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Fertility status, Degradation Rate and Vulnerability Potential of Soils of Sowa Chiefdom in Southern Sierra Leone

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Abstract

The present research was undertaken to study the fertility status of physicochemical properties and assess the degradation rate and vulnerability potential of soils of Sowa Chiefdom and suggest best management practices. Thirty-two composite samples from 0-20 and 20-40 cm were collected at fifteen locations and studied. The soils exhibited an irregular trend in particle size distribution with high proportion of sand in decreasing trend of sandy loam > sandy clay loam > loamy sand > sandy clay > clay. The soils were slightly acidic to moderately acidic in soil reaction (soil pH) with low to high organic carbon, medium to high nitrogen and low to high phosphorus. The content of exchangeable Ca^{2+} was medium to high, exchangeable Mg^{2+} was high, exchangeable Na^{+} was low to high and exchangeable K^{+} was low. The level of exchangeable acidity was low although the pH was slight to moderately acidic. The effective CEC values were within themedium to high range and the base saturation was high, thus indicating the potential availability of basic elements in the soils. The organic carbon, total nitrogen, available phosphorus, exchangeable Ca and Mg and base saturation were neither degraded nor vulnerable to degradation and therefore better soil quality indicators while exchangeable K was extremely degraded and highly vulnerable to degradation and therefore a poor soil quality indicator. The texture, soil pH, exchangeable Na and effective CEC showed moderate rate of degradation and vulnerability and these might be good soil quality indicators in the long term if the recommended soil management strategies are adopted.

Key words: Fertility status, degradation rate, vulnerability potential, Sowa chiefdom, Sierra Leone.

Introduction

Soil fertility plays an important role in sustaining crop productivity of any area, particularly in situations where input of nutrients application differs and the information on the nutritional status can go a long way to develop economically viable alternatives for management of deficient nutrients in the soil[1]. **S**oils of Sierra Leone have inherently low fertility and do not receive adequate nutrient replenishment and with many farmers typically applying insignificant amounts of fertilizers, coupled with continuous cropping, soil degradation and declining soil fertility continue to pose major threat to sustainable food production by smallholders [2]. Coupled with other constraints including soil moisture stress, low nutrient capital, erosion risks, low *p*H with aluminium (Al) toxicity, high phosphorus (P) fixation, low levels of soil organic matter, poor farming methods and a loss of soil biodiversity, it has been reported that food security may not be achieved in the near future unless urgent intervention measures are undertaken [3].

Soils in Sierra Leone differ in their physical and chemical characteristics and productivity due to differences in physiography. Deficiencies of available major and micronutrients are widespread and information on soil fertility status is lacking [1]. Therefore, a good knowledge of soil resources is indispensable for the planning of agricultural development and achieving food security in Sierra Leone. However, limited research has been done to study the soil resources. The country recorded high agricultural productivityin the 70s and 80s but over the past two decades productivity has declined due to several reasons including the 11 years rebel war which devastated the country's farming communities. Being resource limited, most smallholders cannot afford the conventional soil fertility management strategies dominated by high use of inorganic fertilizers and agrochemicals considering their escalating prices. As a result, many of these farmers are dependent on short-term natural fallow to maintain soil fertility. A recent report by [2] has indicated that the high level of deforestation, poor management practices and lack of inputs have led to a decline in productivity, soil erosion and loss of vegetation in most part of Sierra Leone. Hence, the present study was carried out to assess the soil fertility status and ascertain the rate of soil degradation and vulnerability potential of soils of Sowa chiefdom and suggest possible management strategies that could help improve the quality and productivity of soils.

Materials and Methods

Description of the study area

The study area is located between 7°29'46" to 7°36'0" N latitude and 11°33'17" to 11°40'0" W longitude in Sowa Chiefdom, Pujehun District, Southern Province of Sierra Leone. The soils of Sowa chiefdom have been classified as soils of the interior plain developed from acid igneous and metamorphic rocks [4]. These soils have a deep gravel-free, colluvial layer over gravelly lower subsoil capable of supporting a great variety of crops including tree crops like rubber, oilpalm and coffee.

