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Assessment of soil fertility status of cocoa farms around the Ankasa National Park in the Jomoro District of the Western Region of Ghana

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Abstract

The Western Region currently produces over 50 per cent of Ghana's cocoa. Information on the fertility status of soils within the cocoa growing region and possible fertilizer recommendations do not exist. Since cocoa yield is generally related to the fertility status of the soil, a study was conducted to evaluate the fertility status of soils supporting growth of cocoa around the Ankasa National Park area in the Western Region. The soils were sampled at two depths, 0 - 15 cm and 15 - 30 cm on 40 different cocoa farms and analysed for selected fertility characteristics. Analyses of the top soil showed a mean soil pH of 4.91±0.06 which is considered to be moderately acidic. This range is outside the optimum range required for sustainable and competitive cocoa production. Mechanical analyses of the soil indicate very high percentage of sand around 70 per cent, clay mineral of 20 per cent and 10 percent silt which enhances percolation and leaching of basal cations. Exchangeable Ca and Mg were therefore generally below threshold. Organic carbon status of the soils averagely ranged between 0.78-2.68 % with a mean of 1.53±0.07 which was low. Mean available phosphorus, 11.31±0.5 $mgkg^{-1}$ was below the optimum and phosphorus is the most limiting nutrient that will affect cocoa yield. In general, nutrient levels were higher in the top soils than the sub soils. The evaluation showed that the soils suffer from multi-nutrient deficiency. It is concluded that nutrient levels of the soils are low to very low, and will not support good cocoa growth and yield. Application of fertilizers rich in calcium, magnesium and phosphorus will improve on the soil reaction (pH) which will subsequently bring most of the trace elements into solution at their right levels. Additionally, the farmers are encouraged to invest in organic fertilization using available organic materials or residues generated from the farms or locality to produce organic manure.

Key words: *fertilizer recommendation; fertility; soil reaction*

Introduction

Cocoa is a cash crop of economic importance to many tropical African countries which produce 70 % of the world cocoa supply and involve over 2 million households (Wessel and Quist-Wessel, 2015). Ghana is the second largest producer of cocoa in Africa with an annual production of > 800,000 tonnes which represents the mainstay of the economy. It is the second leading foreign exchange earner, worth about 30 per cent of all revenue from export and responsible for about 57 per cent of overall agricultural export (FAOSTAT, 2008). The traditional cropping system is low inputted system with little or no application of fertilizer, which results in depleted soil fertility and reduced crop yield in the long run. The low input cropping system has been shown to be the driving force behind deforestation in African cocoa growing countries (Gockowski and Sonwa, 2011).

Currently the Jomoro District remains the last frontier for the expansion of cocoa due to the presence of patches of non-reserved and reserved forest in the country. Majority (56.33%) of the total cocoa production in Ghana happens in the Western Region (Acheampong, 2012) and this has led to the understanding of this tree plantation for the local economy. Increase in cocoa production in Ghana has been achieved mostly through expansion and encroachment upon the remnant forest, particularly in the Western Region where soils are said to be unsuitable for cocoa production (Appiah *et al*., 2000). This encroachment on forest reserves would be spared or greatly reduced, if increased cocoa yield can be obtained through the adoption of good agronomic practices including judicious fertilizer application during intensified cocoa production (Gockowski and Sonwa, 2011).

Soil fertility play a vital 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. Cocoa-growing soils are depleted of nutrient elements annually. Most soils under cocoa cultivation in Ghana are moderate to marginal suitable in fertility status (Ofori and Fianu, 1996; Anim-Kwapong, 2006). Soils under this plantation therefore require an integrated soil fertility management technique to achieve optimum crop production on sustainable basis. Due to inadequate quantity of fertilizer supply and the high cost (Germer, 1995), most farmers do not use fertilizers (MoFA, 1998) and the farms therefore depend on native soil fertility. Over the years research efforts have indicated that there was short supply of P, Ca and Mg on soils under cocoa plantation resulting from nutrient mining from harvests of cocoa pods, which subsequently results in nutrient deficiency symptoms and low yields (Wood and Lass, 1985; Rhodes, 1995). The soil nutrient factor has therefore been found to be very important in the production of cocoa in Ghana (Hartemink, 2005). The evaluation of the soil physical suitability and continuous monitoring of soil nutrient status have been advocated, to ensure site specific or agro-ecology type fertilizer recommendation for profitable cocoa production in Ghana (Snoeck *et al*., 2010; Dossa *et al*., 2017). This study was therefore carried out to assess the physico-chemical status of some cocoa plantations around the Ankasa National Park for possibility of remedying nutrients deficiency and imbalance to enable cocoa farmers improve productivity and income as means to motivate and empower them to avoid further deforestation and also help preserve the biodiversity in the productive landscape and critical ecosystem of the Ankasa National Park.

