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Land Suitability of the Nkrankwanta Lowland for Rice Cultivation in the Dormaa West District, Ghana

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Authors' contributions

This work was carried out in collaboration between both authors. Authors AAA and RA designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript, managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Suitability of land for growing crops, which considers the spatial distribution of soil characteristics, is an important factor to consider in order to maximize yields and ensure judicious land-use planning. This study was conducted to assess the suitability of Nzema series according to Land Suitability Classification for rainfed rice cultivation. The study was undertaken at Nkrankwanta lowland in the Dormaa West District, Ghana.
Methods: Two pedons were dug at a depth of 0-140 cm for both sampling locations. A total of 50 soil samples were collected at a depth of 0-20, 20-40, 40-60, 60-100, and 100-140 cm depth. Suitability assessment was done using the FAO Land Quality Index with input parameters including pH, texture, stoniness, nitrogen, depth, organic carbon, slope, and drainage.
Results: Chemical analysis revealed that nitrogen, phosphorus and organic matter were generally low. The results showed that pH for both pedons ranged from very strongly acidic to slightly alkaline

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(4–7.8) which could be as a result of leaching of basic cations due to the regular flooding of the lowland. The two pedons are deep >140 m and the drainage is imperfect to poorly drained. Soil Quality Index was 0.8 whilst Nutrient Availability Index was 0.05, indicating highly suitable and marginally suitable land for rice production respectively.

Conclusion: Based on this analysis, Nkrankwanta lowland is marginally suitable (0.04) for rice production. The soil is potentially highly suitable if continuous monitoring of the pH status is carried out. Nutrient management is recommended to improve the low fertility status of the soil.

Keywords: Dormaa West district; Ghana; land suitability; low fertility status; rice cultivation.

1. INTRODUCTION

Increase in worldwide population, especially developing countries has significantly resulted in the demand for arable crops such as maize, wheat, rice among others and pressure on natural resources [1]. To meet the ever-growing food requirements of the world, current production levels must be increased to match demand [2]. Rice is the second most important arable crop in terms of worlds cereal cultivation (163 x 106 ha) and production (719.7 x 106) [3]. Rice accounts for nearly half of world's population serving as an important source of daily calories [4]. In the rural areas of Asian and sub-Saharan Africa (SSA), rice production also serves as a source of employment boosting the revenue of rural inhabitants [5].

Currently, the cultivation of rice in SSA, especially Ghana, has registered deficits largely due to small-scale resource farmers, erratic rainfall patterns, low irrigation facilities, weeds infestations, drought, an abundance of upland farms and low yielding cultivars [6]. According to [7], 70% of the total land area in Ghana are upland farms making them difficult to cultivate rice. Hence, the production of rice in the dry Semi-deciduous Agro-ecological zone of Ghana must be commercialized due to abundance of poorly drained lowlands to meet the production-consumption gap. In their works, [8] and [9] observed the high potential of the Semi-deciduous zone of Ghana for lowland rice cultivation. Generally, rain-fed rice production areas in sub-Saharan Africa (SSA), especially Ghana, are limited to floodplains, poor drained areas, valley bottoms and hydromorphic valley fringes [8].

Rice production in Ghana is limited to the inland valleys which form about 12% of the total land area [10]. However, in other countries within the sub-region such as Ivory Coast, rice is cultivated in both lowland and upland areas, provided rainfall in the upland areas is adequate to support its growth. In Ghana, inland valleys are found in fragmented portions of all the six (6) Agro-ecological zones of Ghana. However, such important rice production areas are not uniform in terms of production (yield) potential due to climatic conditions, soil type and characteristics, soil and water management practices, and social factors [8]. According to [11], soils in the region are basically poor in fertility status for crop production. However, nutrient elements such as calcium, magnesium, nitrogen, potassium, and phosphorus have been identified to be associated with the growth and development of rice [12]. To generally improve agriculture production in Ghana, several projects from both Government of Ghana (GoG) and NGO's (e.g. AGRA, RSSP) have been carried out to help improve the soils and crop yields.

As such, vital information about soil fertility status (physical and chemical properties) and site conditions of an area are necessary for land users in the cultivation of rice. Therefore, land suitability assessment is an important aspect of land-use planning which provides interpretive land or soil data for different land uses. Rainfed lowland suitability analysis is a requirement in ensuring the maximum utilization of its resources for sustainable production [13]. Land suitability analysis for crop production employs evaluation processes involving climatic variables, soil data, hydrological characteristics, slope/topography and the components of the local environment (e.g. access to land and market) [14].

Rice, like most other crops, requires specific soil conditions for optimal performance. Therefore, identification of suitable lowland rainfed areas is key in improving rice cultivation in Ghana, West Africa, and Africa as a whole. In their studies, [15] and [16] conducted suitability analysis in the Ashanti and Savannah Regions of Ghana, and Gokirmak catchment in Turkey, respectively. They used a multi-criteria approach in the evaluation of soil suitability which included data sets from social aspects of the community, environmental condition, technical know-how, and soil bio-physical characteristics. However, replicating such studies in other lowland areas/ floodplains in Ghana is difficult and challenging due to the large number of data sets involved. It is, therefore, necessary to limit such data sets in other areas which might be time consuming and resource-intensive or expensive. Studies from [13] and [17] reduced land suitability assessment criteria for rice cultivation to 8 and 6 data sets in Bangladesh and Kenya respectively. This study was therefore conducted to determine the land quality index (Nutrient Available Index and Soil Quality Index) of the Nkrankwanta lowland for rice cultivation. Knowledge about the current soil of the study site could lead to the adoption of good measures to address some soil related problems at the site, which can help promote and sustain rice production in the area.

