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Comparison of soil nutrient status of some rice growing environments in the major agro-ecological zones of Ghana

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Abstract

Soil fertility management and maintenance has been a major problem to crop production in Ghana, varying considerably across agro-ecological zones within the country. With an increasing intensity in the use of lowlands for rice cultivation, a random fertility survey was conducted within some watersheds in two major agro-ecological zones to ascertain their current fertility status and to possibly develop management options that can ensure their sustainable use for crop production, particularly rice. Types of lowlands encountered within these two watersheds were mainly inland valleys and river flood plains. Rectilinear valleys were encountered within the Jolo Kwaha watershed within the Savannah agro-ecological zone while convex valleys were observed within the Mankran watershed in the Forest agro-ecological zone. Concave valleys were, however, observed in both watersheds. Major soil types encountered were basically Gleysols and to a lesser extent Fluvisols in both watersheds. *Volta* and *Lima* series were prominent within the Jolo Kwaha while *Oda, Kakum* and *Temang* series were prominent within the Mankran watershed. Soil fertility levels, as observed for selected parameters were low across locations, particularly within the Jolo Kwaha watershed. Available phosphorus (P) was the most deficient nutrient within both watersheds with over 80% of both watersheds recording very low levels (< 3 mg kg^{-1}). Soils of Jolo Kwaha were also observed to be quite acidic. Exchangeable cations (K, Ca, Mg, Na) were quite moderate across locations within the Forest agro-ecology but relatively low across the Savannah, particularly Ca. Both total carbon and nitrogen levels, even though low, were comparatively higher for the Mankran than Jolo Kwaha watershed. Soils of lowlands within the Jolo Kwaha watershed are deeper than the relatively shallow soils of the Mankran watershed. The adoption of simple but effective eco-technologies such as the "Sawah" system would help to enhance and maintain nutrient availability for sustainable rice production within these lowlands.

***Key words**: Agro-ecology, environment, Ghana, lowlands, management, rice, soil nutrients, sustainability.*

Introduction

Environmental problems such as land degradation, desertification and pollution of water bodies, which have assumed global dimensions, have opened new debates on the multifunctional role of soils. In Ghana the impacts of agricultural practices on soil and water have given rise to new and more challenging issues as more and complex land use systems emerge, with the increasing use of lowlands for crop production in particular. According to UNU-IAS [1], degradation of natural resources reduces the productivity of the poor who most rely on them and that understanding the link between livelihood and managing essential services provided by natural ecosystems is critical for achieving sustainable economic growth and poverty reduction. The same report continues to state that while Africa is facing diminishing agricultural stocks, high food prices and decreasing productivity, environmental stability is at the same time being lost.

In Africa, human-induced climatic change threatens agricultural productivity. Naturally, the shapes and extent of lowlands differ greatly across the different agro-ecological zones and this is mainly affected by lithology, climate and morphological processes. Every landscape generally varies in characteristics. Such variations may be more pronounced even in the lowlands. Three different cross-sectional profiles of inland valleys (in particular) are described by Rannet [2] as cited by Andriesse and Fresco [3]. These include (i) rectilinear inland valleys which are broad with rectilinear slopes of less than 3%. They have flat bottoms and generally more than 300 m wide. (ii) Concave inland valleys have concave slopes. These valleys are less than 300 m wide, flat in the central part and concave (1-2%) towards the sides. These valleys are generally deep ranging between 20 and 40 m. (iii) Convex inland valleys have moderately steep convex sides. Their bottoms are flat and range between 20 and 400 m wide. These valleys are normally deep up to 50 m.

Crop production systems vary across agro-ecological zones in Ghana. Therefore, site specific study to determine suitability or potential for the development of various types of rice production systems is necessary. Generally in West Africa, the land is used in a continuum of the whole topo-sequence for the cultivation of crops from the upland to the valley bottom [4]. Generally, farming system along a topo-sequence involves the cultivation of rice as a major crop in the lowlands while on the fringes and uplands, food crops such as maize, sorghum, cassava, yam, cowpea, soybean and others are grown. In Ghana, rice is now competing with other crops such as citrus, oil palm, cocoa, mango and vegetables in lowland crop cultivation [5].