Materials and methods

Brief description of the study area

It is located in the south western corner of the Western Region of Ghana. It is bounded on the South by Latitude 4.80^0 N and the Atlantic and in the North, Latitude 5.21° N and the Nini River. It also lies between Longitude 2.35^0 W to the East and 3.07^0 W to the West. It shares boundaries with Wassa-Amenfi and Aowin-Suaman to the North, Nzema East District to the East and Ivory Coast to the West and the Gulf of Guinea at the South (JDA, 2009). The south-central part of the District, including the Ankasa National Park, is an area of rolling granite topography consisting of frequent steep-sided small round hills rising to 60-180 metres with no flat uplands and no broad valleys. Around the coastal area, the relief is lower consisting of flat upland areas and steep valleys. A minor relief feature is the one formed by a ridge of highlands running northwest to southeast from the Tano to Bonyere that terminates on its northern side in the Nawulley scarp (JDA, 2009).

Climate

The District is believed to be the wettest part of the country with a mean annual precipitation of 1732 mm. Temperature in the District is generally very high with a monthly mean of 26 ^{0}C (JDA, 2009). Relative humidity throughout the District is also very high about 90% during the night and falling to about 75% when temperature rises in the afternoon. The District is characterized by two rainy seasons from April to July and September to November. There is a short dry spell in August and longer dry periods in December to January. Although February and March are relatively hot, a number of rains usually allow cropping to begin.

Soil sampling and analyses

The study was carried out in nine (9) cocoa farming communities around the Ankasa National Park. In all 40 cocoa farms were sampled. The communities and their respective number of cocoa farms were as follows Anwiafutu Junction-13, Paradise - 6, New Ankasa - 2, Odoyefew - 2, Fayah - 4, Frenchman - 3, Old Ankasa - 7, Sowodadzem - 1 and Amokwaw Suazo - 2. Soil samples were taken from two distinct depths of 0-15 cm and 15-30 cm from each farm taking into consideration the topography of the land. In each farm, 10-20 soil cores were dug per depth with the aid of earth chisel. The soils from each depth were bulked, mixed thoroughly in a plastic bucket and then sub samples were taken. Two composite samples were then obtained per farm to give a total of 80 composite samples from the 40 farms. Three profiles were dug for detail description. 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 both chemical and physical analyses. The soil samples were analyzed for sand, silt, clay, pH, organic carbon, total N, available P, exchangeable K, Ca and Mg. Soil particle size distribution was by hydrometer method (Bouyoucous, 1962), while the soil pH was in soil/water ratio of 1:2.5 and read with electronic pH-meter. Soil organic carbon was determined by the procedure of Walkley and Black by wet oxidation using chromic acid digestion (Nelson and Sommers,1982). Soil total N was determined by micro-Kjeldahl method (Bremmer, 1996) and available P was by Bray P_1 method (Bray and Kurtz, 1945). The exchangeable bases were extracted by 1*N* NH_4OAC at pH 7 and the K, Ca and Mg contents were read using atomic absorption spectrophotometer (Thomas, 1982). Nutrient values of the composite soils per farm were averaged and compared across the communities with the soil critical values for cocoa. This was done for appropriate soil and fertilizer management needs for continuous optimal and sustainable cocoa yield.

Results and Discussions

Soil types and their descriptions

The soil types observed in the district and their major profile characteristics are presented in Table 1.

Ankasa and Boi series. These soils have similar physical characteristics (Table 1). They are generally deep and sandy, and have no physical limitation. The sandy nature of these soils allows free drainage under flooding or when rainfall is high. The underlying sandy clay texture prevents excessive drainage leading to droughty condition during the dry season.

