integrity Research Journals

Journal of Agricultural Science and Practice
Volume 8(3), pages 45-52, June 2023
Article Number: 37EB678D2
ISSN: 2536-7072
https://doi.org/10.31248/JASP2023.411
https://integrityresjournals.org/journal/JASP

Full Length Research

Characterization and suitability assessment of the soils of Iwo series for cocoa production in rainforest area Southwestern, Nigeria

Ruth Oluwakemi Adegbenro[1*], Julius Olayinka Ojetade[2], Sikiru Adekoya Muda[2], Alani Adeagbo Amusan[2], Oladele Abdulahi Oguntade[1], and Olubunmi Mary Faturoti[2]

[1]Department of Crop Production, College of Agricultural Sciences, Olabisi Onabanjo University, Ayetoro Campus, Nigeria.
[2]Department of Soil Science and Land Resources Management, Faculty of Agricultural Sciences, Obafemi Awolowo University, Ile-Ife, Nigeria.

*Corresponding author Email: adegbenro.at@oouagoiwoye.edu.ng/kemiadegbenro@yahoo.com

Received 18th May 2023; Accepted 16th June 2023

ABSTRACT: Characterization and soil suitability assessment is a vital tool for understanding the nature and status of soils. It is one of the strategies for achieving food security as well as sustainable environment. This study was conducted to assess the suitability of the soils of Iwo series for sustainable production of cocoa. The study was carried out in 2022, in an area located approximately between 7°32' N and 7°33' N and longitudes 4°32' E and 4°40' E within the Teaching and Research Farm (T&R-F) of Obafemi Awolowo University (OAU), Kajola, Ile-Ife, Nigeria. Three profile pits were established, described and sampled with one at different physiographical units following the guideline for soil profile description according to FAO/UNESCO guideline. The soil samples collected were analyzed for particle size distribution, pH, total nitrogen, available phosphorus, exchangeable bases, and organic matter using standard method. Land characteristics obtained were matched with the crop requirements for cocoa to obtain the soils' suitability classes using parametric method. The results showed that all the soils are well drained and deep. The texture of the soils ranged from sandy loam to sandy clay loam at the surface and sandy clay loam to clay at subsurface. Soil reaction ranged from highly acidic to slightly acidic (4.2-5.8 water and 3.9- 5.7 pH$CaCl_2$) with low to moderate amounts of organic matter (0.4 to 1.74%) and available nitrogen (0.02-0.14%). Available phosphorus varied from 0.52-24.77 mg/kg in all the horizons in the profiles with the highest values at the surface soil horizons, an indication that soil organic matter contributes significantly to the available P in these soils. The exchangeable bases were low and the relative abundance of the exchangeable bases followed the order: Ca> Mg > Na>K at the exchangeable site. Suitability evaluation of the soils was carried out using parametric approach and the result showed that the soils of mapping units A and B are presently not suitable (N1) while mapping unit C is marginally suitable for cocoa production. With the appropriate fertility management, the soils of mapping unit A were classified as marginally suitable (S3) while soils of mapping unit B and C were classified as moderately (S2) for cocoa production. The limiting factors were mainly low soil fertility (low level of available phosphorus, macro-nutrients, nitrogen and organic matter). Therefore, combined application of organic fertilizer with inorganic fertilizers should be encouraged for optimum productivity.

Keywords: Characterization, cocoa, Nigeria, rainforest, southwestern, suitability.