The climate is tropical with two distinct seasons determining the agricultural cycle, *viz.*, rainy season which starts from May to November and dry season from December to May. The average temperature is 26 °C and varies from around 26 °C to 36 °C during the year [5]. The average annual rainfall is 3067 mm, which is highest at the coast, 3000-5000 mm. The original vegetation had been a primary rain forest. However, this vegetation has been destroyed by human activities. Primary forest remains in only a few places, one of which is the Tiwaii forest reserve area. The predominant vegetation at present is a rather low secondary bush or farm bush, which covers the upland and terraces. The swamps and bollis have predominantly grassy vegetation.

Major land use systems are agriculture, grassland, forest and tree cropping (plantations) but agriculture is most prevalent, comprising of upland mixed farming and swamp farming.

Soil sampling and analysis

All terrain observations were done with a hand-held GPS along traverses at an interval of 1 km^2 distances.In these survey lines, thirty-two composite soil samples were collected at the two depths, *viz.*, 0-20 and 20-40 cm from sixteen locations in the study area (Fig. 1). The collected soil samples were processed and analyzed for interpretation of soil health status. Particle size analysis was carried out by hydrometer method [6] using sodium hexametaphosphate (calgon) as dispersant. Soil pH was determined in soil water ratio of 1:2.5 usinga glass electrode pH meter. Organic carbon was determined by the Black [7] method while total nitrogen was by the Kjeldahl digestion method [6]. Available phosphorus was determined following the method of [8]. Exchangeable bases (Ca, Mg, K and Na) were extracted in 1 N NH_4OAc at pH 7. Potassium and sodium were determined with a flame photometer while Ca and Mg were determined by the EDTA titration method [9]. Exchangeable acidity was by titration method using 1 N KCl extract as recommended by [10]. Effective cation exchange capacity was a summation of exchangeable bases (Ca, Mg, K and Na) and exchangeable acidity. Percent base saturation was obtained by dividing the total exchangeable bases (Ca, Mg, K and Na) by the effective cation exchange capacity multiplied by 100.

Soil degradation rating (SDR)/vulnerability potential (Vp)

The rating scheme for soil degradation (SDR) and vulnerability potential (Vp) suggested by [11] and guidelines for interpretation of soil physicochemical properties by [12]were used in the present study.For the SDR, the weighting sequence was as follows: 1 = none, 2 = slight, 3 = moderate, 4 = severe and 5 = extreme. In this way, good soils have the lowest SDR and poor soils the highest value. For the vulnerability potential, the weighting order was the reverse as follows: 5 = none, 4 = low, 3 = moderate, 2 = high and 1 = very high [11].

Statistical analysis

The data collected were analysed using SPSS software and the results were presented as mean, range and standard deviation.

Results and Discussion

Soil physical properties

According to the results (Tables 1and 2), the soils of the study area are high in sand content. The sand fraction of surface soils (0-20 cm) ranged from 32-81 per cent with a mean of 61 per cent. Silt fraction ranged from 10-33 per cent with a mean of 16 per cent while clay content varied from 5-55 per cent with a mean of 22 per cent. In subsurface soils (20-40 cm), sand fractions ranged from 33-84 per cent with a mean of 60 per cent, silt fraction varied from 9-26 per cent with a mean of 17 per cent while clay fraction ranged from 3-54 per cent with a mean of 23 per cent. In general, the texture of soils showeda decreasing trend with sandy loam > sandy clay loam >loamy sand > sandy clay > clay. The soils exhibited an irregular trend in particle size distributionwith high proportion of sand whichcould be attributed to the high rainfalland variation in weathering of parent material[13].

Soil chemical properties

*pH:*The soil pH ranged from 4.78-6.7 with a mean of 5.43 in surface soils (Table 1) and 4.75-6.64 with a mean of 5.44 in subsurface soils(Table 2), which indicates that the soils are slightly acidic to moderately acidic. The acidic nature of the soils might be attributed to the acid igneous and metamorphic rocks parent material [4], their well-drained condition due to high sand fractions[13] and high rainfall which could leach out basic cations from the soil solum [14].The subsurface soils showed lower pH than surface soils. This could be due to leaching out of large amount of bases from the solum as a result of high proportion of macro pores, leaving behind iron and aluminium oxides. According to [15], decreasing content of exchangeable bases and their complete downward leachingmight lead to decreasing pH with depth.In addition, the low pH observed is likely to cause acid potent cations in the long run due to the high rainfall prevailing in the study area and this might encourage leaching of base forming cations from the surface and their accumulation in lower layers. However, the moderate acidity implied that nutrients are likely to be available for crop uptake. According to [16], pH range of 5.5- 6.5 is optimum for the release of plant nutrients.