Table 1: Summary of profile characteristics of the soils

Soil series	Classification (WRB, 1998)	Profile description	Soil limitation (physical)
Ankasa	Haplic Ferralsol	Deep (>120 cm), moderately well-drained, sandy loam topsoil, underlain by sandy clay loam in the subsoil. The subsoil contains gravels consisting of only quartz materials without ironstone concretions	Gravelly subsoil
Boi	Haplic Ferralsol	Deep (>120 cm), moderately well-drained, sandy loam topsoil. The underlying subsoil is sandy clay loam and contains gravels consisting of quartz and ironstone concretions and iron impregnate small rocks. The gravelly layer is however, porous and does not in any way impede root growth.	Gravelly subsoil

Soil texture

The soils of the cocoa farms varied in their sand, silt and clay contents. Sand ranged from 61-75 %, silt 8-16 % and clay 15-39 % in the top 0-15 cm depth (Table 2). The sandy nature of the soils indicate that they might not retain and supplied sufficient water to meet the needs of cocoa trees. There will be a need for irrigation, most especially over a long period of dry spell. Sufficient water supply, during flowering and fruit setting, is very critical. Lack of water supply at such a time will lead to flower and fruit abortions with accompanying low fruit yield. The soils could be better managed by making sure that there is adequate desirable shade tree species on the farms, while the floor was covered with leaf litter falls to serve as preventive measures against loss of soil water through evaporation (Ofori-Frimpong *et al*., 2010; Asare, 2016).

Table 2: Soil particle size and textural class at the different communities

Community	Depth (cm)	% Sand	% Clay	% Silt	Textural class
Awiafutu Junction	0 - 15	67.24	18.76	14	Sandy Loam
	15 - 30	63.24	22.76	14	Sandy Clay Loam
Paradise	0 - 15	65.24	24.76	10	Sandy Clay Loam
	15 - 30	63.24	28.76	8	Sandy Clay Loam
New Ankasa	0 - 15	71.24	14.76	14	Sandy Loam
	15 - 30	61.24	22.76	16	Sandy Clay Loam
Odoyefew	0 - 15	61.24	30.76	8	Sandy Clay Loam
	15 - 30	51.24	38.76	10	Sandy Clay
Fayah	0 - 15	69.24	18.76	12	Sandy Loam
	15 - 30	69.24	20.76	10	Sandy Clay Loam
Frenchman	0 - 15	69.24	22.76	8	Sandy Clay Loam
	15 - 30	63.24	28.76	8	Sandy Clay Loam
Old Ankasa	0 - 15	75.24	16.76	8	Sandy Loam
	15 - 30	73.24	20.76	6	Sandy Clay Loam
Sowodadzem	0 - 15	65.24	18.76	16	Sandy Loam
	15 - 30	61.24	22.76	16	Sandy Clay Loam
Amokwaw Suazo	0 - 15	65.24	18.76	16	Sandy Loam
	15 - 30	61.24	28.76	10	Sandy Clay Loam

Soil pH

The range of the soil pH was from 4.57–5.12 in the top 0-15 cm which indicated that they were acidic. This however, falls below 5.7–7.2 reported to be normal for cocoa (Ahenkorah, 1981; Opeke 1987). This is to be expected since the soils in the area fall into the soil classification group, oxisols (pH < 5.5) (Ahn, 1961). This is critical and has a negative influence on the production potential of the crop since pH values are below the acceptable range required by the crop. The soil pH will need to be corrected with the use of organic or liming materials or manures for optimal microbial activities in the soils and ease of macronutrient release for crop usage. This will also help to make sure that micronutrients are not released in a rate too much for normal crop growth and production performance (McKenzie, 2001).

Soil organic carbon

The organic carbon content ranged from 0.98–1.71 % in the top soil. These were generally lower than 3.5 % considered optimum for good cocoa growth (Ahenkorah, 1981). The very low level of organic carbon indicates that nutrients supply, availability and uptake by crops will be difficult. This is because soils low in organic carbon (less than 2%) is prone to have lower nutrient availability (McKenzie, 2001).