INTRODUCTION

Soil is one of the world's greatest valuable assets. It is an essential natural resource that sustains most of the planet's life, directly or indirectly and it is a fundamental need for civilizations to thrive, therefore needs to be treasured (Olasoji *et al*., 2022). Soils of southwestern Nigeria are dominantly formed in basement complex rocks areas and the landscape is characterized by undulating topography (Obi *et al*., 2009). Soils of Iwo association, derived from coarse-granite gneiss are very extensive in southwestern Nigeria (Symth and Montogomery, 1962) and are extremely important on the account of their suitability for both arable and tree crops. Poor knowledge and appraisal of land suitability for agricultural production is a major problem of agricultural development in Nigeria. The result is poor farm management practices, low yield and unnecessarily high cost of production (Aderonke and Gbadegesin, 2013). Healthy soil is vital to blossoming agriculture (Olasoji *et al*., 2022). Hence, one of the tactics to accomplish sustainable agriculture in a sustainable environment is to examine soil properties and in particular through soil characterization and land evaluation for several land utilization types (Esu, 2004). The soil suitability of a given piece of land is its natural ability to support a specified land use; such as rain-fed agriculture, livestock production, forestry, etc. Suitability, therefore, is the fitness of a given type of soil for a defined agricultural use (FAO, 2016). Before the discovery of petroleum in 1956, agriculture of which cocoa (*Theobroma cacao)* production was a major part constituted the mainstay of the Nigerian economy. Since the 1970s when petroleum became the major foreign exchange earner for the country, Nigeria had lost its position as one of the leading cocoa exporters, and cocoa production has not kept pace with export market demand. Cocoa export declined from over 200,000 t in mid-1980s to about 170,000 t in the late 1990s (FAO, 2016). More than 70% of Nigerian cocoa farmers are smallholders with average farm size less than 1.5 ha, and most of the increase in yield is due to expansion of land area devoted to cocoa. Cocoa yields are principally affected by soil and climatic variables (Wood and Lass, 1985; Hartemink 2003). As such, cocoa cultivation is restricted to southwestern and eastern parts of Nigeria where the annual rainfall is above 1200 mm. Though cocoa is vital for Nigeria's economy, there is currently the lack of a land evaluation system that provides information on the potential of land resources of different areas for the crop. Rather, scientists and farmers resort to terms such as "ideal cocoa soils," "ideal cocoa climate" and "marginal cocoa climate" in describing the suitability of soils of Iwo series within cocoa agroecosystems in Nigeria. Therefore, the objectives of this study were to characterize and assess soils of Iwo series with a view to encourage sustainable production of cocoa in the area.

MATERIALS AND METHODS

The study was conducted in 2022 at the Teaching and Research Farm of Obafemi Awolowo University, Ile-Ife, Nigeria. The region is located in southwestern part of Nigeria, spanning between latitudes 7°32' N to 7°33' N and longitudes 4°32' E to 4°40' E. The area is about 200 meters above mean sea level. The area has hot, humid tropical climate with distinct dry and bimodal rainy season. Mean annual rainfall is approximately 1400 mm and mean monthly air temperature is approximately 27.9'C. The vegetation of the area consists of cacao, oil palm and citrus. Guided by soil map of southwestern Nigeria produced by Symth and Montogomery (1962), a topo sequence fallen within the soils classified as Iwo series was selected for the study. Three profile pits were established, described and sampled with one at different physiographical units (upper slope, mid slope and lower slope) following the guideline for soil profile description according to FAO/UNESCO (2006) guideline. Samples were collected from delineated diagnostic horizons, starting from the lowest to the uppermost profile depths, in order to prevent cross-contamination of soil samples. The soil samples collected were bagged, labeled and analyzed in laboratory for particle size distribution, pH, electrical conductivity, organic matter, exchangeable cation, available phosphorous and total nitrogen.

Laboratory analysis

The soil samples were air dried, crushed gently in a ceramic mortar and passed through 2 mm sieve to separate gravel content and obtain the less than 2 mm fractions for laboratory analyses. Particle size distribution was evaluated by the modified Bouyoucos hydrometer method (Bouyoucos, 1962) as reported by Gee and Or (2002). Soil pH was determined in 1:2 soil water suspension using a glass electrode pH meter (Mclean 1965), electrical conductivity was evaluated by the saturated paste method (Clay *et al*., 2012) and determined using conductivity meter (JENWAY 4510 model). Soil organic matter (SOM) was determined by the Walkley Black method (Walkley and Black, 1934) using the chromic acid digestion (Allison, 1965) as reported by Nelson and Sommers (1996). Exchangeable cations were extracted using 1. 0 N NH4OAC (pH. 7.0) and read using flame photometer for sodium and potassium, and atomic absorption spectrophotometer for calcium and magnesium. The total nitrogen was and determined using the Kjeldahl method (Bremner, 1996) and available phosphorus was determined by the Bray-1 method (Kuo, 1996).

Suitability evaluation

The FAO framework for soil suitability evaluation was used for the study (Sys *et al*., 1993). Land characteristics recognized on the field were combined with those determined in the laboratory to make the preferred land qualities which were used as basis for the land assessment. A numerical rating of the land characteristics

Table 1. Physical properties of the soils.