2. MATERIALS AND METHODS

2.1 Study Site

The study was carried out in the 2019 major rainy season at the Nkrankwanta lowland field, located in the Dormaa West District of the newly created Bono Region of Ghana (Fig. 1). The lowland is situated in the western portion of the Bono Region between latitude 7°80' N to 7°25' N and longitude 2°35' W to 2°45' W [18]. Nkrankwanta lowland field lies within the semi-deciduous Agro-ecological zone of Ghana. Climatic variations in the area are noticeable by marked wet and dry seasons conditioned by the passage of the Inter-Tropical Convergence Zone (ITCZ). The lowland is characterized by a bimodal rainfall pattern with an annual rainfall of 1200mm. Mean annual temperature experienced in the lowland ranges from 26°C to 30°C. Geologically, soils in the area are characterized

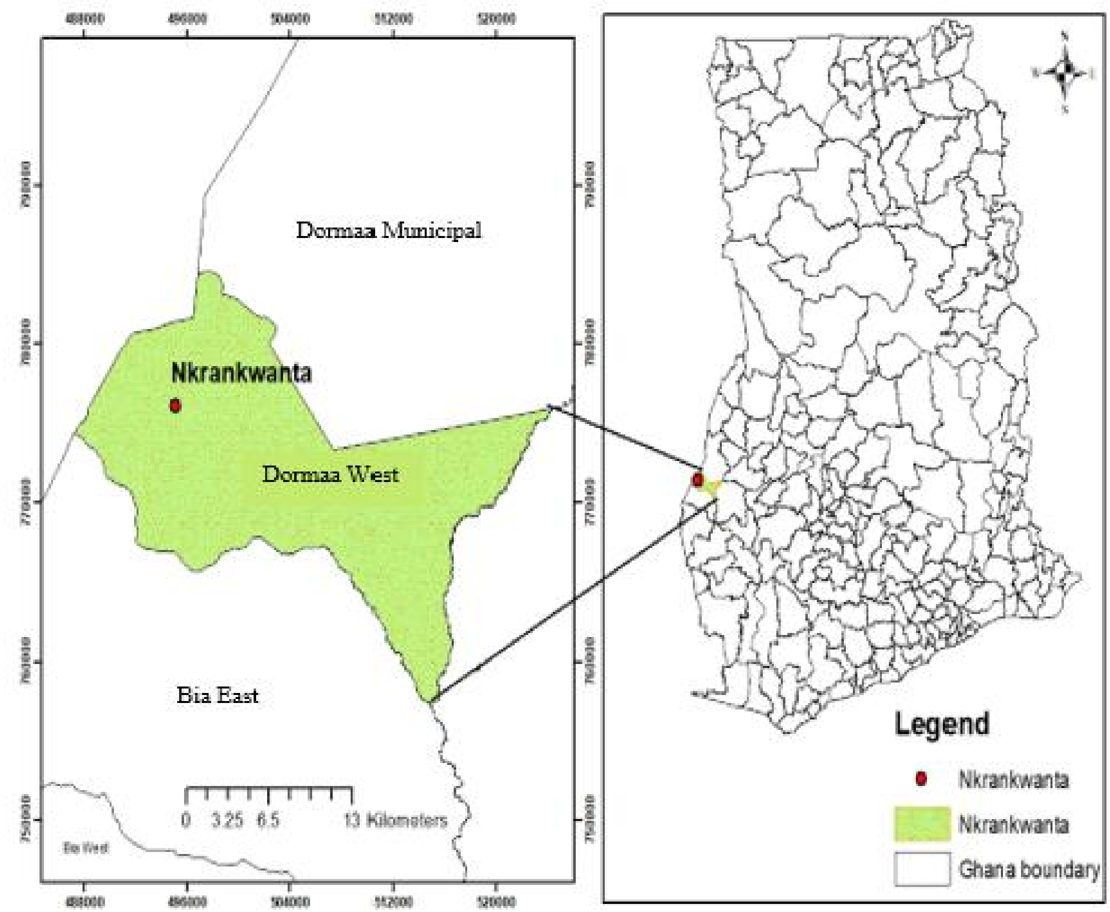

Fig. 1. Map showing the study area

Table 1. Land suitability orders, classes and index values for rice production

Order	Class	Meaning	Suitability rating	Index value
S	S1	Highly suitable	1.0	1.00 – 0.25
	S2	Moderately suitable	0.8	0.25 – 0.10
	S3	Marginally suitable	0.5	0.10 – 0.025
N	N	Not suitable	0.2	<0.025

Source: Adapted and modified from [19-22]

Table 2. Landscape and soil requirements for rain-fed wetland rice production

Land characteristics	**Suitability rating**			
	S1 = 1	**S2 = 0.8**	**S3 = 0.5**	**N = 0.2**
Topography (%)	< 2	2-5	5-8	>8
Drainage	Very poor	Moderately well/imperfect/ poor	Well	Excessive
Texture	Sandy Clay to Clay	Sandy Clay Loam Silty Loam Silty Clay Loam Loam	Loamy Silt Sandy Loam Clayey Loam	Gravels/sand
Coarse fragments (vol. %)	<5	5-15	15-35	>35
Soil depth (cm)	30-60	30-20	20-10	<10
Soil reaction (pH)	5.5-7.0	5.5-4.5, 7.0-8.0	4.5-4.0, 8.0-8.5	<4.0, >8.5
Soil N (%)	>0.2	0.1 – 0.2	<0.1	-
Available P	>25	10-25	<10	-
K^+	>60	30-60	<30	-
Soil CEC	>25	15-25	5-15	<5
Organic carbon	>10	4-10	2-4	<2