With varying land use intensity and cultivation systems, a random fertility survey of selected lowlands in the Jolo-Kwaha watershed and the Mankran watershed within the Savannah and Forest agro-ecological zones of Ghana, respectively, were undertaken. The objectives of the study were (i) to identify major soils types, (ii) determine their current fertility status and (ii) to propose management options that will ensure their continued and sustainable use for lowland rice cultivation.

Materials and Methods

Location: The Jolo Kwaha watershed is located within the Savannah agro-ecological zone between latitude 9°17'N and 9° 26'N and longitude 0° 52'W and 0°59'W, covering a total area of 22,500 ha with 28% being lowlands. The Mankran watershed also covers an area of 22,500 ha with 29% being lowlands and lies within latitudes 6°47'N and 6°55'N and longitude 1°48' W and 1° 57'W in the Forest agro-ecological zone.

Field data collection: Reconnaissance visits were made to the selected lowlands. The widths and length of valleys were measured (using a measuring tape) where possible while others were estimated. The current vegetation of the sites were observed, current land use patterns noted and the occurrence of any significant landforms were also noted. Ninety soil samples were collected from forty five lowlands within the Jolo Kwaha watershed. One hundred and twenty-two samples from sixty one lowlands were covered within Mankran watershed. Soil sampling was done using an auger, with the location of sampling points determined using a GPS.

Table 1. Mean nutrient levels across lowlands within Jolo Kwaha watershed in the Savannah agro-ecological zone.

Parameter	Mean	Range	St. Dev.
pH (water)	4.6	3.7 - 7.4	0.5
Total C (g kg^{-1})	6.1	0.6 - 19	3.0
Total N (g kg^{-1})	0.65	0.1 - 1.6	0.3
C:N ratio	9.3	5.0-14.3	1.4
Available P (mg kg^{-1})	1.5	Tr - 5.4	0.9
Exchangeable K {cmol(+) kg^{-1}}	0.22	0.04 - 1.1	0.17
Exchangeable Ca {cmol(+) kg^{-1}}	2.1	0.53 - 15	1.9
Exchangeable Mg {cmol(+) kg^{-1}}	1.0	0.27 - 5.87	0.27
Exchangeable Na {cmol(+) kg^{-1}}	0.12	0.1 - 0.72	0.11
Exchangeable. Acidity {cmol(+) kg^{-1}}	1.0	0.05 - 1.80	0.48
Clay content (g kg^{-1})	66	40 - 241	39
Silt content (g kg^{-1})	607	347 - 810	107

Number of samples = 90.

Table 2. Mean nutrient levels across lowlands within Mankran watershed in the Forest agro-ecological zone.

Parameter	Mean	Range	St. Dev.
pH (water)	5.7	4.1 – 7.6	0.89
Organic C (g kg^{-1})	12	3.6 – 36.5	0.58
Total N (g kg^{-1})	1.1	0.30 – 3.20	0.05
C: N ratio	11	4.9 – 14.2	1.26
Available P (mg kg^{-1})	4.9	0.1 – 28.5	5.36
Exchangeable K {cmol(+) kg^{-1}}	0.42	0.03 – 1.28	0.25
Exchangeable Ca {cmol(+) kg^{-1}}	7.5	1.1 – 26.0	5.1
Exchangeable Mg {cmol(+) kg^{-1}}	4.1	0.3 – 12.3	2.6
Exchangeable Na {cmol(+) kg^{-1}}	0.32	0.04 – 1.74	0.26
Exchangeable. Acidity {cmol(+) kg^{-1}}	0.31	0.04 – 1.15	0.29
Clay content (g kg^{-1})	127	41 - 301	8.2
Silt content (g kg^{-1})	502	187 - 770	45.8

Number of samples = 122.

Laboratory analysis: 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 [6]. Particle size analysis was done using the pipette method [7]. Total nitrogen was determined by the modified Macro-Kjeldahl method [8]. Available phosphorus was extracted with Bray's P_1 solution and measured on a spectrophometer [9]. Organic carbon was measured by the method of Nelson and Sommers [10]. Exchangeable bases were extracted with 1.0 M ammonium acetate solution. Sodium and potassium contents in the extract were determined by flame photometry while calcium and magnesium by atomic absorption spectrophotometry. The method of Thomas [11] was used for the determination of exchangeable acidity. Effective cation exchange capacity (CEC) was calculated as the sum of exchangeable cations (K, Ca, Mg, Na) and exchangeable acidity.