Soil Total N Content

Nitrogen content of all the soil samples from the different communities was adequate for cocoa production. Since all the values recorded were higher than the critical level of 0.09 % required for cocoa cultivation (Thong and Ng, 1978; Egbe *et al.*, 1989; Aikpokpodion *et al.*, 2010). The nitrogen values obtained for the cocoa farms showed that adequate and proper management techniques that would improve on the soil N build up was necessary to avoid N limitation in the long run which might result due to harvest of pods from cocoa. A harvest of 1.0 tonne of cocoa leads to a loss of over 45 kg N ha^{-1} (Wood and Lass, 1985).

Available phosphorus

Phosphorus (P) is an essential major primary nutrient required by cocoa and it is the most limiting nutrient to the production of cocoa in Ghana. Available P contents ranged from 8.47 mg kg^{-1} to 14.21 mg kg^{-1} in the top soil (Table 2). Available P contents of 20 mg kg^{-1} or more in the top soil is adequate for cocoa (Ahenkorah, 1981). The available P contents observed were low. Under very strong soil acidity serious fixation is expected, and partly explains the situation regarding available P. Similar low level of available P values has been reported for soils under cocoa cultivation in Nigeria (Ogunlade and Iloyanomon, 2009). However, the application of recommended phosphate fertilizers and the adoption of good soil fertility management practices can help increase the available P levels thereby making them more adequate for cocoa production.

Exchangeable Cations

The top soil exchangeable K contents ranged between 0.27 and 0.59 cmol kg^{-1}, Ca contents 1.20 and 3.23 cmol kg^{-1} and Mg 0.20 and 0.64 cmol kg^{-1} (Table 3). These K values for each of the cocoa farms were above their critical value of 0.25 cmol kg^{-1}, Ca value was below the critical value of 7.5 cmol kg^{-1} and Mg values were also below the established critical value of 1.33 cmol kg^{-1} for cocoa soils in Ghana (Ahenkorah, 1981; Ahenkorah *et al*., 1982). Calcium and Mg levels of the soils were below the critical values for continuous and sustainable economic cocoa production. The general low contents of Ca and Mg for the cocoa farms must have been due to nutrient removal over the years through crop harvest without replacement because of lack of fertilizer usage. Application of Ca and Mg containing fertilizers and implementing management practices that will protect the soil's superficial layer from all forms of soil erosion and leaching are recommended.

Table 3: Soil chemical properties of cocoa farms in communities around the Ankasa National Park

Communities	Depth cm	pH	Org C (%)	Avail. P mg/kg	Total N %	Exchangeable cations ($cmolkg^{-1}$) K	Mg	Ca
Anwiafutu Junction	0-15	4.94	1.71	10.17	0.18	0.28	0.64	3.23
	15-30	4.82	1.16	7.70	0.14	0.25	0.26	2.11
Paradise	0-15	5.12	1.52	9.73	0.16	0.28	0.46	2.98
	15-30	5.01	0.90	6.40	0.12	0.26	0.22	1.58
New Ankasa	0-15	4.83	0.98	8.47	0.14	0.27	0.23	1.43
	15-30	4.72	0.73	6.91	0.10	0.20	0.12	1.06
Odoyefew	0-15	4.57	1.32	13.96	0.16	0.31	0.27	1.26
	15-30	4.50	0.94	10.82	0.11	0.28	0.12	0.80
Fayah	0-15	5.02	1.65	14.21	0.20	0.59	0.60	2.76
	15-30	4.65	1.01	8.73	0.13	0.35	0.27	1.29
Frenchman	0-15	5.03	1.67	10.58	0.18	0.33	0.45	3.89
	15-30	5.02	1.02	7.07	0.12	0.28	0.27	2.57
Old Ankasa	0-15	4.69	1.43	13.23	0.17	0.31	0.24	1.57
	15-30	4.63	1.00	9.30	0.12	0.23	0.09	0.81
Sowodadzem	0-15	4.73	1.03	11.43	0.13	0.29	0.28	1.20
	15-30	4.66	0.61	7.26	0.10	0.25	0.15	0.94
Amokwaw Suazo	0-15	4.60	1.20	11.57	0.15	0.32	0.20	1.49
	15-30	4.83	0.71	7.58	0.12	0.28	0.06	1.15