*Organic carbon:*The organic carbon content ranged from 11.6-30.3 g kg^{-1} with a mean of 20.8 g kg^{-1} in surface soils (Table 1) and 6.7-16.1 g kg^{-1} with a mean of 10.9 g kg^{-1}in surface soils(Table 2). According to the guidelinesfor rating soil fertility indicators suggested by [12], the soils of the study area could be categorized as having low tohigh amount of organic carbon content. As expected, the organic carbon content was observed to decrease with increasing depth. The surface soils contained higher organic carbon than subsurface soils. The high amount of organic carboncould be attributed to the high amount of litter and crop residues at the surface layers and rapid rate of organic matter mineralization.

*Total nitrogen:*The total nitrogen ranged from 1.0-2.7 g kg^{-1} with a mean of 1.8 g kg^{-1} in surface soils (Table 1) and 0.1-1.0 g kg^{-1} with mean of 0.7 g kg^{-1} in subsurface soils(Table 2). As with organic carbon, the total nitrogen content decreased with depth. The surface soils contained higher nitrogen levels than subsurface soils. This high nitrogen content in surface soils could be attributed to the high organic carbon content.The study revealed that the total nitrogen content of the soils could be categorized as medium to high according to the guidelines suggested by [12], except for one subsurface sample which recorded a nitrogen content of 0.1 g kg^{-1}. In filed crops especially cereals, nitrogen is a very important nutrient of high demand because these crops are by nature incapable of fixing the free atmospheric nitrogen.

*Available phosphorus:*The available phosphorus ranged from 7.4-62.7 mg kg^{-1} with a mean of 17.4 mg kg^{-1} in surface soils (Table 1) and 12.9-128.8 mg kg^{-1} with a mean of 38.3 mg kg^{-1} in subsurface soils(Table 2). According to the guidelinesfor rating soil fertility indicators suggested by [12], the soils of the study area could be categorized as having low tohigh amount of phosphorus. The most limiting nutrient in tropical soils can be regarded as soil nitrogen followed by phosphorus [11] and according[2], the soils of Sierra Leone are known to be deficient in available phosphorus. However, the present study has revealed that there is an need for soil scientists to review the phosphorus status of soils of Sierra Leone in order to ascertain whether the widely held notion of low phosphorus in soils of Sierra Leone is still holding or not.

*Exchangeable bases:*The exchangeable bases of soils were in the order of Ca^{2+}> Mg^{2+}> Na^{+}> K^{+} on the exchange complex. Exchangeable bases were as follows: Ca (4.38-9.5 cmol (+) kg^{-1} with a mean of 6.21 cmol (+) kg^{-1} in surface soils and 4.44-11.72 cmol (+) kg^{-1} with a mean of 6.35 cmol (+) kg^{-1} in subsurface soils), Mg (1.32-5.64 cmol (+) kg^{-1} with a mean of 3.47 cmol (+) kg^{-1} in surface soils and 1.8-8.42 cmol (+) kg^{-1} with a mean of 3.54 cmol (+) kg^{-1} in subsurface soils), Na (0.08-0.48 cmol (+) kg^{-1} with a mean of 0.28 cmol (+) kg^{-1} in surface soils and 0.03-0.43 cmol (+) kg^{-1} with a mean of 0.26 cmol (+) kg^{-1} in subsurface soils) and K (0.06-0.15 cmol (+) kg^{-1} with a mean of 0.09 cmol (+) kg^{-1} in surface foils and 0.04-0.14 cmol (+) kg^{-1} with a mean of 0.09 cmol (+) kg^{-1} in subsurface soils)(Tables 1and 2). The trend showed that the exchange complex was mostly saturated with Ca^{2+} followed by Mg^{2+}, Na^{+} and K^{+}. This order of abundance was in accordance with [17] view that the leaching causes preferential losses of Na^{+} and K^{+}. The higher values of exchangeable Ca/Mg ratio indicated a decrease in extractable magnesium content in the soils.From the distribution of Ca^{2+} and Mg^{2+}, it was evident that Ca^{2+} showed the strongest relationship with all the species. Mg^{2+} was present in low amount than Ca^{2+}. This could be attributed to its higher mobility. The low value of exchangeable monovalents compared to divalents might be due to the preferential leaching of monovalents compared to divalents [18]. According to the guidelinesfor rating soil fertility indicators suggested by [12], the soils of the study area could be categorized as having medium to high content of exchangeable Ca^{2+}, high content of exchangeable Mg^{2+}, low to high content of exchangeable Na^{+} and low content of exchangeable K^{+}.However, the high content of exchangeable Na^{+}should be noted as a point of concern because Na concentration is not recommendable to high level as it deteriorates soil structure and make the soil liable to soil erosion and being devoid of beneficial organisms [19].