Source: Adapted from [20]

by the Birimian formation (Pre-Cambrian) belonging to the Bekwai-Nzema Compound Associations, and also accounts for the mineral exports from Ghana. The Birimian formation (Nzema Series) consists of quartz gravels and ironstone. The relief of the area is gently undulating and rises 185 m and 240 m above sea level [18]. Generally, the area is moderately well-drained and supports crops such as cassava, maize, cocoa, plantain and rice.

2.2 Land Suitability Analysis and Soil Suitability Standardization for Rice Production

Land suitability classification employed in the study was adapted from the [19-22] approach (Table 1). The [19-22] two-staged approach to land evaluation involves an initial evaluation based on the biophysical characteristics of the area, followed by a socio-economic analysis in the second stage. However, this survey was geared towards the biophysical characteristics (Soil properties, topography, and climate) of the selected lowland rice fields.

Landscape characteristics and soil requirements for rain-fed wetland rice were used for the rating of the Nkrankwanta lowland rice field (Table 2). All sensitive parameters were standardized using the FAO approach (i.e. S1, S2, S3, and N) in land evaluation for rice production [19-22].

The land quality model was used to determine the suitability of the land (Fig. 2). Sensitivity parameters relevant to the lowland rice suitability classification were collected under the biophysical parameters. Such relevant biophysical parameters included rainfall amounts (mm), landscape requirements of the lowland (e.g. slope %) and soil fertility status (e.g. pH, %N, CEC, etc) [19-23]. The model assumes the Land Quality Index (LQI) as a function of Nutrition Availability Index (NAI) and the Soil Quality Index (SQI), presented in equations 1, 2 and 3.

$$LQI = NAI \times SQI \quad (1)$$

Where,

LQI = Land Quality Index
NAI = Nutrient Availability Index
SQI = Soil Quality Index

But:

$$NAI = pH \times TN \times Av.\ P \times CEC \times O.C \quad (2)$$

Where:

pH = Soil acidity/alkalinity,
TN = Total nitrogen
Av. P = Available phosphorus,
CEC = Cation Exchange Capacity
O.C = Organic Carbon

And

$$SQI = Slope \times Soil\ Depth \times Soil\ Texture \times Soil\ drainage \times Stoniness \quad (3)$$

2.3 Soil Sampling and Analytical/ Laboratory Procedures

To help describe the lowland for soil sampling, 2 modal profile pits (pedons) were dug at a dimension of 1.5 m x 1.5 m x 1 m by dividing the lowland into two zones (upslope and downslope) which measured a total of 1.03 ha. In both pedons, 5 soil samples were collected each at a depth/horizon of 0-20, 20-40, 40-60, 60-100 and 100-140 cm. Thus, profile pits were dug up to 140 cm in both locations before cementation of the soils were observed. Soils in each horizon were composited, mixed thoroughly and a sub-sample taken to represent each horizon or depth.

Soil samples collected from each pedon were prepared for laboratory analysis. Collected samples from each horizon were further air-dried, crushed and sieved through a 2 mm sieve. All collected soil samples from each horizon in both pedons were analyzed at the Soil Research Institute (SRI) – Kwadaso, Ghana. Soil pH in the experiment was determined in a 1:2.5 soil: water suspension using an H1 9017 Microprocessor pH meter. Recorded soil organic carbon and total nitrogen in both pedons were determined by the Walkley and Black method [24] and Kjeldahl digestion and distillation procedure [25], respectively. Other chemical properties of the study area were available P and was determined by blue ammonium molybdate method using a spectronic 21 D spectrophotometer at a wavelength of 660 nm [26], exchangeable

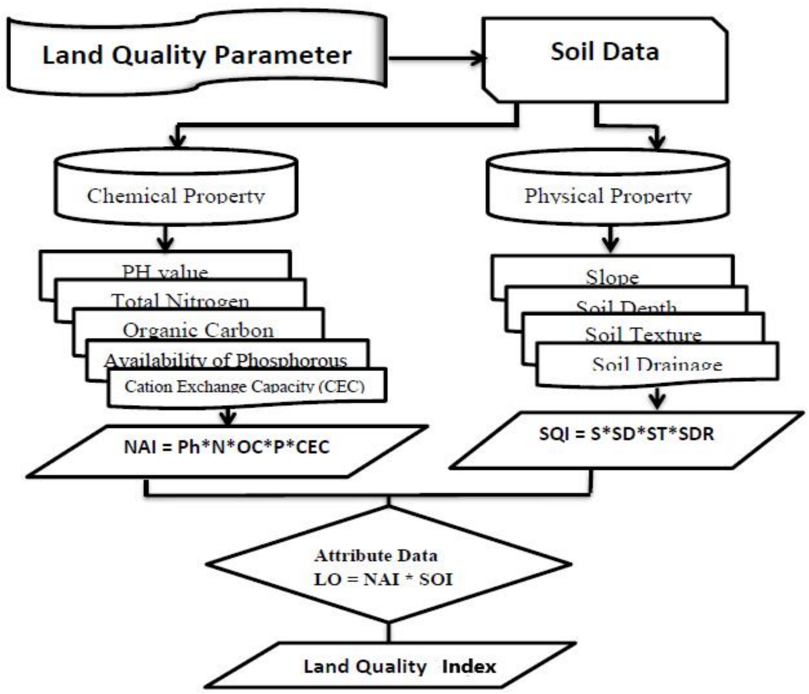

Fig. 2. Land Quality Index model for rainfed rice production. Adapted from [4]

