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Physicochemical Characteristics, Degradation Rate and Vulnerability Potential of Obudu Cattle Ranch Soils in Southeast Nigeria

A. U. Akpan-Idiok*, K. I. Ofem

Department of Soil Science, University of Calabar, Cross River State, Nigeria.
Email: *ackleyaidiok@yahoo.com

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ABSTRACT

Obudu Cattle Ranch covers an area of 2400 hactares at an altitude of 900 - 1500 m above mean sea level and is suitable for cultivation of cucumber (*Cucumis sativus*), tomato (*Solanum lycopersicum*), Irish potato (*Solanum tuberosum*), spinach (*Spinacia oleracea*) cabbage (*Brassica oleracea*), lettuce (*Lactuca sativa*) because of its semi-temperate climate. Physicochemical characteristics, degradation rates and vulnerability potential of the soils were studied. Eighteen composite soil samples (0 - 15 and 15 - 30 cm) were collected at interval of 500 m along North-South and East-West transects in nine locations. The soils were characterized as follows: texture of sandy loam for the surface and subsurface soils; $pH_{(H2O)}$ (4.7 - 5.7), organic carbon (4.9 - 74.8 gkg^{-1}), total nitrogen (0.2 - 4.8 gkg^{-1}), carbon-nitrogen ratio (14 - 25), available P (6.66 - 107.89 $mgkg^{-1}$), effective cation exchange capacity (ECEC) (5.58 - 14.62 $cmol\cdot kg^{-1}$) and base saturation (49.37% - 85.28%); the surface soils were generally higher in organic carbon, total nitrogen, available P and ECEC than the subsurface. The Soil Degradation Rate (SDR)/ Vulnerability Potential (Vp) weighted values of texture (3/3), soil $pH_{(H2O)}$ (4/2), organic carbon (1/5) and base saturation (2/4) showed moderate to low susceptibility of the soils to degradation or vulnerability. The soils could be managed by liming, practicing crop rotation and using soil conservative measures.

KEYWORDS

Physicochemical Characteristics; Obudu Cattle Ranch; Soil Degradation; Vulnerability Potential

1. Introduction

Obudu Cattle Ranch covers an area of 24 km^2 at an altitude of 900 - 1500 m Above Sea Level in a hilly and mountainous region of Northern Cross River, Nigeria [1]. Exploration of the ranch took place in 1949, while McCaugley started its development in 1951. At present, the Cross River State government has turned the ranch into a world well-known and tourist resort centre in Nigeria. It is otherwise known as *Obudu Mountain Resort*. The basement complex of Obudu Cattle Ranch consists of Precambrian migmatites, gneisses and Schists with intrusive igneous rocks such as granodiorite, diorite, gabbro and dolerite [2,3]. This study therefore focuses on the soils' particle size distribution, $pH_{(H2O)}$, organic carbon, basic cations, available P, base saturation and cation exchange capacity. The productivity of the soils under agricultural management systems was evaluated through the soil degradation rate (SDR) and vulnerability potential (Vp) [4, 5].

Studies have reported that most soils on Plateau are not well developed in most African countries and even in Southern Asian countries [6]. However, soils of Mambilla Plateau in Nigeria are well developed with deep profiles (>100 cm) and colour variation between red and yellow for soils developed from Basement Complex rocks. Those developed on Basaltic rocks are reddish brown to yellowish red and coarse to fine in texture with considerable amounts of sand (>60%) and clay (>20%) [1,6]. Si-

*Corresponding author.

milarly, the soils of Obudu Cattle Ranch are deep (>150 cm) with colour variation of dark brown silt, loam or gravelly loamy sand surface over very dark grey sandy loam, loam or loamy sand subsurface. The soils are further characterized by coarse texture, low contents of organic carbon (0.93%), cation exchange capacity and clay (15%) [1].