*Exchangeable acidity:*The exchangeable acidity ranged from 0.12-1.63 cmol (+) kg^{-1} with a mean of 0.51 cmol (+) kg^{-1} in surface foils (Table 1) and 0.1-0.7 cmol (+) kg^{-1} with a mean of 0.4 cmol (+) kg^{-1} in subsurface soils(Table 2). Although the pH showed that the soils are slight to moderately acidic, the acidity nature of soils was not as evident as exchangeable acidity values were low when compared with the ratings given by [20], even though the impact of such low values in the soils solution could still be significant in terms of influencing the biochemical behaviour of the soils [14].

*Effective Cation Exchange Capacity (ECEC):*The ECEC ranged from 7.32-15.84 cmol (+) kg^{-1} with a mean of 10.57 cmol (+) kg^{-1} in surface soils (Table 1) and 7.6-20.6 cmol (+) kg^{-1} with a mean of 10.6cmol (+) kg^{-1} in subsurface soils(Table 2). According to the results of the study, the effective CEC values fell within themedium to high range suggested by [12]. Cation exchange capacity is the dominant factor in measuring soil fertility which affects exchange of ions on the clay surface. The effective CEC of subsurface soils was higher than those of surface soils and above 7.5 cmol (+) kg^{-1}, the minimum level for adequate exchange capacity according to soil fertility capability classification system suggested by[21], except for one surface sample which had 7.32 cmol (+) kg^{-1}. The high effective CEC in subsurface soils could be attributed to the high organic carbon content of these soils and the accumulation of bases in subsurface layers due to leaching from surface layers.

*Base saturation:*The base saturation of the soils ranged from 88.1-98.7 per cent with a mean of 95.3 per cent in surface soils(Table 1) and 92.1-99.4 per cent with a mean of 96.1 per cent in subsurface soils(Table2). The base saturation was high in both surface and subsurface soils according to the guidelines for rating soil fertility indicators suggested by [12]. This is an indication of the potential availability of basic elements in the soils of the study area.

Soil degradation rating (SDR) and vulnerability potential (Vp) of soils

Tables 3 and 4 present the rate of soil degradation and vulnerability potential of the soils of the study area. Eleven soil fertility limiting parameters, viz., texture, soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable Ca, Mg, Na and K, effective CEC and base saturation were evaluated and used to assess the rate of soil degradation (SDR) and vulnerability potential (Vp) of the soils of the study area. The study revealed that the organic carbon, total nitrogen, available phosphorus, exchangeable Ca and Mg and base saturation of soils are neither degraded nor being vulnerable to degradation as the SDR/Vp weighting factors showed a ratio of 1/5 which indicated that soils are not degraded and not vulnerable to degradation. On the contrary, the texture, soil pH, exchangeable Na and effective CEC of soils showed an SDR/Vp weighting factor ratio of 3/3 indicating that these parameters are moderately degraded and moderately vulnerable to degradation. The exchangeable K status of the soils seemed to be more alarming with the SDR/Vp weighting factor ration of 5/1 which showed that the soils have suffered extreme rate of soil degradation and have very high vulnerability potential respectively.

Based on the principles and guidelines that “a good soil quality has the least SDR and a poor soil quality has highest SDR and vice versa for Vp” [22], the study revealed that the better soil quality indicators were organic carbon, total nitrogen, available phosphorus, exchangeable Ca and Mg and base saturation while the poor soil quality indicator was exchangeable K. However, though texture, soil pH, exchangeable Na and effective CEC showed moderate rate of degradation and vulnerability, they might be good soil quality indicators in the long term if the recommended soil management strategies are adopted.

Sustainability of land use

The sustainability of the land use in the study area has been assessed in relation to the cumulative rating index based on the eleven soil quality indicators as suggested by [11]. Based on the cumulative rating index for SDR and Vp of soils and the principle that a sustainable land use has a low cumulative rating index for SDR and high cumulative rating index for Vp, the study revealed that the land use in the study area is sustainable (Table 5). This means that under the present conditions, both SDR and Vp can be sustained with current level of soil quality indicators.