Horizon	Depth (cm)	Particle size distribution (%)			Silt/clay	Textural class
		Sand	Silt	Clay		
Profile 1						
AP	0-38	68	14	18	0.80	SL
AB	38-75	37	09	54	0.20	C
Bt1	75-98	35	13	52	0.25	C
Bt2	98-157	33	17	50	0.34	C
Profile 2						
Ap	0-20	55	29	16	1.80	SL
AB	20-52	60	8	32	0.25	SCL
Btv1	52-74	51	7	42	0.17	SC
Btv2	74-94	36	12	52	0.23	C
Profile 3						
Ap	0-21	70	7	23	0.30	SCL
AB	21-44	48	9	43	0.21	SC
B_t1	44-75	40	7	53	0.13	C
B_t2	75-115	38	9	53	0.17	C
C	115-184	40	13	47	0.28	C

SC= Sandy Clay, SL= Sandy Loam, SCL=Sandy Clay Loam, C=Clay, CL= Clay Loam.

in a normal scale from a maximum (normally 100) to a minimum value (20) was employed. If a land characteristic was optimal for the considered land utilization type, the maximal rating of 100 was attributed; if the land characteristic was unfavorable, a minimal rating of 20 was applied. The index of suitability (actual and potential) was calculated using the square root method: IP = A x √ ((B/100) x (C/100) x … x (F/100)). Where: IP = land index A = overall lowest characteristic rating B, C…F = lowest characteristics ratings for each land quality group (Udoh *et al*., 2006). For actual (current) aggregate suitability, all the lowest characteristic ratings for each land quality group were substituted into the aggregate suitability equation above. However, in the case of potential aggregate suitability, it was assumed that the corrective fertility measures would no longer have fertility constraints. Therefore, other qualities except fertility (f) were used to calculate the potential aggregate suitability.

RESULTS AND DISCUSSION

Characteristics of the soil

Table 1 showed that the profiles were very deep and were all considered suitable for cocoa production. Cacao requires a minimum depth of 100-150 cm which would ensure a good anchorage against tropical storm and adequate moisture supply during dry season. Although, Hardy (1960) had earlier given a general rule of 1.5 m as minimum soil depth for optimum cocoa growth, nevertheless; where all other aspects are particularly favourable soils only 1 m deep may be acceptable. The texture of the surface ranged from sandy loam to sandy clay loam and sandy clay loam to clay at subsurface. The sand particles seemed to be the most dominant size fraction with a range from 33 to 70% but decreased with depth. The high sand particles fraction could have been responsible for the well-drained nature of the soils (Symth and Montogomery, 1962; Amusan, 1991; Ogunkunle, 1993). The clay content varied from 16 to 54% which increased with depth of the profiles. This is an evidence of illuviation. The contents of silt in the soils were comparatively lower than those of the sand fraction. There was no consistent pattern of distribution of silt in all the profiles. The values ranged between 9 to 17 % which decreased with depth. The low silt content of the soils irrespective of their location is in line with the reports of several researchers who worked in similar environment in the basement complex area of Southwest Nigeria (Okusami and Oyediran, 1985). The silt/clay ratios of 0.20 to 1.80, 0.17 to 1.80 and 0.17 to 0.30 were observed in mapping unit A, B and C respectively. Mapping unit C was more weathered than others because of the lower silt/clay ratios of subsoil.

The chemical properties of the soils studied are presented in Table 2. The pH of the soils was slightly acidic ranging from 4.0-6.0 and 3.0-5.7 in water and $CaCl_2$

Table 2. Chemical properties of the soils.

Horizon	Depth (cm)	pH		Exchangeable cations (cmol/kg)				Organic matter (%)	Available P (ppm)	Total N (%)
		H_2O	$CaCl_2$	Ca	Mg	Na	K			
Profile 1										
AP	0-38	6.0	5.7	2.38	1.72	0.34	0.20	1.01	21.30	0.14
AB	38-75	5.8	5.2	2.15	1.42	0.20	0.22	0.81	24.77	0.10
Bt1	75 – 98	5.2	4.5	2.15	0.92	0.32	0.21	0.40	3.16	0.08
Bt2	98 – 157	5.0	4.7	1.70	1.03	0.36	0.26	0.54	18.64	0.05
Profile 2										
Ap	0 – 20	5.6	4.6	1.20	0.74	0.18	0.07	1.48	1.32	0.14
AB	20 – 52	5.8	4.9	1.50	1.06	0.19	0.07	1.01	3.16	0.06
Btv1	52 – 74	5.2	4.2	1.00	1.19	0.23	0.06	0.81	12.11	0.05
Btv2	74 -94	5.0	4.1	1.00	1.20	0.25	0.10	0.60	3.68	0.03
Profile 3										
Ap	0 – 21	4.2	3.9	0.70	0.55	0.19	0.08	1.74	5.00	0.12
AB	21 – 44	4.6	4.1	1.00	0.73	0.19	0.09	1.07	5.79	0.07
B_t1	44 – 75	4.9	4.5	1.50	0.85	0.22	0.08	1.01	0.52	0.06
B_t2	75 – 115	4.7	4.3	1.20	0.77	0.22	0.08	0.77	8.95	0.02
C	115 – 184	4.5	4.1	0.80	0.59	0.43	0.27	0.54	12.11	0.50