The soils of Obudu Cattle Ranch are used for the cultivation of cucumber, tomato, Irish potato, spinach and tea [7,8]. This is because its semi-temperate climate supports the growth of these crops. Others are forages (Alfalfa), cereals (wheat, sorghum), vegetables (cabbage and lettuce), cotton and peanuts. The livestock industry has also recorded a huge success in the ranch as it encourages dairy products. With conversion of the ranch to mountain resort which attracts tourists from all over the world, most of the land used for agriculture will be encroached into and the rate of degradation enhanced. There is therefore need to study the physicochemical characteristics, Soil Degradation Rate (SDR) as well as vulnerability potential (Vp) of the Obudu Cattle Ranch soils and also suggest ameliorative measures for improved productivity of the soils.

2. Materials and Methods

2.1. Description of the Study Area

Obudu Cattle Ranch Resort (6˚15' N; 6˚30' N and 9˚15' E; 9˚30' E) is located in Northern Cross River State, Nigeria (**Figure 1**). It constitutes the highest elevated part of south-eastern Nigeria with a maximum height of 1576 m above sea level [3,9]. The soils of the area are underlain by Precambrian Schists and gneisses with intrusive of igneous rocks such as granodiorite, diorite, gabbro and dolerite [2]. The topography of the land scape is rugged with north-easterly trending ridges separated by low lands which form valleys and passes [3]. The climate of Obudu Cattle Ranch (Obudu Mountain Resort) has characteristics of temperate region though is found in tropical region. It has a mean rainfall of 2000 - 3100 mm/annum and temperature of 15˚C - 23˚C [3,10]. The vegetation types in the study area are Guinea savanna and montanne vegetation. Tall grasses are interspersed with trees, while riparian forests with tall trees occupy river valleys. Among trees in the Guinea savanna area include acacias, baobab and shea-butter [3].

2.2. Soil Sampling

Eighteen composite soil samples were collected at the depths of 0 - 15 cm and 15 - 30 cm from nine locations along North-South and East-West directions at 500 m interval of Obudu Cattle Ranch, Obanliku Local Government Area of Cross River State, Nigeria (**Figure 1**). Each composite soil sample was stored in a well labelled polyethylene bag and transported to the laboratory for analysis.

2.3. Laboratory Analysis

Soil samples were air-dried and sieved through a 2 mm mesh. Particle size analysis was carried out by hydrometer method [11] using sodium hexametaphosphate as dispersant. Soil pH was determined in soil-water ratio of 1:2.5 using a glass electrode pH meter. Organic carbon was determined by the Walkley and Black, 1934 [12] method, while total nitrogen was by the Kjeldahl digestion method [11]. Available phosphorus was determined by the Bray and Kurtz, 1945 [13] No. 1 method. Exchangeable bases (Ca, Mg, K and Na) were extracted in 1N 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 [14]. Exchangeable acidity was by titration method using IN KCl extract [15]. 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 ECEC.

2.4. Soil Degradation Rating (SDR)/Vulnerability Potential (Vp)

The rating scheme for soil degradation developed by Lal, 1993 [4] for soil physicochemical properties, namely: texture, pH, total nitrogen, organic carbon, available P, effective cation exchange capacity and base saturation were used in this study. The vulnerability potential of these properties was also determined. 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 Vp, the weighting was the reverse such that: 5 = very low, 4 = low, 3 = medium, 2 = high and 1 = very high [4,5].

2.5. Statistical Analysis

The data collected were analysed using descriptive statistics (mean and range) with the help of Genstat software.

