An evaluation of some selected inherent chemical characteristics of soils supporting the growth and yield of cocoa for fertility improvement in Ghana

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***Abstract*- For cocoa production in Ghana to be competitive and sustainable, there is the need to move away from general to agro ecology soil specific type fertiliser recommendations that take into account the initial soil fertility status and actual nutrient requirements of soils supporting the growth of cocoa. A soil fertility evaluation was conducted between 2012 and 2014 in four major cocoa growing regions of Ghana namely, Ashanti, Brong Ahafo, Eastern and Western. Ninety-six cocoa farms made up of 24 farms from each region were surveyed. Composite surface soils (0-15 cm) were sampled and analysed for selected chemical properties. The major soil groups identified were Acrisols, Lixisols, Luvisols, Fluvisols, Alisols and Ferrasols with the Acrisols accounting for over 70%. The results of soil chemical analyses indicated that most of the cocoa soils have low inherent fertility characterized by low organic carbon content. The soils generally are acidic, and soils in the Western region, had the most acidic reaction. The results suggest there is the need for an integrated soil fertility management approach to support sustainable cocoa production in Ghana. Use of soil neutralizer in the acidic soils especially those found in the Western region is recommended.**

***Keywords*: soil fertility; integrated soil fertility management; soil group; cocoa.**

1. INTRODUCTION:

Cocoa production represents a mainstay of the Ghanaian economy. The cocoa industry accounts for 8% of the gross domestic product (GDP) and employment of some 800,000 farming households [1]. Records indicate that Ghana's cocoa production has seen a steady increase in the last decades [2] from 350,000 tonnes in 1998 to 900,000 tonnes in 2014 [3; 4]. However, the average productivity of 400 kg ha-1 remains low compared to yields of 500-600 kg ha-1 in Côte d'Ivoire [3] and compared to experimental yields as high as 3000 kg ha-1 [5]. The low yields recorded by Ghanaian cocoa farmers are attributed in part to agronomic and socio-economic issues. The agronomic and technical challenges include soil fertility decline resulting from long periods of cultivation of the same land [6; 2; 7]. Soil fertility plays a key role in cocoa production, and there is the need to evaluate the nutrient status of soils cropped to cocoa by way of periodic or routine soil analysis to ascertain their nutritional levels.

Most soils under cocoa plantations in Ghana have been identified as being moderately to marginally suitable [8; 9]. Soils under these plantations therefore require an integrated soil fertility management strategy to achieve optimum crop production on a sustainable and competitive basis. Over the years research efforts have shown that there was short supply of phosphorus, calcium and magnesium on soils under cocoa plantation resulting from nutrient mining through harvesting of cocoa pods, which subsequently leads to nutrient deficiency and low cocoa bean yields [10; 11; 12].

Replacement of soil nutrients that are being mined through cocoa pod harvest annually needs to be done via application of fertiliser [13]. However, most of the smallholder cocoa farmers are constrained in their ability to use fertiliser [14]. Furthermore, the current fertiliser recommendation of 375 kg ha-1yr-1 for matured cocoa (> 3 years) does not take into account the soil fertility status and the varying nutrient removal capacity of the different cocoa farms and therefore does not support sustainable cocoa production [6]. In plantations that have good inherent soil fertility status through nutrient recycling, the general fertiliser recommendation may result in luxury of nutrient use while insufficient supply of nutrients may occur in plantations with little or no litter to recycle plant nutrients [15]. One key strategy towards enhancing productivity on the small holder cocoa farms would be to revise the current general fertiliser recommendation for all cocoa farms that have been cropped for more than three years. This strategy will ensure judicious use of farm input resources to optimize higher cocoa bean yields. The evaluation of soil nutrient status have been advocated, to ensure site specific or agro-ecology type fertiliser recommendation for sustainable and competitive cocoa production in Ghana [16; 17; 13]. The objective of this soil fertility evaluation therefore, was to determine variations in nutrients status of the cocoa farms for effective and efficient nutrient management strategies for competitive and sustainable cocoa production in Ghana.

2. MATERIALS AND METHODS

2.1. Study area and site selection

The soil survey was conducted in the high rainforest and semi deciduous forest agro-ecological zones of Ghana in farms which were used for the Mapping Cocoa Productivity programme. These areas have the bimodal rainfall regime with mean annual rainfall of 1500 mm in the semi deciduous forest zone and over 2000 mm in the high rain forest zone. Sites for soil sampling were selected in four administrative cocoa regions of Ghana; Ashanti, Brong Ahafo, Eastern and Western (24 farms per region). Selection of farms was purposeful to ensure that a range of farming practices were included in the survey. To achieve this, farms were selected for soil sampling that were either signed up, or not, to particular intervention schemes (where farmers receive advice on good agricultural practice).