Management strategies of the soils

The study revealed that the major limitations of soils of the study area are moderate acidity and low exchangeable K while potentials limitations could be texture, exchangeable Na and CEC. Based on the above findings, the following management strategies have been suggested for sustainable crop production;

1. Liming of soils. The study area is well known for tropical crop such as rice, maize, cassava and yam and these crops thrive well at a pH range of 5.5 – 6.5 at which soil nutrients are present in ionic forms in the soil solution for crop uptake. Therefore, some parts of the study area showing low pH (<5.5) should be limed. According to [23], application of about 0.5 – 1.0 t ha^{-1} of lime to the plough layer of 15 cm depth can ameliorate the acidic condition of tropical soils and would promote good crop yields.
1. Balanced application of fertilizers according to the recommended dose of the Ministry of Agriculture, Forestry & Food Security should be adopted by farmers so as to maintain nutrient levels in the soil and improve the soil water holding capacity of the soils.
2. Low tillage practices should be promoted in order to minimize loss of organic matter.
3. Continuous monitoring of fertility status of the soil for quality evaluation should be carried out regularly by concerned authorities.

Conclusion

The soils have sandy loam to sandy clay loam texture, slight to moderately acidic, low to high organic carbon, medium to high total nitrogen, low to high available phosphorus, medium to high exchangeable Ca, high exchangeable Mg, low to high exchangeable Na, low exchangeable K, medium to high effective CEC and high base saturation. The soil properties showed slight variation in their SDR and Vp. However, it can be concluded that both SDR and Vp can be sustained with current status of soil fertility and quality indicators under the prevailing conditions.

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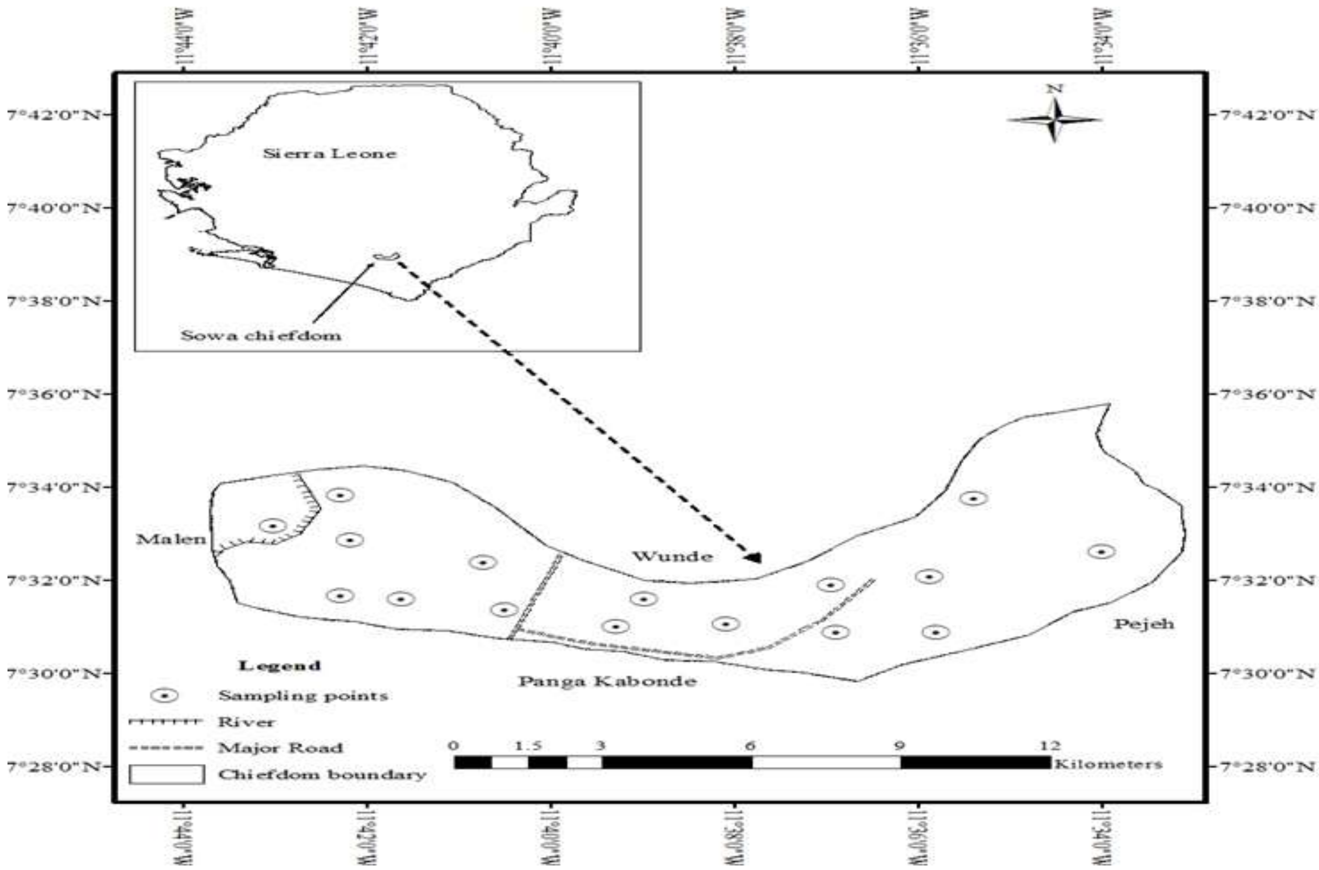