3. Results and Discussion

3.1. Particle Size Distribution

Sand fraction ranged from 605.4 - 845.4 gkg^{-1} with a mean of 725.5 gkg^{-1} in the soils (**Table 1**). Silt fraction varied between 66.2 - 241.6 gkg^{-1} with a mean of 190.48 gkg^{-1} while clay fraction ranged from 41.8 - 269.2 gkg^{-1} with a mean of 84 gkg^{-1} in the soils. The soils are coarse

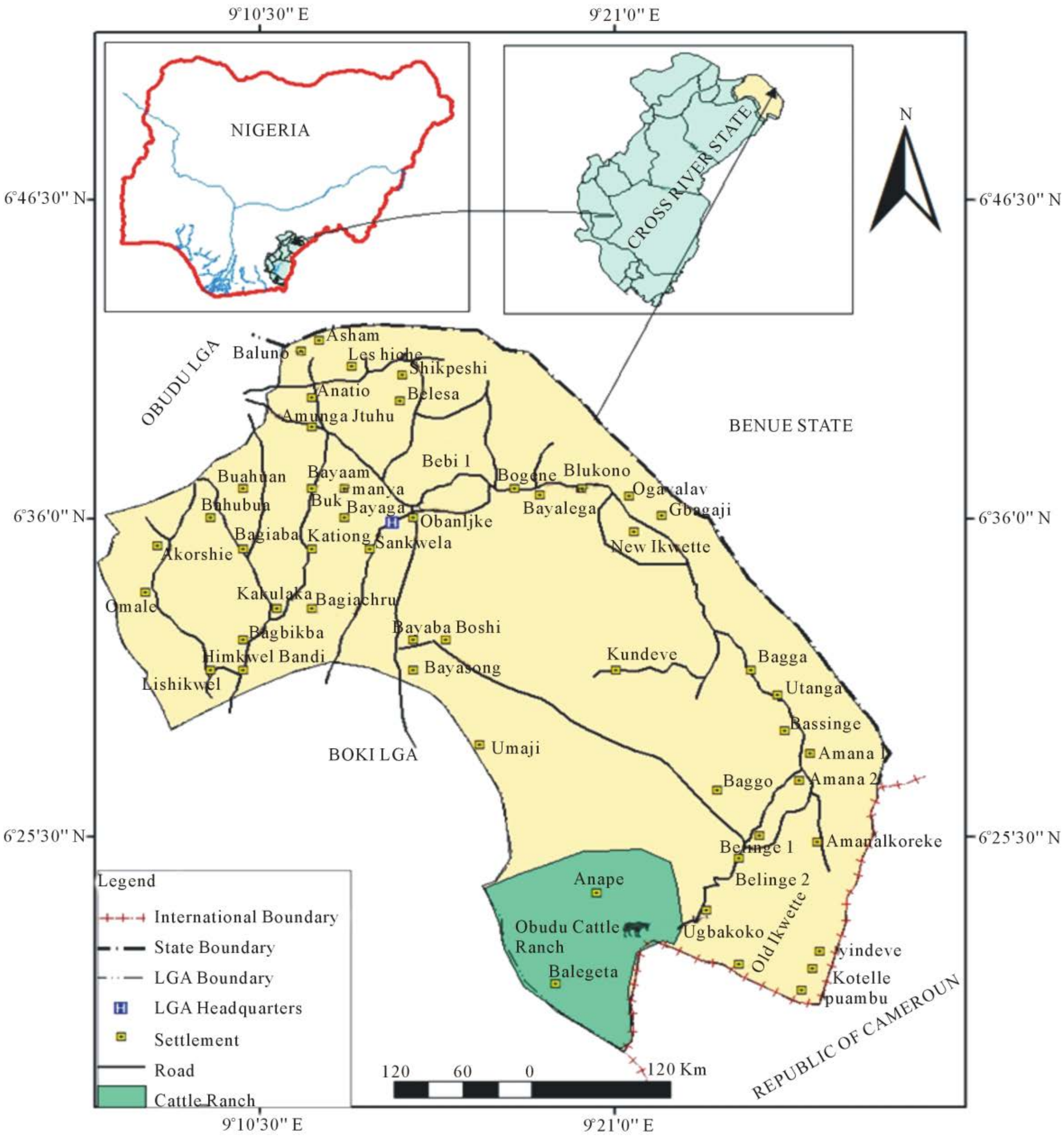

Figure 1. Map of cross river state showing Obanliku local government area.

textured with a high content of sand in surface and subsurface layers exceeding 700 gkg^{-1}, giving a dominant textural class of sandy loam. Similar results were obtained for the Obudu Cattle Ranch soils [16]. Such soils lack adsorption capacity for basic plant nutrients and water.