Conclusion and Recommendations

The results of the soil analyses indicate that the soils are acidic with low organic carbon content. Available P contents of the soils were below the critical level considered adequate for cocoa cultivation. Furthermore, exchangeable Ca and Mg were deficient in all soils at all the cocoa growing communities even though the soil physical properties did not constitute any major limitation to good cocoa growth and yield. From the results of the laboratory analyses carried out on the soil samples, it was recognized that there is the need to apply organic and inorganic fertilizer to the soil in order to enhance its capacity to support the growth of cocoa and avoid any potential negative impacts on the sites (environment). Application of fertilizers rich in calcium, magnesium and potassium in split application will improve on the soil reaction (pH) which will subsequently bring most of the trace elements into solution at their right levels reducing artificial shortages of nutrient resulting from fixation and others. Additionally, the farmers must be encouraged and supported to invest in organic fertilization using available organic materials or residues generated from the farms or locality to produce organic manure. NutriSmart which is an environmentally friendly microbial fertilizer is recommended for use to increase the carbon and other nutrients to complement its microbial activities. The application of Cocoa Pod Husk Ash (CPHA) and Phosphate Rock is also recommended to ensure an increase in potassium and phosphorus respectively and by so doing adjusting the soil pH up to optimum range. Further, leguminous trees with low C: N ratios such as Gliricidia can be used as shade trees in addition to some timber species which will serve as nutrient pumps. Having the farmers supported in all these critical areas financially, cocoa production will be sustainable and competitive.

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References

Acheampong, A.I. (2012). Multiple comparison and random effect model on cocoa production in Ghana (from 1969/1970 to 2010/2011 production years). MSc Thesis. Kwme Nkrumah University of Science and Technology, pp 93.

Ahenkorah, Y., Halm, B.J., Appiah, M.R. and Akrofi, G.S. (1982). Fertilizer use on cacao rehabilitation projects in Ghana. *8th International Cocoa Research Conference*, 1981 Cartagena, Colombia pp 165 – 170.

Ahenkorah, Y. (1981). The influence of environment on growth and production of the cacao tree: soils and nutrition. *Proceedings of the 7th International Cocoa Research Conference*, 1979, Douala, Cameroon, pp 167 – 176.

Ahn, P. (1961). Soils of the Lower Tano Basin, South-Western Ghana. Ministry of Food and Agriculture, Scientific Service Division, Soil and Land use Survey Branch, Kumasi.

Aikpokpodion, P.E, Uloko B. and Edibo, G., (2010). Nutrient dynamics in soil and cashew (*Anacardium occidentale* L.) leaf and kernel in Kogi State, Nigeria. Journal of Applied Biosciences 25: 1573 - 1578

Anim -Kwapong, G.J. (2006). Potential of planted and natural tree fallows for rehabilitation of degraded cocoa farmlands in Ghana. Paper presented at conference on extending cacao for biodiversity conservation, Kumasi, Ghana, 14-18.

Appiah, M.R., Ofori-Frimpong, K. and Afrifa, A.A. (2000). Evaluation of fertilizer application on some peasant cocoa farms in Ghana. Ghana J. of Agric. Sci. 33:183-190.

Asare, R. (2016). The relationship between on-farm shade trees and cocoa yields in Ghana department of Geosciences and Natural Resource Management, University of Copenhagen. pp. 1-46.

Bouyoucous, G.J. (1962). Hydrometer method improved for making particle size analysis of soils. Agron. Jour: 54:
464 – 465.

Bray, R.A. and Kurtz, L.T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Sci* 59: 39 – 45.

Bremmer, J.M. (1996). Methods of Soil Analysis, Part 3. Soil Science of America and America Society of Agronomy, SSSA Book series No. 5, Madison, USA.

Dossa, J.E., Arthur, A. Dogbe, W. Mando, A. Afrifa, A.A. and Acquaye, S. (2017). An assessment of inherent chemical properties of soils for balanced fertilizer recommendations for cocoa in Ghana. Nutrient cycling in agroecosystem. Vol 1. In press.

