Soil Fertility for Sustainable Crop Production: A Case Study of Gyerentor in Kete Krachi, Oti Region of Ghana

ABSTRACT

Soil fertility management is important for sustainable crop production. In the bid to boost the agricultural development in Ghana, Krachi Farm Ltd, identified Gyerentor in Kete Krachi within the West District of the Oti Region, formally Volta Region as a potential area for cashew, cowpea, maize and mango production. However, the fertility status of the soil is not known hence the assessment of the suitability of the soil for the above crop production. 30 soil samples were collected randomly from depths of 0-30 and 30-50 cm. Soil sampling points were identified using a GPS device. Following standard methods adopted by Laboratory Analytical Services Department of Soil Research Institute, Ghana, the collected soil samples were analyzed to find out their texture, pH, organic matter (OM), nitrogen (N), calcium (Ca), magnesium (mg), potassium (K), sodium (Na) and available phosphorus (P). The soil was acidic with the mean value of 4.5 in the topsoil, OM (1.0%), Ca (2.1 me/100g), mg (0.8 me/100g), K (0.3 me/100g) and P (4.6 ppm). The soil texture was sandy loam and sandy clay loam. The fertility of the soil was low in almost all the studied parameters, especially with respect to OM and the NPK levels. Assessment for various land utilization type (LUT) types did not find it suitable for cashew, cowpea, maize and mango especially due to the extremely acidic condition.

Keywords: Soil degradation, Soil fertility, Soil nutrient, Agronomy,

1. INTRODUCTION

The sustainability of any system has become a major concern and the center of studies in the global world nowadays. The assessment of soil fertility is the most basic decision-making tool in order to apply appropriate nutrient management strategies [1]. Soil fertility evaluation is very crucial in the agricultural sector because of soil fertility declining rapidly in cultivated lands through leaching, soil erosion and crop harvest [2].

Soil fertility is the ability of the soil to supply essential nutrients in sufficient amount for the growth and development of the plant. Soil fertility determinations or evaluation is the bases for making fertilizer recommendation [3]. In Africa, soil fertility depletion and soil degradation are the crucial setback which needs to be addressed [1]. According to [3] study, African soils lose an annual average of 48 kg/ha of nutrient, which is equivalent to 100 kg/year of fertilizer.

Tropical smallholder farming systems lack sustainability due to nutrient leaching, lack of fertility restoring inputs, and unbalanced nutrient applications [4].

Understanding soil nutrient status is fundamental for crop/plant production. Soil physical, chemical and biological analysis determines the fertility/productive status of soil with an influence on crop or plant yield [5]. The erratic nature of the rainfall pattern, coupled with long periods of drought renders agriculture as a risky business in Ghana. Beside low soil fertility levels of most Ghanaian soils, the poor performance of the agricultural sector is due partly to the over-reliance on rainfall as the main source of water supply for crop growth [3]. Under these prevailing climatic conditions, the country’s agriculture cannot sustain the growing population without the introduction of extensive and intensive irrigation as well as effective soil management systems [5].

Krachi Farms Ltd. Company is joining a revolutionizing mechanized cashew farming in Ghana with modern technologies and guaranteed high yielding planting material with irrigation to sustain high-density planting, with the goal of processing cashews for export.

In this regard, Krachi Farms Ltd. contracted Soil Research Institute of the Council for Scientific and Industrial Research for a soils and land suitability assessment for cashew, which forms part of the company’s feasibility study with the intention of producing cashew crops by employing the application of modern agricultural technology in agronomy, mechanization and irrigation on its newly acquired 401.90 ha land.

The overall goal of this study was to assess the suitability of the soils for agriculture on approximately 405 hectares of land at Kete Krachi, for the utilization of the areas that would be suitable for cashew, cowpea, maize and mango production.

2. MATERIAL AND METHODS

Experimental Site Description

The land is located at Gyerentor in Kete Krachi within the Krachi West District of the Oti Region of Ghana. It lies 800 m to 2 km west of the Volta River, and lies within longitudes 0°0'58.59"E – 0°2'58.59"E and latitudes 7°50'9.20"N – 7°50'58.6"N. The site is situated within the transitional agro-ecological zone of Ghana and covers an approximated area of about 993.08 acres or 401.90 hectares with an average elevation of 112.16 m.