***Statistical analysis*: ** Descriptive statistics was used to analyse data on soil parameters.

Results

(a) Jolo Kwaha watershed (Savannah agro-ecological zone): Table 1 shows summarized results of soil parameters determined across all locations for Jolo Kwaha watershed. Lowlands within the watershed have relatively deep soils with textures that vary from sandy loam to silty loam (Fig. 1) and are mainly Gleysols [12]. Chemical characteristics, however, show that most of the soils are very acidic (Fig. 2). Soil pH ranged from 3.7 to 7.4 with a mean of 4.6. Organic carbon levels were quite low (Fig. 3) and varied considerably across locations recording a mean of 6.1 g kg^{-1}. This translated into lower total nitrogen levels (Fig. 4) with a mean of 0.65 g kg^{-1}. Available phosphorus levels were very low (Fig. 5) across locations and showed the greatest deficiency (> 90% of lowlands showed levels below 3 mg kg^{-1}). Some lowlands even showed only trace levels of available P. Exchangeable cations (K, Ca, Mg, Na) levels were not better and showed wider variability (Fig. 6). Exchangeable K had a mean of 0.22 cmol (+) kg^{-1}. Exchangeable Ca had a mean of 2.07 cmol (+) kg^{-1} and the cation whose levels were generally very low across the watershed. Exchangeable Mg had a mean value of 0.97 cmol (+) kg^{-1} while exchangeable Na had a mean value of 0.11 cmol (+) kg^{-1}. Effective cation exchange capacity (eCEC) values were a true reflection of the general low levels of cations. Mean eCEC was 4.40 cmol (+) kg^{-1} within a range of 2.28 to 21.72 cmol (+) kg^{-1}.

(b) Mankran watershed (Forest agro-ecological zone): Types of inland valleys encountered were mostly concave and convex inland valleys. Their extent and shapes also varied markedly. Soil parameters determined for lowlands under the Mankran watershed are shown in Table 2. While soils of some lowlands are relatively deep with textures that vary from sandy loam through silty loam to loam (mainly Gleysols and Fluvisols - FAO, 1998), others were shallow (Fig. 1). Chemical characteristics show that some of the soils have relatively low pH values but on a limited scale. Soil pH ranged from 4.1 to 7.6

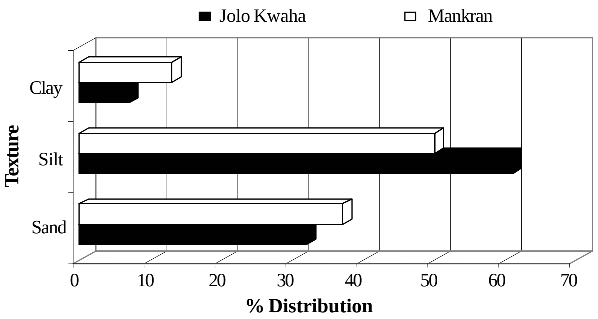

Figure 1. Distribution of texture within lowlands in the Savannah and Forest agro-ecological zones of Ghana.

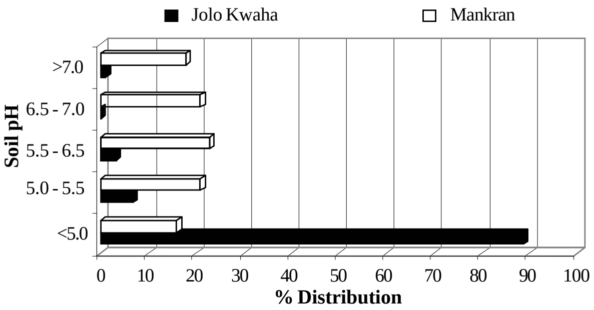

Figure 2. Distribution of soil pH within lowlands in the Savannah and Forest agro-ecological zones of Ghana.

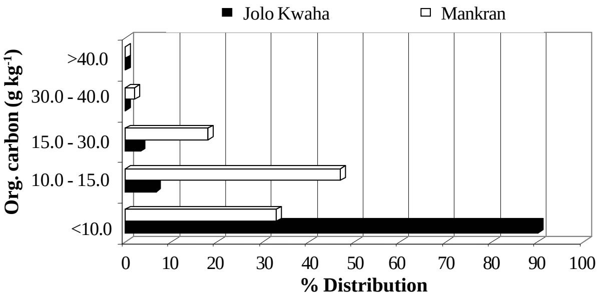

Figure 3. Distribution of organic carbon within lowlands in the Savannah and Forest agro-ecological zones of Ghana.