solution respectively. The higher pH in profile 1 relative to others could be attributed to higher rate of phytocycling. Generally, the soil pH fluctuated irregularly with the soil depth. The organic matter content was low (0.4-1.74%). The soil organic matter ranged from 0.4 to 1.74% with the highest values observed at the surface horizons. The soil organic matter content of all profiles was low to medium and this may be due to the prevalence of tropical conditions where the degradation of organic matter occurs at faster rates coupled with low vegetation cover, thereby leaving less organic carbon in the soils (Nayak *et al*., 2002). The value decreased with depth. The higher SOM content at the surface of most of the profiles could be attributed to more decomposable plant materials on the surface soil (Lal, 1991). The total nitrogen content was low and varied from 0.02-0.14% and the values decreased with depth. The values were low to medium compared with the critical value of plant nutrient of 0.20% and in close association with organic matter. Available phosphorus varied from 0.52-24.77 mg/kg in all the horizons in the profiles with the highest values at the surface soil horizons, an indication that soil organic matter contributes significantly to the available P in these soils. The available P values were all considered low in most of the horizons as they were below or only slightly above the 10 ppm critical limit recommended for most commonly cultivated crops in the area (Uponi and Adeoye, 2000). The low value of available P might be due to the fixation of phosphorus by iron and aluminum sesquioxides under well-drained and acidic conditions of the soils (Onyekwere *et al*., 2001). Hence, for optimum production of cocoa, guided P fertilizer recommendation and application would be necessary. The exchangeable bases were low. Symth and Montogomery (1962) reported that the soils of the upland area of central western Nigeria have low exchange capacity in keeping with the essentially kaolinitic nature of their clay content. Relatively low amounts of exchangeable bases were present in all the profile pits examined. The exchangeable calcium for the soil varied from 0.7 to 2.38 cmol/kg. The soil Ca^{2+} values for each profile pit were less than the critical value of 5.0 cmol/kg for ideal cocoa production (Egbe *et al*., 1989) Application of Ca^{2+} containing fertilizer is required to achieve ideal cocoa yields. The exchangeable magnesium (Mg^{2+}) content varied from 0.55 to 1.72 cmol/kg soil. Most of the soils examined had their exchangeable Mg content higher than 0.9 cmol/kg which is the critical value for Mg in cocoa production (Egbe *et al*., 1989). Exchangeable potassium (K) contents ranged between 0.4 and 1.78 cmol/kg. The soil K levels were higher than the critical level of 0.3 cmol/kg soil. This indicates that the soil K content were adequate and would therefore not need the use of K supplying fertilizer. The sodium content ranged from 0.07-0.27 cmol/kg. Uwitonze (2016) reported that when the value of Na content is <1 cmol/kg, it cannot be detrimental to plant roots. The relative abundance of the exchangeable bases followed the order: Ca > Mg > Na > K at the exchangeable site. The low values of exchangeable bases of the soils may be attributed to high rainfall intensity, intensity of weathering, leaching and lateral translocation

Table 3. Land requirement for suitability classes for cocoa cultivation

Land qualities	S1	Sl$_2$	S2	S3	N1	N2
Climate (c)						
Annual Rainfall (mm)	>1000	900-1000	800-900	600-800	600-500	<500
Annual Temperature (0C)	>25	22-25	20-22	18-20	16-18	<16
Relative humidity (%)	>75	70-75	65-70	60-65	<60	
Topography (t): Slope (%)	<2	3-4	5-6	7-8	9-10	>10
Drainage (S)						
Wetness	WD	MWD	MD	ID	PD	PD
Soil physical properties						
Texture	L – CL	SCL – SC	LFS – SL	CL	S, HC	
Soil depth (cm)	>120	100 – 120	50 – 90	30 -50	20 – 30	10- 20
Fertility (f)						
pH	5.5-6.5	5.5-5.0	4.5-5.0	4.0-4.5	<4	
Organic matter (%)	>2.0	2.0-1.5	1.2-1.5	1.2 – 1.0	1.0	<1.0
Nitrogen (%)	>2.0	1.5 – 2.0	1.0 -1.5	0.5 – 1.0	<0.5	
Phosphorus (ppm)	>20	15-20	8-15	5-8	3-5	<3
Potassium (cmol/kg)	>0.5	0.3 – 0.5	0.2 – 0.3	0.1 – 0.2	<0.1	