Climate conditions such as temperature, rainfall, relative humidity, sunshine day, and wind speed influence soil formation and crop/plant growth. The area under consideration lies within the Equatorial Climatic Zone, which like the rest of the country is greatly influenced by the South West Monsoons from the South Atlantic and the dry Harmattan winds from the Sahara. The movements of these winds affect the climatic conditions of the area, both in time and space [6,7].

The average annual rainfall varies from 900 mm to 1,841 mm, of which 80% is recorded in the wet season. The site is characterised with two well defined rainy seasons: The major season from mid-April to early July and the minor from September to November. From November to February, the climate is considered to be a dry period because, during this time, total rainfall is less than half the total evapotranspiration for each month. Additionally, the relative humidity of the area is around 54 %.

The month of January, February, March and April at Kete Krachi are characterised as the hottest with a temperature of about 40.6 ^{0}C. August is the coldest month in Kete-Krachi. The mean monthly average temperature ranges from 22.0 ^{0}C (minimum) to 32.3 ^{0}C (maximum) while the mean monthly sunshine amounts to 2,527 hours with approximately 7 hours daily. The average diurnal range of temperature is greatest during the harmattan period in December and January and at least in August.

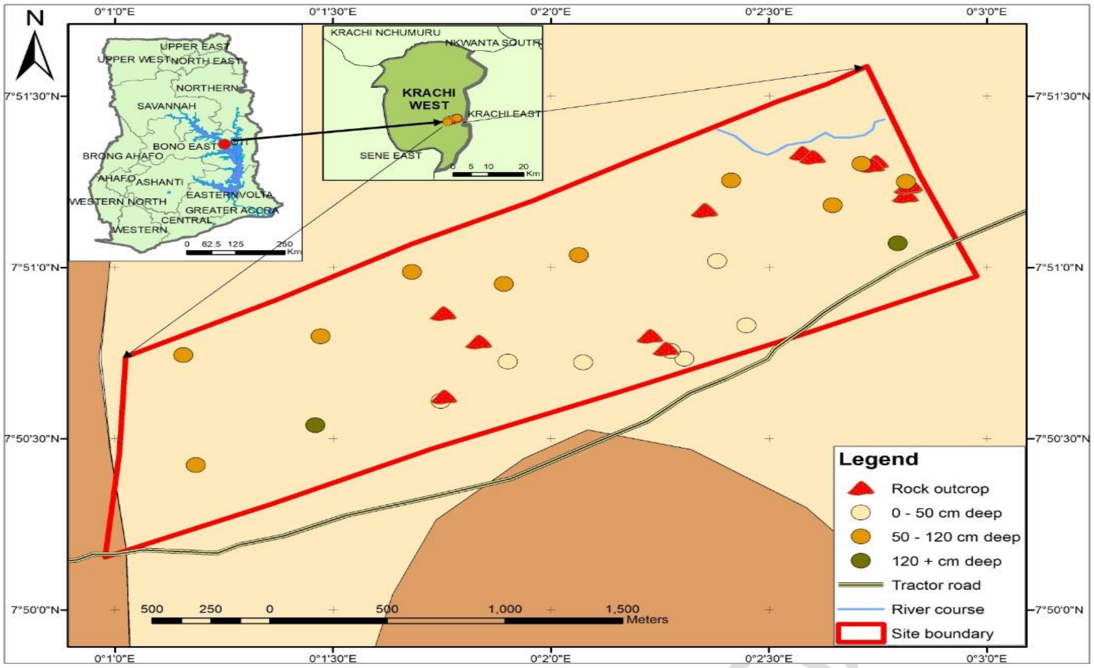

Figure 1: Location and GPS Soil Observation point map of the proposed site

2.1 General description of soils

The soils of the study site comprise of the Kpelesawgu consociation, developed over Voltaian mudstones and shales. Kpalesawgu soils were first studied and reported on by [8] during a soil survey of the Central Agricultural Research Station at Nyankpala. Since then these soils have been encountered extensively elsewhere in East Dagomba and the Sene-Obosum basins of Ghana [9, 10] and the rest of the country, including the study site with respect to this report. The consociation is dominated by *Kpelesawgu series*, which is made up of both shallow and deep phases. Areas occupied by *Kpelesawgu series* may, however, also have small patches of *Wenchi series*, made up of exposed plinthites.