2.2. Soil sampling and analyses

The sampling points were recorded using a GPS device (Ashtec Mobile Mapper 100, Spectra Precision, USA). In each farm, 5 to 10 soil cores were dug at 0-15 cm depth with the aid of an earth chisel. The soils were bulked, mixed thoroughly in a plastic bucket and then sub samples of about 500 g were taken. The soils were bagged, labeled and sent to the laboratory for analyses. They were air-dried, ground and sieved through a 2 mm mesh sieve and stored for chemical analyses. The soil samples were analyzed for pH, organic carbon, total N, available P, exchangeable K and Mg. Soil pH was in soil: water ratio of 1:2.5 and read with Metler Toledo electronic pH-meter. Soil organic carbon was determined by the procedure of Walkley and Black wet oxidation using chromic acid digestion [18]. Soil total N was determined by micro-Kjeldahl method [19] and available P was by Troug method [20]. The exchangeable bases were extracted by 1N ammonium acetate solution at pH 7 and the K and Mg contents were read using atomic absorption spectrophotometer [21].

2.3. Statistical analysis, One-way Analysis of variance (ANOVA) was used to test for the significant differences and similarities between the soil chemical properties from the different regions, soil type, shade level (farms with > 5% light interception are described as shaded) and parent material. Significant means obtained were separated by least significant differences (LSD) at $\alpha = 0.05$. Pearson correlation analysis was also carried out to establish the degree of relationship between the soil chemical characteristics measured.

3. RESULTS

3.1 Major soil groups identified

The major soil groups identified from the soil survey were Acrisols, Lixisols, Luvisols, Fluvisols, Alisols and Ferrasols with the Acrisols accounting for over 70%.

3.2 Soil pH and organic carbon

The soil pH in water varied from acidic (5.4) in the Western region to slightly acid (6.2) in the Brong Ahafo region. Considering the two dominant cocoa soil groups identified, Lixisols had the less acidic soil (6.05) whereas the Acrisols exhibited the lowest soil pH (5.67). Mean soil organic carbon value was significantly higher in the Western region with Ashanti and Brong Ahafo regions the lowest. There was no significant ($p>0.05$) soil group trend with regard to soil organic carbon. However, Lixisols had the highest organic carbon content (1.52 %). With respect to the parent materials, the Birimian type had higher soil organic carbon.

3.3 Soil N and P levels

Soil total nitrogen was not significantly ($p>0.05$) influenced by soil type, parent material or shade. Within the two dominant soil groups, Lixisols recorded the highest value for phosphorus (24.90 mg kg-1) with the Acrisols the lowest (15.34 mg kg-1). There was a significant ($p<0.05$) effect of parent material on soil available phosphorus content. Dahomeyan soils had highest phosphorous content while Birimian soils the lowest (Table 1).

1. Table 1: Selected soil properties of parent materials and soil groups (0-15 cm)

	pH	OC (%)	N (%)	P (mg kg^{-1})	K (cmol kg^{-1})	Mg (cmol kg^{-1})
Parent material						
Birimian	5.50	1.50	0.14	15.91	0.36	1.17
Dahomeyan	5.97	1.48	0.15	19.20	0.34	1.81
S.E.D	*0.13*	*0.09*	*0.01*	*2.24*	*0.02*	*0.21*
Soil group						
Acrisols	5.67	1.46	0.14	15.34	0.35	1.18
Lixisols	6.05	1.52	0.14	24.90	0.33	2.50
S.E.D	*0.19*	*0.11*	*0.01*	*3.37*	*0.03*	*0.23*

Shade level did not significantly ($p>0.05$) influence available phosphorus (Table 2). Mean values of available phosphorus under unshaded farms was higher (19.51 mg kg-1) compared with shaded farms (16.28 mg kg^{-1}).

3.4 Exchangeable bases

Exchangeable potassium was not significantly influenced by soil type, parent material, shade or region. Regional analysis showed significant differences ($p<0.05$) in exchangeable magnesium with Brong Ahafo region recording the highest value (2.17 cmol kg-1) and Ashanti region the lowest (0.34 cmol kg-1). With respect to the parent materials, the Dahomeyan soils had higher exchangeable magnesium content compared to the Birimian soils (Table 1). Within the soil groups, Lixisols had higher magnesium content than the Acrisols (Table 1). Shade did not influence exchangeable magnesium content (Table 2).