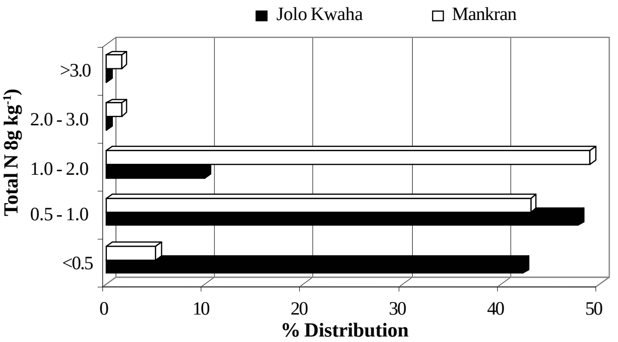

Figure 4. Distribution of total nitrogen in lowlands within the Savannah and Forest agro-ecological zones of Ghana.

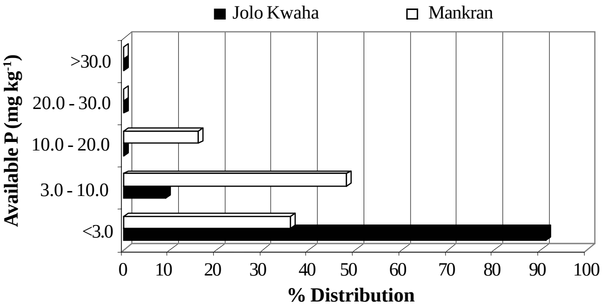

Figure 5. Distribution of available phosphorus within lowlands in the Savannah and Forest agro-ecological zones of Ghana.

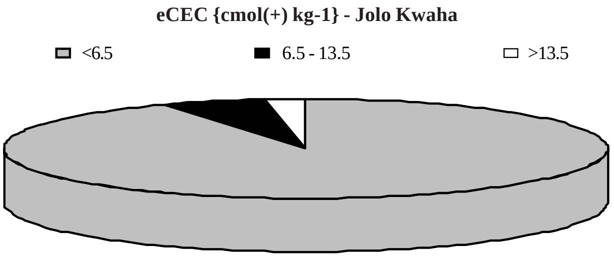

Figure 6. Distribution of effective cation exchange capacity (eCEC) in lowland soils within the Savannah agro-ecological zone of Ghana.

with a mean value of 5.7 (Fig. 2). With the generally low levels of organic carbon (Fig. 3), which gave a mean value of 12. g kg^{-1}, levels of total nitrogen showed a similar trend (Fig. 4), showing a mean of 1.1 g kg^{-1}. Available phosphorus levels were also generally low with a mean value of 4.9 mg kg^{-1} but showed much wider variability (Fig. 5). Available P was the most variable and most limiting nutrient. Exchangeable cations (K, Ca, Mg, Na) levels were relatively moderate (Fig. 7). Exchangeable potassium (K) had a mean value of 0.42 cmol (+) kg^{-1} with exchangeable Ca, Mg and Na giving mean values of 7.48, 4.13 and 0.32 cmol (+) kg^{-1} respectively. Effective cation exchange capacity (eCEC) values were relatively moderate (mean = 12.7 cmol (+) kg^{-1}.), a reflection of the moderate levels of cations.

(c) Comparison with other lowland areas: Table 3 shows a comparison of soil properties of variable lowlands types across the West African sub-region and Tropical Asia. Even though mean nutrient levels are quite low across the West African sub-regions, mean nutrient levels are even lower and more deficient across the Jolo -Kwaha watershed, particularly organic C, total N and available P, a direct impact of the Savannah agro-ecology. The very low levels of nutrients of the drier areas makes them more fragile.