2.1.1 Soil sampling and analysis

Field soil sampling was carried out according to the random sampling technique, guided by predetermined points using GPS generated locations. Handheld GPS Garmin devices were then used to track these observation points at intervals between 310 m to 660 m. Soil samples were taken at random locations for chemical and physical analysis including; soil texture, pH, organic matter (OM), nitrogen (N), calcium (Ca), magnesium (mg), potassium (K), sodium (Na) and available phosphorus (P).

The soils were identified using physical characteristics such as physiographic position, soil colour, texture and relative amounts of coarse fragments, and depth to gravelly layer. The Munsell Colour chart (1994 revised edition) was used in determining the soil colour. Soil texture was determined by manipulative test and feel [12].

Soil samples were air-dried, ground and passed through a 2-mm sieve. Soil pH was measured in a soil to water ratio of 1:2.5 [11]. Total nitrogen was determined by the modified Macro-Kjeldahl method [12]. Available phosphorus was extracted with Bray's P solution and measured on a spectrophotometer [13]. Organic carbon was measured by the method of [14]. Exchangeable bases were extracted with 1.0M ammonium acetate solution.

Sodium and potassium contents in the extract were determined by flame photometry, while calcium and magnesium were determined by atomic absorption spectrophotometry. The method of [15] was used for the determination of exchangeable acidity. Effective cation exchange capacity (ECEC) was then calculated as the sum of exchangeable cations (K, Ca, Mg, and Na) and exchangeable acidity (Al+H). Particle size analysis was done using the pipette method [16].

2.1.2 Statistical Analysis

Analysis of variance for the measured parameters was performed using GENSTAT 12th Edition.

3. RESULTS AND DISCUSSION

The chemical properties of the top soils (0-30 cm) were characterised by extremely acid to very high acid soils (pH range, 4.3-4.6) (Table 1). This was likely to cause aluminium (Al) or manganese (Mn) toxicity, molybdenum deficiencies as well as Ca, Mg, and K deficiency (due to possible leaching) and reduced microbial activity. Most nutrient elements are available in the pH range of 5.5 – 6.5 and also crop yields are normally high in soils with pH values between 6.0 and 7.5 [3]. Liming is therefore recommended to increase the pH levels of the profile soils.

Soil organic matter (SOM), and for that matter soil organic carbon (SOC), in both top and subsoils was very low. SOM average was 0.6% and 0.5% in top and sub soils respectively, and SOC average was 1.0% and 0.9% in top and sub soils respectively (Table 1 and 4). Organic materials are a critical component of nutrient recycling as well as an established storehouse for plant nutrients. Nutrients associated with OM are not plant-available immediately but are slowly released as the material decomposed by soil microbes [17]. The decomposition rate depends on the material's physical and chemical characteristics as well as climate [17]. To maintain the fertility of the soils, management practices that promote the accumulation of OM are recommended e.g. cover cropping, soil and water conservation, manure application etc.

The chemical results indicated an inadequate status in soil nutrient in all the three main parameters: nitrogen (N) was low with an average of 0.07%, available phosphorus (P) was low with an average of 6.6 ppm and the corresponding exchangeable potassium (K) was medium with an average of 0.3 me/100g (Table 1).

With the exception of exchangeable K, exchangeable cations were low in sodium (Na), calcium (Ca) and magnesium (M). This gave an overall effective cation exchange capacity (ECEC) value of 4 me/100g of soil, which is an indication of low soil fertility. Similar research was conducted by [18,19] on different projects, and their findings showed low levels of soil nutrients (Table 1).