Table 2: Effect of shade on selected soil properties of top 0-15 cm depth

	pH	OC (%)	N (%)	P (mg kg^{-1})	K (cmol kg^{-1})	Mg (cmol kg^{-1})
Shade level						
Unshaded	5.72	1.44	0.14	19.51	0.35	1.59
Shaded	5.81	1.53	0.15	16.28	0.34	1.48
S.E.D	*0.12*	*0.10*	*0.01*	*2.28*	*0.03*	*0.49*

3.6 Relationship between the measured soil characteristics

The correlation analyses showed a positive relationship between the majorities of the soil parameters measured (Table 3). The highest correlation coefficient was observed between soil organic carbon and total nitrogen.

2. Table 3: Pearson's correlation matrix describing the relationship between the measured soil properties in the cocoa regions in Ghana

	OC	pH	N	P	K	Mg
OC	-					
pH	0.22**	-				
N	0.57**	0.29*	-			
P	0.31*	0.33**	0.22*	-		
K	0.33**	0.39**	0.27*	0.36**	-	
Mg	0.26**	0.30*	0.15	0.41*	0.21*	-

3.7 Correcting soil acidity and fertiliser needs

Majority of the farms surveyed had pH values below the critical level required for good growth and yield of cocoa. Soils in Western exhibited more acidic condition compared to other regions (Table 4).

Table 4: Lime requirement for some selected cocoa farms across the regions

Region	Locality	pH	ΔpH (6.0- pH)	Suggested application rate (kg ha^{-1})
Ashanti	Manso Dominase	4.88	1.1	880
	Kwakorom	4.71	1.3	1040
Brong Ahafo	Sekyerekrom	5.34	0.7	560
	Ampenkro	5.63	0.4	320
Eastern	Adiembra	5.48	0.5	400
	Akotikrom	4.63	1.4	1120
Western	Wasa Manso	4.30	1.7	1360
	Amaningkrom	4.54	1.5	1200

Soil testing evaluates the availability of nutrients in the soil and classify the soil as very low (VL), low (L), medium (M), high (H) or very high (VH). A field classified as very low in a nutrient will give a yield response to applied fertiliser 80 to 100 percent of the time. A field classified as low will respond to applied fertiliser 40 – 60 percent of time, a medium testing will respond to applied fertiliser occasionally (Table 5).

Table 5: Selected soil chemical properties for some selected cocoa farms across the regions

Region	Locality	OC (%)	N (%)	P (mg kg $^{-1}$)	K	Mg
					cmol kg^{-1}	
Ashanti	Manso Dominase	1.33 (L)	0.14 (H)	12.11 (M)	0.29 (H)	0.04 (VL)
	Kwakorom	1.53 (M)	0.15 (H)	7.56 (L)	0.31 (H)	0.04 (VL)
Brong Ahafo	Sekyerekrom	0.94 (VL)	0.09 (M)	7.45 (L)	0.24 (M)	0.98 (L)
	Ampenkro	0.98 (VL)	0.08 (L)	9.27 (L)	0.35 (H)	1.26 (M)
Eastern	Adiembra	1.52 (M)	0.17 (H)	13.68 (M)	0.36 (H)	1.47 (H)
	Akotikrom	1.58 (M)	0.10 (M)	13.21(M)	0.29 (H)	1.15 (M)
Western	Wasa Manso	1.69 (M)	0.17 (H)	14.40 (M)	0.30 (H)	1.07 (M)
	Amaningkrom	2.05 (M)	0.20 (H)	13.15 (M)	0.30 (H)	0.65 (L)

VL = Very Low; L = Low; M = Medium and H = High

4 DISCUSSION

4.1 Major soil groups identified

The soil surveyed revealed that majority of the soils were Acrisols. This observation is consistent with the work done by [13] who also identified over 70% soil in the cocoa growing regions of Ghana to be Acrisols. The Acrisols have low-activity clays, low base status with poor nutrients status [22]. This is likely to be a factor in the low yields recorded by many cocoa smaller holders who often do not apply fertilisers or sufficient quantities of fertilisers on their farms.

4.2 Soil pH and organic carbon

A larger proportion of farms in the Western region had soils with a pH below the lower threshold considered optimal for cocoa (38% below the threshold of 5.1 proposed by [16] and 63% below the threshold of 5.6 proposed by [23]. Shaded cocoa tended to have slightly higher pH values compared to the unshaded farms. This could be attributable to the protection of the soil from erosion by the layer of partly decomposed cocoa leaf materials as well as those of the shade trees on the soil surface [24]. These results suggest that soil acidity might be an issue that needs remediation, especially in the Western cocoa region of Ghana. The higher soil organic carbon content under shaded farms could be explained by the fact that shade trees might have added litter to the soil through litter fall and decomposition. Nevertheless, it should be noted generally that the levels of shade were low on the farms in the survey [25] and so this might account for the small difference in organic carbon between shaded and non-shaded farms. On a large proportion of farms, the concentration of soil organic carbon was below the lower threshold of 1.7% proposed by [16]. Amongst other factors, maintenance of soil organic carbon is important in improving the water retention capacity of soils, a factor that may become more important with more variable rainfall patterns associated with climate change. Benefits of soil organic carbon also include higher plant available nutrients, cation exchange capacity, lower bulk density and pH stabilization [26].