Ca, Mg, K, and Na ($cmol_{(+)}/ kg^{1}$) soil were determined by 1.0 *M* ammonium acetate (NH_4OAc) extract [27]. Effective cation exchange capacity (ECEC) was determined by the summation of exchangeable bases (Ca^{2+}, Mg^{2+}, $K^{+,}$ and Na^{+}) and exchangeable acidity (Al^{3+} + H^{+}). The textural class of the soil was determined by the Bouyoucos hydrometer method [28], employing the USDA textural triangle to read the final soil textures.

2.4 Data Analysis

Storie criteria decision-making model was used for land suitability analysis in this study which included data sets from SQI (soil depth, slope, drainage, stoniness, and soil texture) and NAI (pH, OM, CEC, avail. P, etc). Standard parameters for rainfed rice production in the lowland were compared between the top soil (0-20 cm) and the subsoils. Results for illustrations were further presented in tables and figures.

3. RESULTS

3.1 Soil Chemical Properties

The results for the pH measurement at the Nkrankwanta lowland for both pedons generally increased with soil depth (Tables 3 and 4). In pedon 1, pH generally increased from 5.4 in the 0-20 cm horizon to 7.8 in the 60-100 cm horizon, and then declined slightly to 7.7 in the 100-140 horizon (Table 3). The pH in the top 20 cm of pedon 2 also increased from 4 to 7.1 in the 100-140 cm soil depth (Table 4). This indicates that both pedons recorded pH values which are slightly higher than the pH requirement for rice production (Table 2).

The level of total N in both pedons (Tables 3 and 4) generally fell below the range limits for rice production (Table 2). In pedon 1, total N decreased from 0.12% in the 0-20 cm depth (topsoil) to 0.01% in the 100-140 cm horizon (Table 3), whilst total N values decreased from 0.09% in the 0-20 cm horizon to 0.03% in the 100-140 cm soil depth in pedon 2 (Table 4).

Results in this study revealed that available P levels in pedon 1 was 4.54 mg kg^{-1} in the top 20 cm horizon which decreased to 1.59 mg kg^{-1} in the 20-40 cm horizon, and recorded trace levels in the subsequent horizon (Table 3). In pedon 2, the available P level was 0.48 mg kg^{-1} in the 0-20 cm horizon with trace levels recorded in the subsequent horizons except for the 40-60 cm horizon which recorded available P level of 1.91 mg kg^{-1} (Table 4).

Data from the study revealed variable amounts of organic matter (OM) irrespective of the pedon (Tables 3 and 4). Pedons 1 and 2 showed a gradual reduction of organic matter content from the 0-20 cm horizon to the 100-140 cm horizon. The OM for pedon 1 decreased down the profile from 1.61% in the 0-20 cm horizon to 0.42% in the 100-140 cm horizon (Table 3). The OM for pedon 2 also followed similar trend which generally decreased down the profile from 1.13% in the top 20 cm to 0.48% in the 100-140 cm soil depth.

Results of the exchangeable cations (Ca, Mg, Na, and K) and Total Extractable Bases (TEB) are shown in Tables 3 and 4. In pedon 1, the exchangeable cations generally increased with soil depth. The level of Ca increased from the 0-20 cm horizon to the 60-100 cm horizon, before declining in the 100-140 cm horizon. Similarly, the Mg levels, K and Na content followed the same trend which increased from the top 20 cm to the 60-100 cm horizon, before reducing in the 100-140 cm depth (Table 3). Generally, the total amounts of the extractable bases in pedon 1 followed in the order of abundance as Ca > Mg > Na > K. The total extractable bases (TEB) in the study area also increased from the 0-20 cm horizon with a mean value of 5.5 $cmol_{(c)}$ kg^{-1} to 51.17 $cmol_{(c)}$ kg^{-1} in the 60-100 cm horizon, and declined in the 100-140 cm horizon with a recorded value of 31.96 $cmol_{(c)}$ kg^{-1}. Nkrankwanta pedon 2 showed a similar trend of exchangeable cations as shown in pedon 1 and which generally followed in the order Ca > Mg > Na > K.

Percentage Base Saturation (PBS) values recorded in both pedons at Nkrankwanta lowland fields were generally high. The PBS of pedon 1 increased with an increase in soil depth. It increased from 91.7% in the top 20 cm horizon to 163.0% in the 60-100 cm horizon but decreased to 78.3% in the bottom (110-140 cm) horizon (Table 3). The PBS of pedon 2 also followed a similar pattern as pedon 1, increasing from 84.9% in the 0-20 cm horizon to 99.4% in the 60-100 cm horizon, but decreased to 55.2% in the 100-140 cm horizon (Table 4).

