a correlation between leaf Fe and soil Fe ($r = 0.99$, $p \leq 0.05$), leaf Fe and soil Mn ($r = 0.97$, $p \leq 0.05$).

There was also a correlation between soil Fe and soil Mn ($r = 0.97$, $p \leq 0.05$), soil Cu and soil Zn ($r = 0.97$, $p \leq 0.05$)

Old coffee plantations:

At old coffee plantation (20 years old), leaf Cu negatively correlated with soil Mn ($r = -0.97$, $p \leq 0.05$) leaf Fe with soil Mn ($r = 0.97$, $p \leq 0.05$).

There was also a correlation between soil Fe and soil Mn (r = 0.97, $p \leq 0.05$).

Young and Old cashew plantation:

At young cashew plantation (2 years old), there was a significant correlation between soil Fe and leaf Zn (r = 1.00, $p \leq 0.05$), soil Zn with leaf Fe (r = 1.00, $p \leq 0.05$), Soil Mn (r=1.00, $p \leq 0.05$) and leaf SO_4, soil Fe and soil SO_4 (r=0.99, $p \leq 0.05$)

Old cashew plantation:

However, at old cashew plantation (45 year old), there was a correlation between leaf Fe and soil Cu (r=0.95, $p \leq 0.05$), soil Mn and leaf Zn (r=0.99, $p \leq 0.05$), soil SO_4 and leaf Mn (r= 0.94, $p \leq 0.05$), soil Fe and soil SO_4 (r=0.93, $p \leq 0.05$), soil Fe and soil Zn (r=0.93, $p \leq 0.05$), soil Fe and soil Mn (r=0.94, $p \leq 0.05$).

Furthermore, observation revealed that soil OM influenced the concentration of micronutrients of soil Mn, Fe, Cu and Zn content. The soil samples showing high levels of micronutrient concentration had high OM content. The micronutrient uptake by plants decreased as soil pH value increased. The acidic soil pH caused harmful effect to living beings through food chain. Soil pH and high total OM content had a higher retention capacity of micronutrient metal in soil. The maximum permissible limits of micronutrients in soils were 2 to 250 mg kg^{-1} for copper and 10 to 300 mg kg^{-1} for zinc respectively (Kabata-Pendias and Pendias, 1984; Alloway, 1990). Many studies indicated that the accumulation of micronutrients in soil had an adverse effect on growth and development of wide variety of plant species. Low quantity of some micronutrient such as copper and zinc are necessary for proper functioning of most plant system. Higher concentrations of copper and zinc have been found to be responsible for metabolic disturbance and growth inhibition of some plants. These trace elements play an essential biological role in plant and human metabolism. Copper and Zinc are considered as good source of protein (Nwajei *et al*. 2012).

Micronutrients are naturally present in soils as natural components. The presence of micronutrient in the environment has accelerated due to human activities. Zinc concentration above 500 kg^{-1} reduced the ability of soil to absorb Fe and Mn (Rejula and Dhinakaran 2012). Soil forms a repository micronutrient element because soil particles such as clay and humus have charges that help the metal cations to bind themselves with the soil, and thus prevent their release, though temporarily. The soluble forms of micronutrient are more dangerous because they are readily available to plants and animals (Prasanth *et al.* 2013). Also, there was positive correlation between OM contents and micronutrient elements and between leaf micronutrient and soil micronutrient as indicated above.

CONCLUSIONS

There were great differences in soil and leaf nutrient contents between old and young plantations of cocoa, coffee and cashew. The young cocoa plantation was found to contain more nutrient and better chemical properties when compared to old cocoa plantation. It was observed that continuous cocoa cultivation lead to nutrient depletion in soils due to crop removal and damage to soil. In the case of cashew, it was unveiled that the growing of tree crops helped in soil fertility conservation and ecosystem sustainability and as the age of cashew plantations increases, there was a subsequent improvement in the soil fertility (nutrient recycling through uptake of nutrient from deep weatherable mineral zone and litter fall), soil quality (especially soil texture, particle aggregation, infiltration and aeration) and sustainability. Since the economic life of planting, these plantation crops studied were 30-40 years, increase in age of the crop may become uneconomical as yield begins to drop from the maximum yield age ranged of 10-15 years. thus, it is recommended that the old trees shall be replaced. When this is embarked on, there will be a great return of nutrient to the soil from the remains and residues of the trees plus other benefits of protection and soil microbial proliferation.

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