Figure 1: Map of study area showing sampling points

Table 1: Physicochemical properties of surface soils (0-20cm) in Sowa Chiefdom

Sample Location (GPS Points)		Sand	Silt	Clay	Texture	pH	Organic carbon	Total N	P_2O_5 (mg kg^{-1})	Exchangeable cation (cmol (+) kg^{-1})				Exch. Acidity (Al+H)	ECEC	BS (%)
Latitude (N)	Longitude (W)	%					g kg^{-1}			Ca	Mg	Na	K	cmol (+) kg^{-1}		
7.564	-11.705	64	15	21	scl	5.68	16.1	1.4	62.7	5.24	4.22	0.46	0.15	0.68	10.75	93.67
7.548	-11.703	66	16	18	sl	5.98	17.2	1.5	20.9	7.12	3.32	0.23	0.08	0.88	11.63	92.43
7.528	-11.705	73	22	5	ls	6.7	11.6	1	34.8	4.8	2.18	0.08	0.06	0.2	7.32	97.27
7.553	-11.717	78	14	8	ls	5.67	17.4	1.5	10.3	6.02	3.1	0.26	0.06	0.4	9.84	95.93
7.527	-11.694	72	15	13	sl	5.69	19.1	1.6	8.2	6.4	1.84	0.26	0.08	0.32	8.9	96.4
7.540	-11.679	63	19	18	sl	5.81	16.8	1.4	48.8	6.22	2.24	0.26	0.1	0.68	9.5	92.84
7.523	-11.675	66	19	15	sl	5.68	24.5	2.1	11.3	6.22	5.26	0.48	0.11	1.63	13.7	88.1
7.517	-11.655	70	17	13	sl	5.64	20	1.7	9.7	4.96	3.74	0.38	0.1	0.32	9.5	96.63
7.527	-11.650	60	10	30	scl	5.01	29.7	2.6	8.7	4.96	3.94	0.38	0.15	0.8	10.23	92.18
7.518	-11.635	53	16	31	scl	4.91	30.3	2.7	9.1	9.5	5.22	0.36	0.08	0.68	15.84	95.71
7.532	-11.616	81	14	5	ls	5.14	23.6	2.1	7.4	7.52	1.32	0.18	0.08	0.2	9.3	97.85
7.515	-11.615	55	33	12	sc	4.78	29.2	2.5	8.3	4.38	3.92	0.28	0.07	0.12	8.77	98.63
7.515	-11.597	52	11	37	scl	4.99	15.3	1.4	11.1	5.96	1.94	0.25	0.06	0.44	8.65	94.91
7.535	-11.598	48	15	37	sc	4.99	29.2	2.5	9.3	5.82	2.92	0.21	0.08	0.4	9.43	95.76
7.563	-11.590	45	14	41	sc	5.26	16.6	1.5	7.8	7.58	5.64	0.23	0.11	0.32	13.88	97.69
7.544	-11.567	32	13	55	c	4.98	15.6	1.3	9.8	6.68	4.74	0.16	0.08	0.16	11.82	98.65
Mean		61	16	22		5.43	20.76	1.80	17.4	6.21	3.47	0.28	0.09	0.51	10.57	95.3
Standard deviation		13.03	5.33	14.51	-	0.51	6.10	0.54	16.67	1.30	1.34	0.11	0.03	0.38	2.27	2.84
Range		32-81	10-33	5-55		4.78-6.7	11.6-30.3	1.0-2.7	7.4-62.7	4.38-9.5	1.32-5.64	0.08-0.48	0.06-0.15	0.12-1.63	7.32-15.84	88.1-98.7