3.1 Assessment of Suitability of Soils for Irrigation and Specific Crops

The FAO Framework for Land Evaluation [20] and Guidelines for Land Evaluation for rainfed Agriculture [21] were adopted for the assessment. Evaluation of the land (soil) units was based on major land/soil characteristics derived from the soil investigations. These were grouped under four main characteristics namely; i. topography (slope), ii. Physical (surface texture, coarse fragments, soil depth, calcium carbonate and gypsum), iii. Fertility (CEC, base saturation, organic carbon and pH). The observed soil parameters for each soil unit were 'matched' against rated land characteristics for various crop production.

Maize, botanical name, *Zea mays L.*, grown in a wide variety of soil conditions mainly because of the great efforts made in crop breeding. Thus, a large number of maize varieties have been produced that are suited to a wide range of soil conditions. The crop grows best in soils of neutral to slightly acid pH, range 5.5 - 7.0 and it requires deep, well-drained and fertile soils. The best soil textures for maize are loams to light clays, with growth being reduced in heavy clays and very sandy soils. With regard to soil fertility, maize requires large amounts of nitrogen, phosphate and potash, as well as micronutrients zinc, iron and sulfur [18].

Cowpea or black-eyed pea, *Vigna anguisalata*, is a very popular crop in northern part of Ghana, and could be a good rotation crop in any irrigated cropping program. The crop is reported to have originated in West Africa and to have been grown in that region more than six thousand years, in farming systems that included sorghum [19]. Generally, cowpea, a shallow rooting crop, grows best in moderately deep to deep, well-drained soils of pH in the 5.5 – 6.5 range and can be tolerant of aluminium toxicity in soils, to some extent [19].

Mango, *Mangifera indica*, can grow in many types of soils. It grows best in at least moderately deep (>50 cm) well-drained sandy loam to loam soils with optimum 5.5-7.8 pH [17].

Soya bean, glycine max, has the same soil requirements as cowpea. However, they are less tolerant to soil acidity and aluminum toxicity. Thus, they grow best in moderately deep, well-drained soils of neutral to slightly acid pH [17]. Since it is a legume, bean requires only light applications of nitrogen fertilizer but require phosphate and other macronutrients [21]. Under irrigation, the soils need to be at least 60 cm deep and of sandy loam to well-drained clay texture [21].

The result of matching soil and landscape characteristics of the area against growth and production requirements for oil palm is presented in Table 1.

Table 1. Chemical analysis of the topsoil

Label	pH 1:2.5	OC	N	OM	Ca	mg	K	Na
			%			me/100g		
KK1 - 0-30	4.5	0.40	0.03	0.7	1.8	0.2	0.16	0.04
KK2 - 0-30	4.5	0.76	0.06	1.3	2.4	1.2	0.20	0.04
KK3 - 0-30	4.4	0.40	0.05	0.7	2.6	1.0	0.33	0.04
KK4 - 0-30	4.5	0.36	0.04	0.6	1.2	0.4	0.16	0.04
KK5 - 0-30	4.5	0.48	0.03	0.8	1.5	0.4	0.16	0.04
KK6 - 0-30	4.4	0.32	0.03	0.6	1.8	0.5	0.23	0.04
KK7 - 0-30	4.5	1.13	0.04	1.9	1.6	1.0	0.23	0.04
KK8 - 0-30	4.4	1.12	0.06	1.9	2.8	1.4	0.83	0.04
KK9 - 0-30	4.3	0.44	0.07	0.8	2.6	0.8	0.26	0.04
KK10 - 0-30	4.5	0.40	0.06	0.7	2.0	1.2	0.36	0.04
KK11 - 0-30	4.3	0.36	0.04	0.6	3.2	0.4	0.23	0.04
KK12 - 0-30	4.6	0.92	0.06	1.6	1.7	0.7	0.23	0.04
KK13 - 0-50	4.4	0.40	0.04	0.7	2.6	1.0	0.16	0.04
KK14 - 0-30	4.6	1.10	0.04	1.9	1.8	1.2	0.23	0.04
KK15 - 0-30	4.6	0.45	0.05	0.8	1.5	0.8	0.18	0.04
KKc 16 - 0-30	4.6	0.32	0.04	0.6	1.8	0.8	0.15	0.04
Mean	4.5	0.6	0.0	1.0	2.1	0.8	0.3	0.0