The Effective Cation Exchange Capacity (ECEC) for Nkrankwanta pedon 1 and 2 generally increased with depth (Tables 3 and 4). The ECEC of pedon 1 increased from the 0-20 cm

Table 3. Selected chemical properties of the Nzema series in Nkrankwanta lowland field of the Dormaa West district (Pedon 1)

Depth	pH	% OM	% N	P $mgkg^{-1}$	Extractable cations $cmol_{(c)}\ kg^{-1}$				TEB	Ex. Acid	ECEC	PBS
					Ca	Mg	K	Na				
0-20	5.4	1.61	0.12	4.54	3.2	1.6	0.28	0.42	5.50	0.5	6.00	91.7
20-40	5.5	0.83	0.07	1.59	3.74	1.6	0.28	0.54	6.16	0.4	6.60	93.9
40-60	7.6	0.65	0.03	Trace	28.57	7.48	1.68	1.47	39.20	0.1	32.4	120.8
60-100	7.8	0.54	0.03	Trace	40.05	7.21	2.11	1.8	51.17	0.1	31.4	163.0
100-140	7.7	0.42	0.01	Trace	20.83	8.28	1.43	1.42	31.96	0.1	40.8	78.3

Source: Field survey, 2019

Table 4. Selected chemical properties of the Nzema series in Nkrankwanta lowland field of the Dormaa West district (Pedon 2)

Depth	pH	% OM	% N	P $mgkg^{-1}$	Extractable cations $cmol_{(c)}\ kg^{-1}$				TEB	Ex. Acid	ECEC	PBS
					Ca	Mg	K	Na				
0-20	4	1.13	0.09	0.48	4.81	1.07	0.35	0.51	6.74	1.2	7.9	84.9
20-40	6.1	0.89	0.04	Trace	8.01	5.07	0.95	1.26	15.29	0.15	15.4	99.0
40-60	6.7	1.13	0.05	1.91	7.48	4.54	0.63	1.00	13.65	0.1	13.8	99.3
60-100	6.7	0.54	0.03	Trace	9.08	4.01	0.8	1.38	15.27	0.1	15.4	99.4
100-140	7.1	0.48	0.03	Trace	9.35	7.21	0.78	1.13	18.47	0.1	33.5	55.2

Source: Field survey, 2019

horizon with 6 cmol/kg to 32.4 cmol/kg in the 40-60 cm horizon, decreased to 31.4 cmol/kg in the 60-100 cm horizon and further increased in the 100-140 cm horizon to 40.8 cmol/kg (Table 3). A similar trend was observed in pedon 2, where the ECEC increased from the top 20 cm horizon with 7.9 cmol/kg to 33.5 cmol/kg in the 100-140 cm soil depth. Thus, the ECEC of pedon 2 also increased with an increase in depth (Table 3). Generally, as the clay content of the soil increased from the top to the bottom, the ECEC also increased and vice versa (Figs. 7 and 8).

3.2 Soil Physical Properties

The result on the particle size distribution for the Nzema series of the Nkrankwanta lowland are given in Tables 5 and 6. The soils were generally silty loam in the top horizon but silt clay texture at the bottom for Nkrankwanta pedon 1 and silty clay loam and silty clay for Nkrankwanta pedon 2. The particle size for pedon 1 was generally in the order %Silt > %Clay > %Sand, except in the 0-20 cm soil horizon and 20-40 cm soil horizon where %Sand was > %Clay, that is 19.3% and 24.3% for sand and also 10% and 18% for clay respectively (Table 5). Though %Silt was the highest, it decreased with depth, from 70.7% in the top 20 cm horizon to 39.8% in the 60-100 cm soil horizon but increased to 47.4% in the 100-140 cm soil depth.

The particle size distribution for pedon 2 followed similar trend in the order %Silt > %Clay > %Sand. %Silt decreased from the top 20 cm horizon to 40-60 cm soil horizon that is 78.9% to 49.4 %, but increased to 52.8% in the 60-100 cm horizon and further decreased to 49.1% in the 100-140 cm horizon (Table 6). %Clay increased with depth from 16% in the 0-20 cm horizon to 40% in the 40-60 cm horizon but decreased to 34% in the 60-100 cm horizon, and further increased to 40% in the 100-140 cm soil depth.

The soil depth of the Nkrankwanta lowland ranged from 0- 140 cm from both pedons. Generally, the topography at the lowland was < 2% (Tables 5 and 6) which is highly suitable for rice cultivation. From the Tables 5 and 6, the lowland experiences a poorly drain characteristics for rice production with stoniness/ coarse fragments < 5%.

3.3 Nkrankwanta Soil Suitability Classification

From the data above, LQI, NAI and SQI ratings could be computed by substituting the suitability ratings from the values of the chemical and physical properties of the lowland into equations 1, 2 and 3.