3.2. Chemical Characteristics

The soil pH (H_2O) ranged from 4.7 - 5.7 with a mean of 5.1 (**Table 2**), indicating that the soils are strongly acid in reaction. The acidic conditions might be due to the high rainfall that exceeds 2000 mm/annum and sandy nature of the soils. The electrical conductivity values varied from 0.039 - 0.105 dSm^{-1} with a mean of 0.063 dSm^{-1}. This indicates that the soils are non-saline. Organic carbon contents ranged from 4.9 - 74.8 gkg^{-1} with a mean of 43.09 gkg^{-1}. This level of organic carbon is rated high as most values are higher than 15 gkg^{-1} [17]. Total nitrogen varied between 0.20 and 4.80 gkg^{-1} with a mean value of 2.54 gkg^{-1}; this range of value is rated medium for most soils when compared with the range 2 - 5 gkg^{-1} for productive soils [17]. Available P varied from 6.66 to 107.89 $mgkg^{-1}$ with a mean of 22.14 $mgkg^{-1}$ for surface and subsurface soils. This range of values is high exceeding 15 $mgkg^{-1}$ regarded for productive soils [5,18]. Exchangeable bases were as follows: Ca (1.7 - 7.95 $cmol{\cdot}kg^{-1}$),

Table 1. **Particle size distribution of Obudu Cattle Ranch soils in Cross River State, Nigeria.**

Sample Location	Depth (cm)	Sand (gkg^{-1})	Silt (gkg^{-1})	Clay (gkg^{-1})	Texture
Ranch Bottom I	0 -15	745.4	186.2	68.4	sl
	15 - 30	745.4	186.2	68.4	sl
Ranch Bottom II	0 - 15	645.4	166.2	188.4	sl
	15 - 30	845.4	86.2	68.4	ls
Ranch Reference Point	0 - 15	741.2	207	51.8	sl
	15 - 30	721.2	227	51.8	ls
Ranch South I	0 - 15	712.8	228	59.2	sl
	15 - 30	708.7	238.9	52.4	ls
Ranch South II	0 - 15	713.4	228	58.6	sl
	15 - 30	765.4	106.2	128.4	sl
Ranch North I	0 - 15	712.3	237.8	49.9	sl
	15 - 30	716.6	241.6	41.8	sl
Ranch West I	0 - 15	721.5	218.6	59.9	sl
	15 - 30	725.5	224.6	49.9	sl
Ranch West II	0 - 15	729.2	219.8	51.0	sl
	15 - 30	718.4	234.8	46.8	sl
Ranch West III	0 - 15	605.4	125.4	269.2	sl
	15 - 30	785.4	66.2	148.4	sl
Surface Range		605.4 - 745.5	125.4 - 237.8	49.9 - 269.2	
Surface Mean		702.96	201.89	95.15	sl
Subsurface Range		708.7 - 845.4	66.2 - 241.6	41.8 - 148.4	
Subsurface Mean		748.0	179.08	72.92	sl
Overall Range		605.4 - 845.4	66.2 - 241.6	41.8 - 269.2	
Overall Mean		725.5	190.48	84.0	sl

sl = Sandy loam; ls = Loamy sand.

Mg (1 - 3.04 $cmol \cdot kg^{-1}$), K (0.08 - 0.89 $cmol \cdot kg^{-1}$) and Na (0.06 - 0.11 $cmol \cdot kg^{-1}$). These values are moderate when compared with the acceptable limits of individual basic cations for crop production in the ecological zone. Effective cation exchange capacity (ECEC) values were moderate to high (5.58 - 14.62 $cmol \cdot kg^{-1}$) as established by FPDD, 1990 [18] for productive soils. With mean percentage base saturation of 65, basic nutrients must have occurred in available forms in soil solution for plant uptake.