scl: sandy clay loam; sl: sandy loam; ls: loamy sandy; sc: sandy clay; c: clay; N: nitrogen; Ca: calcium; Mg: magnesium; Na: sodium; K: potassium; ECEC: effective cation exchange capacity; BS: base saturation; GPS: global positioning systems.

Table 2: Physicochemical properties of subsurface soils (20 – 40 cm) in Sowa Chiefdom

Sample Location (GPS Points)		Sand	Silt	Clay	Texture	pH	Organic carbon	Total N	P_2O_5 (mg kg^{-1})	Exchangeable Cation (cmol (+) kg^{-1})				Exch. Acidity (Al+H)	ECEC	BS (%)
Latitude	Longitude	%					g kg^{-1}			Ca	Mg	Na	K	cmol (+) kg^{-1}		
7.564	-11.705	80	17	3	ls	5.69	10.1	0.5	16.1	4.72	2.28	0.11	0.08	0.4	7.6	94.7
7.548	-11.703	67	21	12	sl	5.72	11.4	0.7	39.6	5.14	3.02	0.15	0.07	0.7	9.1	92.1
7.528	-11.705	62	21	17	sl	6.64	6.7	0.3	44.0	5.04	2.46	0.03	0.04	0.4	8.0	95.0
7.553	-11.717	75	12	13	sl	5.65	13.3	1	38.6	6.48	2.78	0.20	0.10	0.3	9.9	96.6
7.527	-11.694	65	25	10	sl	5.72	10.6	0.8	105.8	7.72	1.80	0.07	0.06	0.3	10.0	96.8
7.540	-11.679	58	24	18	sl	5.78	13.2	0.3	128.8	8.06	3.78	0.25	0.14	0.3	12.6	97.5
7.523	-11.675	84	10	6	ls	5.74	9.8	0.1	41.9	8.64	2.48	0.39	0.12	0.6	12.2	95.4
7.517	-11.655	59	11	30	scl	5.4	10.3	0.8	16.0	5.06	3.88	0.43	0.10	0.3	9.8	96.5
7.527	-11.650	61	10	29	scl	5.16	15.1	0.8	23.0	7.96	2.50	0.35	0.14	0.7	11.7	93.8
7.518	-11.635	57	10	33	scl	5.1	16.1	0.8	24.4	5.06	4.52	0.42	0.12	0.7	10.8	93.7
7.532	-11.616	75	18	7	sl	4.98	11.4	0.6	23.0	4.52	3.98	0.38	0.10	0.1	9.1	99.1
7.515	-11.615	49	26	25	scl	5.09	8.5	0.7	21.2	6.64	2.54	0.37	0.07	0.2	9.8	98.0
7.515	-11.597	49	9	42	scl	5.1	12.3	1	12.9	4.74	3.84	0.27	0.06	0.3	9.2	96.5
7.535	-11.598	44	16	40	scl	4.75	9.6	0.8	13.3	4.44	4.14	0.25	0.05	0.4	9.3	95.7
7.563	-11.590	45	22	33	scl	5.21	7.3	0.6	34.0	5.66	4.20	0.18	0.12	0.4	10.6	96.2
7.544	-11.567	33	13	54	c	5.34	9.2	0.7	29.9	11.72	8.42	0.25	0.09	0.1	20.6	99.4
Mean		60	17	23		5.44	10.9	0.7	38.3	6.35	3.54	0.26	0.09	0.4	10.6	96.1
Standard deviation		14	6	15	-	0.45	2.6	0.3	32.8	2.01	1.55	0.13	0.03	0.2	3.0	2.0
Range		33-84	9-26	3-54		4.75-6.64	6.7-16.1	0.1-1.0	12.9-128.8	4.44-11.72	1.8-8.42	0.03-0.43	0.04-0.14	0.1-0.7	7.6-20.6	92.1-99.4

scl: sandy clay loam; sl: sandy loam; ls: loamy sandy; sc: sandy clay; c: clay; N: nitrogen; Ca: calcium; Mg: magnesium; Na: sodium; K: potassium; ECEC: effective cation exchange capacity; BS: base saturation; GPS: global positioning systems.