Table 5. Selected physical properties of the Nzema series in Nkrankwanta lowland field of the Dormaa district (Pedon 1)

Depth cm	Particle size distribution %			Texture	Slope %	Drainage
	Sand	Silt	clay			
0 – 20	19.3	70.7	10	Silt Loam	< 2%	Poorly drain
20 – 40	24.3	57.7	18	Silt Loam		
40 – 60	12.6	41.4	46	Silty Clay		
60 – 100	18.2	39.8	42	Silty Clay		
100 – 140	10.6	47.4	42	Silty Clay		

Source: Field survey, 2019

Table 6. Selected physical properties of the Nzema series in Nkrankwanta lowland field of the Dormaa district (Pedon 2)

Depth cm	Particle size distribution %			Texture	Slope	Drainage
	Sand	Silt	clay			
0 – 20	5.1	78.9	16	Silt Loam	< 2%	Poorly drain
20 – 40	6.2	57.8	36	Silty Clay Loam		
40 – 60	10.6	49.4	40	Silty Clay		
60 – 100	13.2	52.8	34	Silty Clay Loam		
100 – 140	10.9	49.1	40	Silty Clay		

Source: Field survey, 2019

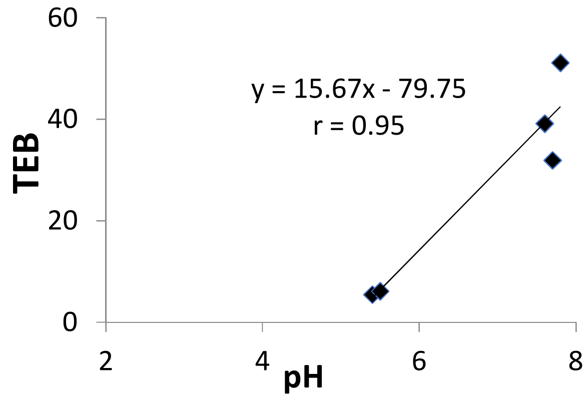

Fig. 3. Correlation between pH and TEB of Nkrankwanta Lowland (pedon 1); r = the correlation coefficient

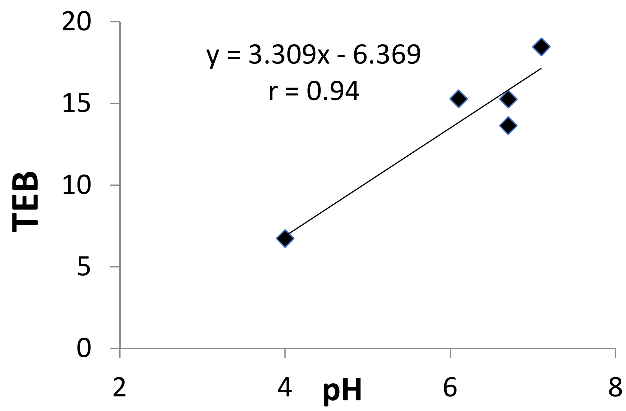

Fig. 4. Correlation between pH and TEB of Nkrankwanta Lowland (pedon 2); r = the correlation coefficient

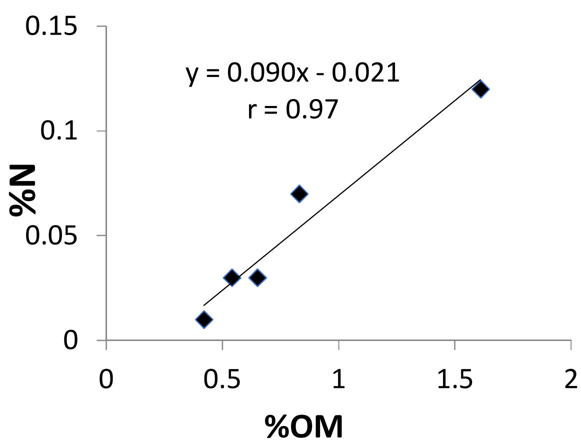

Fig. 5. Correlation between % organic matter and % nitrogen of Nkrankwanta lowland (pedon 1); r = correlation coefficient

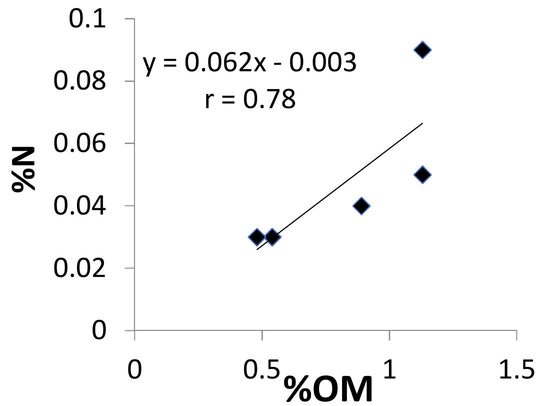

Fig. 6. Correlation between % organic matter and % nitrogen of Nkrankwanta lowland (pedon 2); r = correlation coefficient

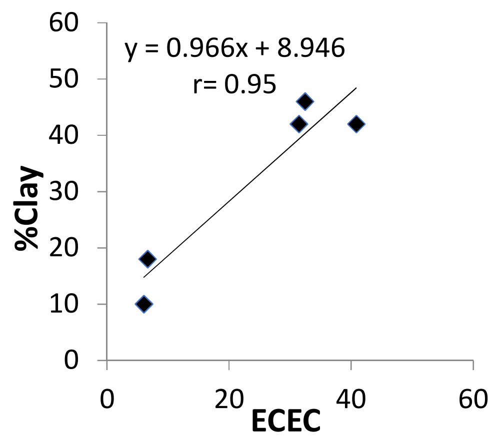

Fig. 7. Correlation between ECEC and % Clay of Nkrankwanta lowland (pedon 1); r = correlation coefficient