Discussion

Rice is grown in a wide range of soils in different climatic and hydromorphic conditions. As a result, the pedogenic and morphological characteristics of rice soils vary considerably. While several authors [13, 14] have reported on these lowlands to be best suited for rice cultivation, others [15-18] have reported on their general low soil nutrient status within the West African sub-region. Even though fertility levels of lowlands soils within the Jolo Kwaha watershed are generally low, the soils are generally deep and uniform, and would therefore be easier to develop into “Sawah” rice fields, when effective nutrient and water management methods (e.g. “Sawah”) are put in place. The low organic matter content of these soils has consequential effects on their chemical properties particularly. Hence, conscious efforts would have to be made to raise organic matter levels with increasing land use intensity. Improvements in certain cultural practices (e.g. discouraging bush burning), introduction of effective crop rotation systems will allow

Table 3. Comparison of mean soil nutrient values of different lowland types.

	pH	TC	TN	Av. P	K	Ca	Mg	eCEC	Silt	clay
Site/Parameter	(H_2O)	gkg^{-1}	gkg^{-1}	mgkg^{-1}	Ex. Cations {cmol (+) kg^{-1}}				gkg^{-1}	gkg^{-1}
Jolo- Kwaha	4.6	6	0.6	1.5	0.2	2.1	1.0	4.4	600	70
Mankran	5.7	12	1.1	4.9	0.4	7.5	4.1	12.7	490	140
West Africa Inland Valleys[1]	5.3	13	1.1	9.0	0.3	1.9	0.9	4.2	230	170
West Africa floodplains[2]	5.4	11	1.0	7.0	0.5	5.6	2.7	10.3	230	290
Tropical Asia[3]	6.0	14	1.3	18.0	0.4	10.4	5.5	17.8	280	380

[1] Issaka *et al.* [17]; [2] Buri *et al.* [16].

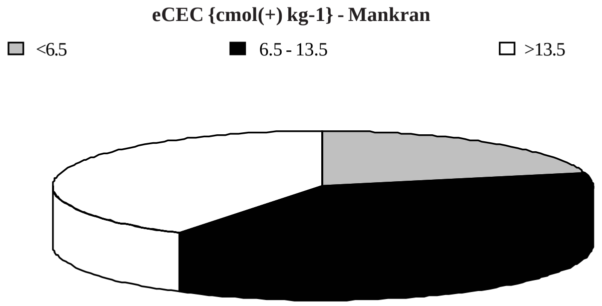

Figure 7. Distribution of effective cation exchange capacity (eCEC) of lowland soils within the Forest agro-ecological zone of Ghana.

for the gradual build up organic matter. The low pH, low organic matter and probably Al and Fe oxides may account for the high P deficiency (over 90% of lowlands recorded P values below 3 mg kg^{-1}).

The Mankran watershed also showed wide variability in nutrient distribution mostly due to slope and nature of lowlands. Apart from available P which showed acute deficiency, other nutrient levels ranged from low to moderate, particularly the cations. Issaka *et al.* [19] reported that, while levels of soil pH and exchangeable cations increased under improved soil management practices such as bunded but non-levelled, bunded and levelled, and “Sawah”, the reverse was observed under normal farmers practice in the Forest agro-ecology of Ghana. The adoption of improved rice cultivation systems coupled with supplementary fertilization in these lowlands would therefore not only result in increased crop yields but more importantly help to sustain soil fertility and reduce soil degradation through reduced erosion.

In its 2008 report, UNU-IAS recommended that, in order to combact climatic change and food security in Africa, emphasises should be place on investing in research and development, for enhancing soil fertility and agricultural productivity. The sustainability of these lowlands for rice cultivation largely depends on the adoption of practices that will reduce soil erosion, improve water retention and increase nutrient availability for crop use. The provision of improved management structures (such as “Sawah”) will greatly improve water utilization and increase nutrient management options available for the use of these lowlands across the different agro-ecological zones in the country.

Conclusions

Lowland soils of these watersheds have variable physical and chemical characteristics which will require variable management options. In order for the full benefits of improved varieties (biotechnology) to be felt in rice production in this country, more emphasise need to be placed on improving the rice growing environment (eco-technology). Establishing a balance between the two would be more beneficial for rice cultivation in the country and the West African sub-region as a whole. The adoption of simple but effective eco-technological systems like the “Sawah” technology of rice production will help to ensure, enhance and maintain soil nutrients for sustainable rice production. The “Sawah” technology can be modified to suit the variety of land forms that exist across these lowlands in the different agro-ecological zones.

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