Table 3: Soil degradation rate (SDR) and critical limits for interpreting levels of soil fertilityin Sowa Chiefdom

Soil properties	Site values						Critical limits for interpretation (Esu, 1991)		
	0 – 20 cm			20 – 40 cm					
	Mean	Weighting factor	SDR*	Mean	Weighting factor	SDR*	Low	Medium	High
Texture	sl	3	Moderate	scl	2	Slight			
Soil pH	5.43	3	Moderate	5.44	3	Moderate	Acidic	Neutral	Alkaline
Organic carbon (g kg^{-1})	20.8	1	None	10.9	1	None	<10	10 - 15	>15
Total nitrogen (g kg^{-1})	1.8	1	None	0.7	1	None	<0.1	0.1 – 0.2	>0.2
Available phosphorus (mg kg^{-1})	17.4	1	None	38.3	1	None	<10	10 - 20	>20
Exchangeable Ca (cmol (+) kg^{-1})	6.2	1	None	6.4	1	None	<2	2 - 5	>5
Exchangeable Mg (cmol (+) kg^{-1})	3.5	1	None	3.5	1	None	<0.3	0.3 – 1.0	>1.0
Exchangeable Na (cmol (+) kg^{-1})	0.3	3	Moderate	0.3	3	Moderate	<0.1	0.1 – 0.3	>0.3
Exchangeable K (cmol (+) kg^{-1})	0.1	5	Extreme	0.1	5	Extreme	<0.15	0.15 – 0.30	>0.30
Effective CEC (cmol (+) kg^{-1})	10.1	3	Moderate	10.3	3	Moderate	<6	6 - 12	>12
Base saturation (%)	98.7	1	None	96.1	1	None	<50	50 - 80	>80
Cumulative Rating Index (CRI)†		23			22				

* Soil Degradation Rate
† Lal (1994)

Table 4: Vulnerability potential (Vp) of soils of study area and critical limits for interpreting levels of soil fertility in Sowa Chiefdom

Soil properties	Site values						Critical limits for interpretation (Esu, 1991)		
	0 – 20 cm			20 – 40 cm					
	Mean	Weighting factor	Vp*	Mean	Weighting factor	Vp*	Low	Medium	High
Texture	sl	3	Moderate	scl	2	High			
Soil pH	5.43	3	Moderate	5.44	3	Moderate	Acidic	Neutral	Alkaline
Organic carbon (g kg^{-1})	20.8	5	None	10.9	5	None	<10	10 - 15	>15
Total nitrogen (g kg^{-1})	1.8	5	None	0.7	5	None	<0.1	0.1 – 0.2	>0.2
Available phosphorus (mg kg^{-1})	17.4	5	None	38.3	5	None	<10	10 - 20	>20
Exchangeable Ca (cmol (+) kg^{-1})	6.2	5	None	6.4	5	None	<2	2 - 5	>5
Exchangeable Mg (cmol (+) kg^{-1})	3.5	5	None	3.5	5	None	<0.3	0.3 – 1.0	>1.0
Exchangeable Na (cmol (+) kg^{-1})	0.3	3	Moderate	0.3	3	Moderate	<0.1	0.1 – 0.3	>0.3
Exchangeable K (cmol (+) kg^{-1})	0.1	1	Very high	0.1	1	Very high	<0.15	0.15 – 0.30	>0.30
Effective CEC (cmol (+) kg^{-1})	10.1	3	Moderate	10.3	3	Moderate	<6	6 - 12	>12
Base saturation (%)	98.7	5	None	96.1	5	None	<50	50 - 80	>80
Cumulative Rating Index (CRI)†		43			42				

*****Vulnerability potential
† Lal (1994)

Table 5: Sustainability of land use in relation to the cumulative rating index

Sustainability		Cumulative Rating Index	
		SDR	Vp
Highly sustainable		<20	>40
Sustainable		20 – 30	35 - 40
Sustainable with high input		30 - 35	30 - 35
Sustainable with another land use		35 - 40	20 – 30
Unsustainable		>40	<20
Source: Modified from Lal (1994)			
Site value	0 – 20 cm	23	43
	20 – 40 cm	22	42