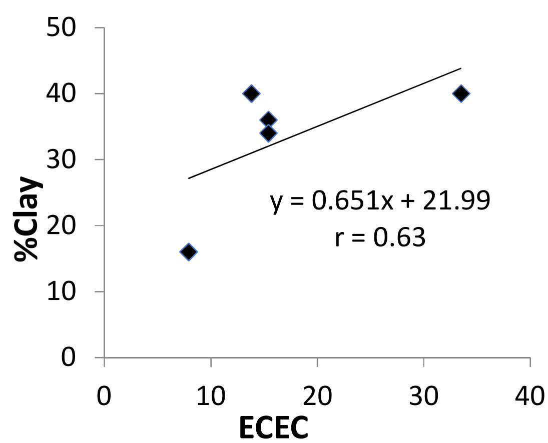

Fig. 8. Correlation between ECEC and % Clay of Nkrankwanta lowland (pedon 2); r = correlation coefficient

NAI = pH x TN x Av. P x CEC x O.C = 0.5 x 0.5 x 1 x 0.2 = 0.05

Where:

pH = Soil acidity/alkalinity = S3 = 0.5;
TN = Total nitrogen = S3 = 0.5
Av. P = Available phosphorus = S3 = 0.5;
O.C = Organic carbon = N = 0.2
CEC = Cation exchange capacity = S1 = 1
SQI = S x D x ST x SD x S = 1 x 1 x 0.8 x 1 x 1 = 0.8

Where:

Slope = S1 = 1;
Soil depth = S1 = 1;
Soil texture = S2 = 0.8
Soil drainage = S1 = 1;
Stoniness = S1 = 1

Therefore LQI = NAI x SQI = 0.05 x 0.8 = 0.04

4. DISCUSSION

4.1 Soil Chemical Properties

The pH of soils is a key property that provides an insight into the overall soil chemical processes. Though the pH range is in the tolerance range of pH 4.0 – 8.0 for rice, the pH level of the 0-20 cm horizons is too close to the critical lower limit of pH 4.0. The soil pH of the Nkrankwanta lowland confirms the findings of [11] who stated that the pH of most Ghanaian soils is generally acidic to neutral. The very strong acidic values were as a result of chemical fertilizer usage by farmers, as well as leaching of basic cations due to the regular flooding of the lowland. This low pH, especially in the top horizons, indicates a significant amount of exchangeable hydrogen (H) present, in addition to exchangeable aluminium (Al) and this decreases the availability of basic cations as evident by the low ECEC (Tables 3 and 4). This explains why phosphorous (P) was acutely deficient in all the soils observed. At low pH, P becomes fixed and unavailable for plant use.

The most important element for plant growth and development is nitrogen (N). Hence, whether it is deficient or in excess, can directly but negatively affect the yield of crops. According to [29], average nitrogen (N) concentration in cultivated soil is 0.15%. As such, N values >1% is considered very high, and <0 – 0.1% is very low and problematic for rice production. Therefore, values recorded at Nkrankwanta lowland rice field ranged from 0.01% to 0.12%, which is generally from very low to low rating [30]. This confirms the earlier works of [8] who concluded that soils in semi-deciduous zone of Ghana are low in total N, carbon, and pH. The low values of N registered in the lowland was due to continuous cropping and inadequate organic amendments in the topsoil.

In most agricultural croplands, elemental phosphorus is considered to be the second most limiting plant nutrient after nitrogen [31]. The results indicated that topsoil P was greater than subsoil P which is often associated with added P sorption, greater biological activities, and accumulation of organic materials. Therefore, available P values less than (<) 3 is considered acutely deficient whereas P > 22 is rich [30]. The current values of P recorded at the field for both pedons ranged from trace levels to 4.54 mg kg^{-1} with trace levels recorded in almost all the horizon under study, which suggest acute P problems [8]. The low levels of P could be attributed to the low pH of the top 0-20 cm horizon, which is very strongly acid. Consequently, at low pH, P becomes fixed and unavailable for plant use.

The bases extracted from the two pedons were generally lowly rated [30] confirming the studies of [32]. The authors revealed that basic cations in their studies were generally in the order of Ca > Mg > Na > K, with this element been dominant in low rainfall areas. A positive correlation was observed between TEB and pH of the soil in both pedons (Figs. 3 and 4). The significance of this correlation is that, as pH increases, the basic cations become available for plant use and also Al becomes less toxic to plant.

The two pedons of the Nkrankwanta lowland recorded variable levels of soil OM. These low OM levels attest to the findings of [11] and [33] who stated that the OM content of the Nzema series is < 1.8%. This low organic matter content could be attributed to continuous cropping at the lowland or may be due to the poorly drained nature of the Nzema series which is subjected to periodic flooding. In their works, [9] concluded that soils with relatively higher amounts of soil OM will mineralize to add more elemental N to the soil and vice versa. A positive correlation was observed between OM and N of the soil in both pedons. This implies that, as OM decreases, there is a resultant decrease in N of the soil and vice versa (Figs. 5 and 6).

Percentage Base Saturation (PBS) values are indicative of the degree of leaching of that soil. The PBS values at the Nkrankwanta lowland fields were generally high [34]. Low PBS values indicate a high degree of leaching of the basic cations and their replacement by Al and H and vice versa. Although the extractable bases were low to moderate, the base saturation was very high. Base saturation > 100% recorded in some of the horizon of pedon 1 was due to the many calcium carbonate nodules present in the soil [35] and thus calcium was extracted from the nodules as well as the exchange sites on colloids. The high base saturation of the Nkrankwanta lowland confirms the findings of [36], who stated that the high levels of base saturation in Ghana is as a result of the deposition of Harmattan dust. Hence, the result from both pedons indicates a high PBS which means low leaching in the Nkrankwanta lowland.