Table 2. Chemical analysis of the topsoil continuation

Label	T.E.B	Ex. Acidity	ECEC	Base sat.	Avail. P
	me/100g			%	ppm
KK1 - 0-30	2.20	0.92	3	71	4
KK2 - 0-30	3.84	0.90	5	81	5
KK3 - 0-30	3.97	0.87	5	82	5
KK4 - 0-30	1.80	0.90	3	67	6
KK5 - 0-30	2.10	0.90	3	70	5
KK6 - 0-30	2.57	0.82	3	76	6
KK7 - 0-30	2.87	0.80	4	78	4
KK8 - 0-30	5.07	0.80	6	86	3
KK9 - 0-30	3.70	0.77	4	83	3
KK10 - 0-30	3.60	0.79	4	82	6
KK11 - 0-30	3.87	0.80	5	83	4
KK12 - 0-30	2.67	0.90	4	75	5
KK13 - 0-50	3.80	0.90	5	81	5
KK14 - 0-30	3.27	0.80	4	80	4

KK15 - 0-30	2.52	0.90	3	74	5
KKc 16 - 0-30	2.79	0.90	4	76	3
Mean	3.2	0.9	4.0	77.7	4.6

Table 3: Physical analysis of the topsoil

Label	% Sand	% Silt	% Clay	Texture
KK1 - 0-30	84	2	14	SANDY LOAM
KK2 - 0-30	83	5	12	SANDY LOAM
KK3 - 0-30	84	5	12	SANDY LOAM
KK4 - 0-30	77	9	14	SANDY LOAM
KK5 - 0-30	79	9	12	SANDY LOAM
KK6 - 0-30	69	9	22	SANDY CLAY LOAM
KK7 - 0-30	75	7	17	SANDY LOAM
KK8 - 0-30	79	3	18	SANDY LOAM
KK9 - 0-30	80	1	20	SANDY LOAM
KK10 - 0-30	78	5	18	SANDY LOAM
KK11 - 0-30	83	3	13	SANDY LOAM
KK12 - 0-30	84	2	14	SANDY LOAM
KK13 - 0-50	79	9	12	SANDY LOAM
KK14 - 0-30	79	2	18	SANDY LOAM
KK15 - 0-30	84	3	13	SANDY LOAM
KKc 16 - 0-30	84	2	14	SANDY LOAM

Table 4: Chemical analysis of the subsoil

Label	pH 1:2.5	OC %	N	OM	Ca me/100g	mg	K	Na
KK1 - 30-50	4.5	0.36	0.03	0.6	1.5	0.2	0.12	0.04
KK2 - 30-50	4.4	0.55	0.06	0.9	2.0	0.9	0.20	0.04
KK3 - 30-50	4.4	0.40	0.03	0.7	2.3	1.0	0.20	0.04
KK6 - 30-50	4.5	0.30	0.03	0.5	1.6	0.2	0.20	0.04
KK7 - 30-50	4.6	0.98	0.04	1.7	1.6	0.7	0.16	0.03
KK8 - 30-50	4.4	1.01	0.05	1.7	2.7	0.8	0.50	0.03
KK9 - 30-50	4.3	0.42	0.07	0.7	2.6	0.5	0.20	0.03
KK10 - 30-50	4.5	0.40	0.04	0.7	1.8	1.0	0.36	0.03
KK11 - 30-50	4.3	0.36	0.04	0.6	2.8	0.3	0.20	0.03

KK12 - 30-50	4.4	0.55	0.04	0.9	1.5	0.5	0.16	0.03
KK13 - 30-50	4.6	0.40	0.04	0.7	2.3	0.9	0.12	0.03
KK14 - 30-50	4.4	0.56	0.03	1.0	1.8	0.9	0.17	0.04
KK15 - 30-50	4.4	0.42	0.04	0.7	1.5	0.5	0.16	0.04
KKc 16 - 30-50	4.5	0.48	0.04	0.8	1.8	0.8	0.15	0.04
Mean	4.4	0.5	0.0	0.9	2.0	0.7	0.2	0.0