Egbe, N.E., Ayodele, E.A. and Obatolu, C.R. (1989). Soils and nutrition of cacao, coffee, kola, cashew and tea. Progress in Tree Crop Research, CRIN Ibadan, pp: 28-38.

FAOSTAT (2008). 'Production' faostat.fao.org.

Germer, H., Asante, E.O, Owusu- Bennoah, E. and Marfo, K. (1995). Ghana fertilizer privatization scheme: Private Sector and Roles and Public Sector responsibilities in meeting needs of farmers. IFDC-African, Lome, Togo.

Gockowski, J. and Sonwa, D. (2011). Cocoa intensification scenarios and their predicted impact on CO_2 emissions, biodiversity conservation, and rural livelihoods in the Guinean rainforest of West Africa. Environmental Management, 48(2):307-321.

Hartemink, A.E. (2005). Nutrient stocks, nutrient cycling, and soil changes in cocoa ecosystem: a review. Advances in Agronomy 86:227-253.

JDA (2009). Medium term development plan 2006-2009 -Jomoro District Assembly.

McKenzie, R.H. (2001). Micronutrient requirements of crops. Alberta Agriculture and Rural development http://www1.agric.gov.ab.ca/$department.

Ministry of food and Agriculture, (1998). National Fertility Management Action Plan; Accra, Ghana.

Nelson, D.W. and Sommers, L.E. (1982). Organic Carbon and Soil Extracts. In: Methods of Soil Analysis. Part 2- Chemical and Microbiological Properties. Agronomy Monograph No.9, 2nd Edition. American Society of Agronomy, Soil Science Society of America, Madison, WI, pp. 539 – 579.

Ofori, C.S. and Fianu, F. (1996). Sustaining Soil Fertility in Ghana: An Integrated Nutrient Managemement Approach .Pp.41-60. In: Ofori, F and E.Y. Safo (eds). Proceedings of the National Workshop on Soil Fertility Management Action plan for Ghana. Cape Coast. Ghana.

Ofori-Frimpong, K., Afrifa, A.A. and Acquaye, S. (2010). Impact of shade and cocoa plant densities on soil organic carbon sequestration rates in a cocoa growing soil of Ghana. African Journal of Environmental Science and Technology. 4(9): 621-624.

Ogunlade, M.O. and Iloyanomon, C.I. (2009). Leaf litter fall and soil Nutrient Status under Cocoa Plantations of different ages in Ibadan, Nigeria. Niger J Soil Sci 19 (1): 25-28.

Opeke, L.K. (1987). Tropical tree crops. Spectrum Books Limited, Ibadan, Nigeria, p 247.

Rhoades, J.D. (1982). Soluble salts. In: A.L. Page, R.H. Miller and D.R. Keeney (eds). Methods of Soil Analysis Part 2: Chemical and Microbiological Properties. Soil Science Society of America, Inc., Madison, WI, pp 167-179.

Rhodes, E.R. (1995). Nutrient depletion by food crops in Ghana and soil organic nitrogen management. Agricultural systems. 1995.48(1).101-118.

Snoeck D., Afrifa A. A., Ofori-Frimpong K., Boateng E., Abekoe M. K., 2010. Mapping Fertilizer Recommendations for Cocoa Production in Ghana Using Soil Diagnostic and GIS Tools. West African Journal of Applied Ecology, 17: 97-107.

Thomas, G.W. (1982). Exchangeable cations -In Page, A.L.R.H. Miller, and D.R. Keeney(eds), Methods of soil analysis, part 2 ; Chemical and Microbiological properties. Madison, WL; Soil Science Society of America, pp. 159-166.

Thong, K. C. and Ng, W. L. (1978). Growth and nutrient composition of monocrop cocoa plants in inland Malaysian soils. In Proceedings of *Int. Conf. Cocoa and Coconuts.* Kuala Lumpar, pp 186-286

Wessel, M, and Quist-Wessel, P.M.F. (2015). Cocoa production in West Africa, a review and analysis of recent developments: Wageningen Journal of Life Sciences 74–75 (2015) 1–7

Wood, G.A.R. and R.A. Lass (1985). Cocoa, 4th ed. London: Longman, 620 - 632.

WRB (1998). World Reference Base for Soil Resources. World Resources Report No. 84. FAO, Rome.