The capacity of a soil to hold cations also gives an indication of the fertility status of the soils. The Effective Cation Exchange Capacity (ECEC) for Nkrankwanta pedon 1 and 2 generally increased with depth. Generally, the ECEC for both pedons ranged from 6.0 to 40.8. It could be concluded that the soil in the study area contains enough cations to support plant growth [30]. Under acid conditions, however, ECEC is a better measure since Al and H is a key factor influencing the availability of other plant nutrients. As evident from the study, ECEC levels range from low to high mainly as a result of very appreciable levels of Ca and Mg [30]. Generally, as the % clay content of the soil increased (Tables 3 and 4) from 0-20 cm to 100-140 cm soil depth, ECEC also increased and vice versa. A positive correlation was observed between ECEC and % Clay content of the soil in both pedons (Figs. 7 and 8). This further implies that as the ECEC increased, the soil can hold more cations and exchange these same ions which can be made available for plant usage.

4.2 Soil Physical Properties

The particle size distribution of soils at the Nkrankwanta lowland was generally silty loam in the top horizon but silt clay texture at the bottom for Nkrankwanta pedon 1 and silty clay loam and silty clay for Nkrankwanta pedon 2 respectively (Tables 5 and 6). Though %Silt was the highest, it generally decreased with soil depth. %Clay generally increased with depth from the top 20 cm horizon to the 100-140 cm horizon. The clay enrichment in the underlying horizon implies the formation of an argillic (Bt) horizon in the pedon. The high clay content beneath 50 cm depth in both pedons could be attributed to illuviation of clay from the horizons above it [37]. This corroborated with the findings of [11] reported that the Nzema series is poorly drained and flooded during the onset of the rainy season. However, this soil develops a very massive, compact clay layer below the sandy topsoil during the dry season. The textures of the lowland are silty loam in the top horizon to a depth of about 60 cm and silty clay/ silty clay loam in the underlying horizons which are moderately suitable for lowland rice.

The Nzema series at Nkrankwanta lowland field is deep, medium and heavy textured, at least in the subsoil and poorly drained. The Topography/slope of Nkrankwanta lowland is gently undulating and has a gradient of < 2 % (Tables 5 and 6) which is highly suitable for lowland rice production.

Drainage characteristics of the lowland are poorly drain and are highly suitable for lowland rice production (Tables 5 and 6). Even though stone concretions were present, the coarse fragment (vol. %) or stoniness was generally < 5 % which is highly suitable for rice cultivation. The soils at Nkrankwanta lowland is very deep > 140 cm and is highly suitable for rice production.

4.3 Nkrankwanta Soil Suitability Classification

Nutrient Availability Index (NAI) recorded a suitability rating of 0.05 which translates to marginally suitable for rice cultivation. Marginally suitable NAI is accounted for by the low values recorded for the soil chemical parameters (e.g. pH, ECEC, total N., etc) measured. Soil Quality Index (SQI) also recorded a suitability rating of 0.8 which is excellent for rice production. Generally, topography, soil depth, coarse fragments/ stoniness, and drainage were all highly suitable with the exception of soil texture which was moderately suitable for rice production. Hence, SQI is highly suitable for the cultivation of rice in the Nkrankwanta lowland for rice cultivation.

Based on the recorded values for Nutrient Availability Index (NAI) and Soil Quality Index (SQI), the Land Quality Index or Soil Suitability rating of the Nkrankwanta lowland is 0.04 which is marginally suitable for rice cultivation. This low value of LQI is attributed to the low NAI value of the lowland.

5. CONCLUSION

The Nkrankwanta lowland is within the dry semi-deciduous agro-ecological zone of Ghana, where rainfall is characteristically bimodal. Based on SQI, the terrain of the lowland is gently undulating. The soil is very deep > 140 cm and is poorly drained. The texture is silty loam in the top horizon to a depth of about 60 cm and silty clay/silty clay loam in the underlying horizons, hence, Soil Quality Index of the Nkrankwanta lowland is highly suitable (0.8) for rice cultivation. Soil reaction (pH) was in the range of 4 – 7.7 indicating very strong acid to slightly alkaline and is in the tolerance range for rice cultivation. The soil is also deficient in nitrogen, phosphorus and exchangeable bases especially magnesium. Organic matter content of the soil is low from 0.42% to 1.61%. This makes the Nutrient Availability Index marginally suitable (0.05) for rice production.

On the basis of the measured physical and chemical parameters of this soil, the suitability assessment of Nkrankwanta lowland is marginally suitable (0.04) for rice cultivation. The limiting factors of the Nkrankwanta lowland are the soil chemical properties (pH, T.N., Organic matter content, CEC, Available P, etc). Hence, Nkrankwanta lowland is potentially highly suitable for rice cultivation if the following land management practices are improved by farmers:

- The addition of organic matter and the incorporation of crop residues in the lowland. This can be done in combination with mineral fertilizers, especially nitrogen and phosphorus fertilizers to increase and sustain the productivity of the soils and crop yields.
- Proper land preparation methods which include levelling and bund construction to aid water control and soil management (e.g. control erosion).
- Liming may be considered since pH levels of the top 20 cm soil layers are too close to the critical lower limit of pH 4.0. This will ensure good crop growth and high yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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