Table 5: Chemical analysis of the subsoil continuation

Label	T.E.B me/100g	Ex. Acidity	ECEC	Base sat. %	Avail. P ppm
KK1 - 30-50	1.86	0.92	3	67	4
KK2 - 30-50	3.14	0.90	4	78	5
KK3 - 30-50	3.54	0.80	4	82	5
KK6 - 30-50	2.04	0.80	3	72	5
KK7 - 30-50	2.49	0.80	3	76	4
KK8 - 30-50	4.03	0.80	5	83	3
KK9 - 30-50	3.33	0.77	4	81	3
KK10 - 30-50	3.19	0.70	4	82	5
KK11 - 30-50	3.33	0.80	4	81	4
KK12 - 30-50	2.19	0.90	3	71	4
KK13 - 30-50	3.35	0.92	4	78	3
KK14 - 30-50	2.91	0.80	4	78	4
KK15 - 30-50	2.20	0.90	3	71	5
KKc 16 - 30-50	2.79	0.90	4	76	3
Mean	2.9	0.8	3.7	76.8	4.1

Table 6: Physical analysis of the subsoil

Label	Sand	Silt (%)	Clay	Texture
KK1 - 30-50	84	3	13	
KK2 - 30-50	83	3	14	
KK3 - 30-50	84	3	13	
KK6 - 30-50	70	7	23	
KK7 - 30-50	75	7	18	
KK8 - 30-50	79	2	18	
KK9 - 30-50	80	3	18	SANDY LOAM
KK10 - 30-50	77	5	18	

KK11 - 30-50	83	2	14
KK12 - 30-50	84	2	13
KK13 - 30-50	80	9	11
KK14 - 30-50	84	2	14
KK15 - 30-50	84	2	14
KKc 16 - 30-50	81	2	16

KK = Kete Krachi
T.E.B = Total Exchangeable Base

Table 7: Soil suitability assessment matrixes (FAO, 1985) [21]

LUT	Slope	Wetness		Depth	Particle size		Soil fertility		ECE	Final suitability class
		Drainage	Flooding		Texture	Gravel	pH	Org. carbon		
Cashew	S1	S1	S1	S1-S3	S1	S2	N1	S2	S2	N1sf
Cowpea	S1	S1	S1	S1-S3	S1	S2	N1	S2-S3	S3	N1sf
Mango	S1	S2	S1	N1-S1	S1	S2	S2-N1	S2-S3	S2	N1sf
Maize	S1	S1	S1	S1-S3	S2	S2	N1	S2-S3	N1	N1sf

S - suitable, with the following subclasses

- S1 : Highly suitable (no or only slight limitations)
- S2 : moderately suitable (moderate limitations)
- S3 : marginally suitable (severe limitations)

N - Not suitable (very severe limitations)

4. CONCLUSION

The fertility of the soils was low in almost all the parameters, especially with respect to organic matter and the NPK levels. The pH was at a critical average of about 4.5 (extremely acid). It is likely to suffer from leaching of plants nutrients and susceptible to erosion, after removal of the plant cover, especially in the shallow areas. A number of exposed iron boulders were also encountered at the middle centre and eastern parts of the site and therefore mechanical cultivation is generally not advisable because of the risk of implements being damaged by the boulders which lie near the surface.

Assessment for various LUT types did not find it suitable for soya bean, maize and mango especially due to the extremely acid condition, with the exception of cashew production which was marginally or fairly suitable. For commercial production, amendments of the soils should keenly be considered. This should include liming to raise the pH of the soils, application of organic matter, inorganic fertilizer application and erosion control measures. However, the shallow parts should be avoided as much as possible.
In conclusion, like other acid-tolerant cash crops, although cashew can be grown with some success in acid soils, the range of acidity in the soils of the study site is likely to be sensitive to higher yields. In view of this, amendments should include activities to increase the pH of the soils of the site, i.e. liming. The limiting factors for soils of the site were mainly due to the low fertility which can be corrected using the right amount of recommended fertilizer or liming of the soil. This can upgrade the suitability rating to moderately or very suitable status, whiles avoiding areas of shallow depths (<50 cm) especially in the case of mango production.

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