3.3. Mineralization/Nutrient Availability Ratios

Carbon-Nitrogen Ratio

Values of carbon-nitrogen ratio were low (range, 14 - 25) as all the values were less than the separating index of 25 [19] (Table 1) for mineralization and immobilization of nitrogen in soils. This ratio indicates high levels of microbial activity, increased decomposition of organic matter and corresponding release of nutrient elements into the soil solution for plant nourishment.

Magnesium-Potassium* (Mg:K) *Ratio

The ratios of Mg:K were high (2.8 - 20.5) when compared with a critical level of 1:2 for productive soils [20]. Mg in the form of Mg^{2+} is more likely to be available to crop plants in the soil relative to K. It is a vital element in the formation of chlorophyll, aids in the translocation of

Table 2. Chemical properties of Obudu Cattle Ranch soils in Cross River State, Niger.

Sample Location	pH (H_2O)	EC dSm^{-1}	Org. C (gkg^{-1})	Total N (gkg^{-1})	C:N Ratio	Avail. P ($mgkg^{-1}$)	Exchangeable Bases ($cmol \cdot kg^{-1}$)				EA ($cmol \cdot kg^{-1}$)	ECEC ($cmol \cdot kg^{-1}$)	BS (%)	Mg:K	Ca:Mg
							Ca	Mg	K	Na					
Ranch Bottom I	4.7	0.042	20.1	0.8	25	18.66	4.54	1.88	0.36	0.07	3.04	9.89	69.89	5.2	2.4
	5.2	0.051	15.6	0.7	22	9.99	5.39	2.40	0.19	0.06	3.42	11.46	70.16	12.6	2.2
Ranch Bottom II	5.2	0.105	25.5	1.8	14	8.66	3.69	1.89	0.19	0.06	3.99	9.82	59.37	9.9	2.0
	5.1	0.053	14.8	0.7	21	8.66	3.12	1.88	0.19	0.07	3.23	8.40	61.96	9.9	1.7
Ranch Reference Point	5.1	0.052	65.3	4.0	16	6.66	2.27	1.00	0.18	0.07	3.61	7.13	49.37	5.6	2.3
	5.0	0.058	62.7	3.7	17	8.66	7.95	2.94	0.38	0.09	2.47	13.86	82.18	7.7	2.7
Ranch South I	5.7	0.098	74.8	4.8	16	19.33	7.36	2.46	0.89	0.11	3.80	14.62	74.01	2.8	3.0
	5.5	0.101	73.3	4.7	16	19.33	4.50	1.90	0.17	0.07	3.80	10.44	63.60	11.2	2.4
Ranch South II	5.1	0.052	42.6	2.1	20	14.66	5.68	2.66	0.25	0.08	4.75	13.42	64.61	10.6	2.1
	5.4	0.042	4.9	0.2	25	18.66	2.56	1.10	0.14	0.07	3.42	7.29	53.09	7.9	2.3
Ranch North I	5.0	0.044	42.0	2.0	21	28.66	3.69	1.48	0.09	0.06	5.13	10.45	50.91	16.4	2.5
	4.9	0.041	50.9	2.8	18	9.33	4.26	1.49	0.13	0.07	4.37	10.32	57.66	11.5	2.9
Ranch West I	5.0	0.060	69.5	4.6	15	9.33	5.11	2.10	0.11	0.07	3.80	11.19	66.04	19.1	2.4
	4.9	0.056	63.1	4.0	16	15.99	3.41	1.40	0.11	0.07	4.37	9.36	53.32	12.7	2.4
Ranch West II	4.7	0.063	60.7	3.8	16	11.99	1.70	1.00	0.14	0.08	2.66	5.58	52.33	7.1	1.7
	4.9	0.039	17.7	1.3	14	64.73	3.69	1.64	0.08	0.08	2.28	7.77	70.66	20.5	2.3
Ranch West III	5.4	0.097	48.6	2.7	18	107.89	7.65	3.04	0.23	0.08	1.90	12.91	85.28	13.2	2.5
	5.7	0.061	23.6	1.2	20	17.33	2.84	1.74	0.09	0.07	1.44	5.88	80.61	19.3	1.6
Overall range	4.7 - 5.7	0.039 - 0.105	4.9 - 74.8	0.2 - 4.8	14 - 25	6.66 - 107.89	1.7 - 7.95	1 - 3.04	0.08 - 0.89	0.06 - 0.11	1.44 - 5.13	5.58 - 14.62	49.37 - 85.28	2.8 - 20.5	1.6 - 3.0
Overall mean	5.1	0.063	43.09	2.54	19	22.14	4.41	1.89	0.22	0.07	3.42	9.99	64.73	11.3	2.3
Surface range	4.7 - 5.7	0.042 - 0.105	20.1 - 74.8	0.8 - 4.8	14 - 25	6.66 - 107.89	1.7 - 7.65	1 - 3.04	0.09 - 0.89	0.06 - 0.11	1.9 - 5.13	5.58 - 14.62	49.37 - 85.28	2.8 - 19.1	1.7 - 3.0
Surface mean	5.1	0.069	49.9	3.0	19	25.09	4.63	1.95	0.27	0.08	3.63	10.56	63.53	10.0	2.3
Subsurface range	4.9 - 5.7	0.039 - 0.101	4.9 - 73.3	0.2 - 4.7	14 - 25	8.66 - 64.73	2.56 - 7.95	1.1 - 2.94	0.08 - 0.38	0.06 - 0.09	1.44 - 4.37	5.88 - 13.86	53.09 - 82.18	7.7 - 20.5	1.6 - 2.9
Subsurface mean	5.2	0.056	36.3	2.1	18	19.19	4.19	1.83	0.15	0.07	3.20	9.43	65.92	12.6	2.3