WD= Well drained; MWD= Moderately well drained; MD= Moderately drained; ID= Imperfectly drained; PD= Poorly drained; L= Loamy; SCL= Sandy Clay Loam; SC= Sandy Clay; SL= Sandy Loam; CL= Clay Loam; LFS= loamy Fine Sand.

Table 4. Qualitative land suitability classes for the different land indices.

Symbol	Definition	Land Index
S1	Highly suitable	75 – 100
S2	Moderately suitable	50 – 75
S3	Marginally suitable	25 – 50
N1	Presently not suitable	12.5 – 25
N2	Permanently not suitable	0.00 – 12. 5

of bases (Solarin, 2000).

Suitability evaluation of the soils for cocoa production

The suitability ratings of the land characteristics (Table 5) were obtained by comparing their values with the land requirement for cocoa production (Table 3) using the ratings for the limited characteristics in Table 5. Aggregate suitability ratings (potential and actual) were computed using the linear parametric approach. The result showed that soil unit A was marginally suitable (S3) for cocoa production for both actual and potential suitability. Soil unit B was not presently suitable (N1) for actual suitability and moderately suitable (S2) for potential suitability. Soil unit C were rated marginally suitable (S3) for actual and moderately suitable (S2) for cocoa production.

Conclusion

Soils of the studied area were characterized and evaluated for cocoa production. The soils were moderately acidic to highly acidic. The soils are deficient in macro nutrients, their values were below the critical level required for optimum cocoa production. Land suitability evaluation result revealed that currently, the soils are presently not suitable to marginally suitable for cocoa production. Potentially, that is, with good management practices, the soils would be marginally suitable to moderately suitable. The limiting factors were mainly low soil fertility such as low levels of potassium, phosphorus, nitrogen and organic matter content. Therefore, agronomic practices such as addition of organic materials, liming and inorganic fertilizer should be employed to enhance optimum production in the area. The application of acidifying fertilizer should be avoided.

Table 5. Land characteristics of the land units.

Land Qualities	Soil unit A	Soil unit B	Soil unit C
Climate (c)			
Annual Rainfall (mm)	1400	1400	1400
Annual Temperature (^{0}C)	27.9^{0}C	27.9^{0}C	27.9^{0}C
Relative Humidity (%)	78	78	78
Topography (t): Slope (%)	2 – 4	2 – 4	2 – 4
Drainage (S)	Well drained	Well drained	Well drained
Soil physical properties			
Texture	SL – C	SL – C	SCL – C
Soil depth (cm)	157	94	184
Fertility (f)			
pH	6.0	5.6	4.2
Organic matter (%)	1.01	1.48	1.74
Nitrogen (%)	0.16	0.09	0.26
Phosphorus (ppm)	21.30	1.32	5.0
Potassium (cmol/kg)	0.20	0.07	0.08

Sandy Clay Loam; SC= Sandy Clay; SL= Sandy Loam; CL= Clay Loam.

Table 6. Suitability ratings of the soils of Iwo series for cocoa production.

Land qualities	Soil A	Soil B	Soil C
Climate (c)			
Annual Rainfall (mm)	100	100	100
Annual Temperature (0C)	100	100	100
	100	100	100
Relative humidity (%)	100	100	100
	100	100	100
Topography (t): Slope (%)	100	100	100
	100	100	100
Drainage (S)	100	100	100
	100	100	100
Soil physical properties			
Texture	85	85	95
	85	85	95
Soil depth (cm)	100	95	100
	100	95	100
Fertility (f)			
pH	95	95	75
	95	95	75
Organic matter (%)	50	75	75
	50	75	75
Nitrogen (%)	75	50	100
	-	-	-
Phosphorus (ppm)	95	50	50
	-	-	-

Table 6. Contd.

Potassium (cmol/kg)	85 -	85 -	85 -
Index	25 40	25 65	34 63
Class	N1sfa S3sfp	N1sfa S2sfp	S3sfa S2sfp

a = actual suitability when nutrient characteristic (f) is not corrected by fertilizer application.
b = potential suitability after correction of nutrient characteristic (f) by fertilizer application.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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