4.3 Soil N and P levels

Nitrogen concentration on the majority of farms was within the range proposed by [16]. Nevertheless, since a crop harvest of 1 tonne leads to a loss of over 45 kg N ha-1 [10], it is important that proper management techniques are adopted to avoid nitrogen limitation in the long run which might result due to harvest of pods from cocoa. [23] stated that available phosphorus contents of 20 mg kg-1 or more in the top soil is adequate for cocoa, whilst [16] proposed a lower threshold of 12 mg kg-1. The available P contents observed in Acrisols were low. Under very strong soil acidity serious fixation is expected, and partly explains the situation regarding available phosphorus on some of the farms surveyed. Similar low levels of available phosphorous have been reported for soils under cocoa cultivation in Nigeria [27]. However, the application of recommended phosphate fertilisers and the adoption of good soil fertility management practices can help increase the available phosphorus levels thereby making them more adequate for cocoa production.

4.4 Exchangeable bases

The Exchangeable potassium values recorded were above the 0.20 cmol kg-1 critical soil potassium value considered adequate for cocoa [16]. According to [23], cocoa growing soils are well buffered against potassium depletion. Therefore, the lack of difference in the exchangeable potassium content of soils between soil types could be due to the ability of the soil to replenish the lost potassium through cropping. The magnesium levels under Birimian parent material and Acrisols soil type were low, and suggest the need for additional magnesium fertiliser application in order to achieve optimal crop nutrition and growth.

4.5 Relationship between the measured soil characteristics

The correlation analyses showed a positive relationship between the majorities of the soil parameters measured (Table 3). This implies that deficiency or over supply of one nutrient element might affect the availability of the other. Soil organic carbon showed a strong positive relationship with total nitrogen with a positive correlation coefficient and relatively higher coefficient of determination. The reason for this relationship is that nitrogen is part of organic matter. The mineralization of organic matter releases nutrients such as nitrogen, phosphorus and sulphur [28].

4.6 Correcting soil acidity and fertiliser needs

Using a target soil pH of 6 and application rate of 80 kg ha^{-1} of soil neutralizer (95%CaCO3+3.5%MgCO3), for a 0.1 increase in pH, it was realized that application rate of 320-1360 kg ha^{-1} would be needed to correct soil acidity in some of the farms surveyed (Table 4). The application of lime in order to reduce soil acidity and precipitate exchangeable aluminium has been reported as an effective solution to decrease the effect of aluminium toxicity on the availability of phosphorus in acidic soils [29]. Over 80% of inorganic phosphorus fertilisers applied in acidic soils become unavailable to the plants during the year due to the adsorption and precipitation of P with Fe, Al and Ca in the soil [30]. Based on the soil test results of the selected farms, a fertiliser formulation; at NPK 6-30-12+4CaO+3MgO at 375 kg ha^{-1} could be adopted for farms 2, 3 and 4. This should be applied together with at least 500 kg ha^{-1} soil neutralizer should. For the rest of the farms, NPK 5-16-15+16CaO+3MgO together with at least 250 kg ha^{-1} soil neutralizer should be applied.

5 CONCLUSION AND RECOMMENDATIONS

Continuous cropping on the same piece of land over a long period depletes the soil of its nutrients. The need to apply fertilisers to restore soil fertility in cocoa cultivation is undeniable. However, the various fertiliser formulations currently being used by cocoa farmers are blanket in nature. They do not take into consideration the initial inherent fertility status of the soil where they are applied. This suggests the need for balanced and agro-ecology type or soil specific fertilizer formulation for sustainable and competitive cocoa production. However, quantitative data for agro-ecology or soil specific type fertiliser recommendation specifically for cocoa in Ghana do not exist. The soil fertility evaluation study suggests that most of the soils in the cocoa regions have low fertility indices and would need adequate management for sustainable cocoa production. Soils in Western region are the most acidic, and this may affect the availability of nutrients for crop uptake. Therefore, they deserve special management geared towards replenishment of base cations status of soils. Soil organic carbon content is low and may impact on properties important to cocoa productivity, especially soil physical properties such as bulk density, soil structure, nutrient retention and porosity. Application of organic manure and inorganic fertilisers in an integrated nutrient management approach will improve soil fertility and productivity for sustainable and competitive cocoa production in Ghana. Use of soil neutralizer, and cocoa pod husk ash in acidic soils especially those found in the Western region, are recommended.

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