EC = Electrical conductivity; EA = Exchangeable acidity; ECEC = Effective cation exchange capacity; BS = Base saturation.

starch within plant, and is essential for the formation of oils and fats. Potassium is absorbed by crop plants as K^+. It improves plant's ability to resist disease and cold, aids in the production of carbohydrates and proteins and an active part of plant enzyme systems [5,21].

Calcium-Magnesium* (Ca:Mg) *Ratio

The Ca:Mg rates were low (range, 1.6 to 3.0) when compared with a normal range of 3:1 to 5:1 for productive soils [20]. This indicates that the soils have low amounts of Ca with considerable amount of Mg in the soil solution. Calcium is absorbed by plants as Ca^{2+}. It is essential for root growth and as a constituent of cell wall materials [5,21]. Replenishing Ca contents in the soils requires liming, which in turn reduces acidity of the soils.

3.4. Soil Degradation Rating (SDR)/Vulnerability Potential (Vp)

Seven physicochemical properties namely: texture, $pH_{(H2O)}$, organic carbon, total nitrogen, available P, effective cation exchange capacity, and percentage base saturation were used as soil quality indicators to assess soil degradation rate (SDR) and vulnerability potential (Vp) of the soils. The soil qualities have varied potential for degradation and vulnerability potential (Vp) of the soils. Based on the selected physicochemical properties, the results (Table 3) indicated that texture (SDR = 3, Vp = 3) showed moderate susceptibility to degradation or vulnerability caused by erosion due to the sandy nature of the soils. The SDR/Vp of soil $pH_{(H2O)}$ (4/2) indicated severe degradation or vulnerability as such level of pH hinders nutrient uptake by plants. The SDR/Vp weighted value for organic carbon (1/5) and total nitrogen (3/3) showed very low and medium degradation or vulnerability; an indication that the soils contain a good amount of organic matter for any intensive crop production. The SDR/Vp of 2/4 for available P showed considerable concentration of available P in the soils. The SDR/Vp of base saturation (2/4) indicated the saturation of soil exchange complex with basic cations and subsequent release of the ions into soil solution for plant absorption. Based on the principle that "good soil quality has least SDR and poor soil quality has the highest SDR and vice versa for Vp", the better soil quality indicators were organic carbon, available P and base saturation in the soils.

Table 3. Rating scheme for soil degradation rates (SDR) and vulnerability potential of selected soil quality indicators.

Parameters	Mean	SDR	Vp	SDR/Vp
$pH_{(H2O)}$	5.1	4	2	4/2
Texture	sl	3	3	3/3
Organic C. (gkg^{-1})	43.09	1	5	1/5
Total N. (gkg^{-1})	2.54	3	3	3/3
Avail. P. ($mgkg^{-1}$)	22.14	2	4	2/4
ECEC ($cmol \cdot kg^{-1}$)	9.99	3	3	3/3
BS (%)	65	2	4	2/4

NB: 1 = none, 2 = slight, 3 = moderate, 4 = severe, 5 = extreme for SDR; 5 = none, 4 = low, 3 = moderate, 2 = high, 1 = very high for Vp; Ratings based on mean soil quality and criteria limits (Lal, 1994, Akpan-Idiok, 2012); SDR = Soil degradation rate, Vp = Vulnerability potential.

3.5. Management Strategies of the Soils

The Obudu Cattle Ranch soils have sandy loam texture and are high in organic carbon, available P and base saturation. Meanwhile, to avoid a decrease in soil fertility, the following management measures should be practiced:

According to statistics provided by Al-amin, 2007 [1] for the soils of Obudu Cattle Ranch, there has been an increase in the use of land for recreation (5% - 20%) and residence (5% - 15%), and a subsequent decrease in its use for agricultural purposes (55% - 40%) between 1987 and 2007. For this reason, crop rotation should be practiced where restorative crops (legumes) will be sequentially alternated with exhaustive crops (cereals, tubers) on the same piece of land.

***Liming of the Soils*:** Acidity of the soils can be ameliorated by liming. Liming supplies Ca and Mg, and eliminates Al^{3+} in soil solution, which is the reason for the high exchangeable acidity in the soils. Crops such as cassava, beans, peanuts, mustards, cabbage, spinach, lettuce, tomato and cucumber thrive well at pH range of 5.5 to 6.5 at which most soil nutrients exist in ionic forms in soil solution for crop absorption. Application of about 0.5 to 1.0 tonne/ha of lime to the plough layer of 15 cm depth can ameliorate the acidic condition of the soils and would promote crop yields [4].

***Planting of Acid Tolerant Crops*:** For increased yield, acid tolerant crop species should be planted. The newly improved varieties of cassava produced by International Institute for Tropical Agriculture (IITA) have been found to yield between 32 and 38 tonnes per hectare. Among the cassava varieties are 98/0505, TME 419, 30572, 98/0510, 98/0581, 4(2) 142 [22].

***Soil Conservation Measures*:** The steep nature of the landscape coupled with high rainfall and sandy texture encourages erosion which is enhanced by human activities such as destruction of vegetation cover, fuel wood collection, bush burning and the grading of these soils mostly in the same direction with the slope. Low populated areas with enough land should therefore encourage bush fallowing (with leguminous crops), cover cropping and the use of organic matter, plant residues and deep ploughing to improve soil moisture storage and reduce erosion.

4. Conclusion

The study highlights the physicochemical properties of Obudu Cattle Ranch soils in Cross River State, Nigeria. The soils are characterized by a dominant textural class of sandy loam, strongly acid in reaction, high contents of organic carbon, available P and percentage base saturation as well as moderate contents of total nitrogen and effective cation exchange capacity. With the low to moderate soil degradation rate and vulnerability potential values for the above stated parameters except for base saturation and organic carbon that had low and very low soil degradation rate and low vulnerability potentials, the soils generally are of good quality. The management strategies of the soils for crop production therefore include the following: liming to neutralize the soil acidity, planting of acid tolerant crops and adoption of cultural conservative practices to check erosion and maintain soil fertility.

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