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EVALUATING LAND SUITABILITY FOR ALFALFA (*Medicago sativa*) PRODUCTION IN MINNA, SOUTHERN GUINEA SAVANNAH, NIGERIA

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ABSTRACT

Land evaluation is the assessment of land performance when used for specified purposes. It is an essential tool for resolving the competing needs in respect to land uses and thus a pre-requisite for a successful and sustainable agricultural enterprise such as crop production. This study assessed and evaluated a parcel of land (1.51 ha) for its suitability for production of alfalfa in Minna, Nigeria. In the centre of the field, a mini soil profile (100 x 100 x 100 cm) was excavated and described according to standard guidelines. The samples were collected from the identified genetic horizons and taken to the laboratory for routine analysis. Square root method was used in land suitability evaluation. Results revealed a moderately deep and imperfectly drained sandy loam, moderately acidic (pH 5.4 - 5.6), low content of organic C ($\leq$ 4.17 g kg^{-1}), total N (0.14 g kg^{-1}), available P (7.20 mg kg^{-1}) and very low exchangeable K (0.43 cmol kg^{-1}). Land evaluation revealed suitability indices of 36 and 51% for actual and potential which corresponded with marginally suitable (S3) and moderately suitable (S2) classes respectively for cultivation of alfalfa. Incorporation of organic matter and fertility management will enhance the sustainable production of alfalfa in the study area

*Keywords**:** Soil characterization, land suitability evaluation, precision farming; alfalfa*

Introduction

The ability of the agricultural sector to produce enough food from crop production for the burgeoning population is to practice precision farming technology in which appropriate farm management decisions, including nutrient source, rate, time, and method of application, choice of crops, to be planted, are taken on the basis of the potential of various component units of the land/soil. One major way to ensure optimum and sustainable production output of land/soil for crop production, mindful of the prevailing scarce land resources, due to competition from other land uses, soil variations, and optimizing need of crops, is to undertake inventory of soil resources by carrying out soil survey and evaluate the potential of the land for defined uses by carrying out land capability/suitability evaluation. This will ensure that the land is properly maintained to remain in better, richer and healthier status for the present and future generations.

Land suitability evaluation is a systematic process used to determine the potential of a given parcel of land for sustainable use, based on its characteristics, potentials and constraints (Kefas *et al*., 2020; Peter and

Umweni, 2020). It involves assessing the physical, chemical, and socio-economic characteristics of land and matching them with the requirements of specific crops (Bintang and Tampubolon, 2018). This evaluation helps farmers, planners, and policymakers make informed decisions about land use, maximize productivity, and minimize environmental degradation.

The suitability of the land could be assessed for present condition (actual land suitability) or after improvement (potential suitability). Actual land suitability is based on current land and soil conditions without applying any corrective measures or inputs, while potential land suitability is the suitability that could be reached after the land is improved. In carrying out land suitability evaluation exercise, individual landscape features and soils are evaluated according to distinct classes and assigned a qualitative ranking for crop production as: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently not suitable (N2).

Alfalfa is a perennial flowering plant in the legume family *Fabaceae*, grown throughout the world either planted as monocultures or in pasture mixes with various grasses (Deng *et al*., 2014). It is an important forage crop cultivated and used for grazing, hay and silage as well as green manure and cover crop. The crop thrives in areas with a temperate to warm climate. While much of Nigeria's climate is tropical, some northern regions with lower rainfall and cooler night temperatures may be suitable for alfalfa cultivation. The production alfalfa in Nigeria is not yet well established compared to other forage and fodder crops. This created a huge gap in information on cultivation of alfalfa in various sections of the country, especially on land suitability evaluation and mapping of spatial variability in soil properties as it relates to precision management of the crop.

To address some of the soil and environment challenges, conducting land suitability evaluation would provide needed data to bridge the huge information gap necessary for alfalfa cultivation in Nigeria. Outcome of land suitability assessment can be used to address the questions such as "where" in terms of land and resource use; to establish conditions favourable for sustainable production of a particular crop (Bera, 2017). Therefore, this study was designed to evaluate the suitability of land for cultivation of alfalfa in Minna, southern Guinea savannah of Nigeria.

Materials and Methods

Site Description

A parcel of land which measured 1.51 ha located at Barikin-Sale, Minna, Niger State, Nigeria identified on Latitude 9° 34' 28.430" N and Longitude 6° 31'59.790" E, on elevation of 244 m above mean sea level, was chosen as the study site (Figure 1). Minna falls under the southern Guinea savannah vegetation zone of Nigeria. Climate of the area was sub-humid Tropical. Mean annual rainfall of the area is 1,200 mm distributed between April and October with peak in August. Mean monthly maximum temperature was 33 °C. The hottest period peaks at 40 °C coinciding with the months of February-March (Adeboye *et al*., 2020; Weather Spark, 2024). The geology of the area is basement complex rocks made up of granites, migmatites, gneisses and schists. Inselbergs of "Older Granites" and low hills of schists rise conspicuously above the plains. Beneath the plains, bedrock is deeply weathered and constitutes the major soil parent material (Ojanuga, 2006). The site was previously cropped to melon, ground nut, soybean, cowpea and maize.

Soil Profile Description and Soil Sample Collection

In the centre of the 1.51 hectare field, a mini soil profile (100 x 100 x 100 cm) was excavated and morphological properties recorded according to the USDA guidelines for soil profile description (Soil Survey Staff Division, 2017). Soil colour was described using Munsell Soil Colour Charts (Munsell

Soil Colour Company, 2009). Soil samples were collected from the identified genetic horizons and sent to the laboratory for routine analysis.

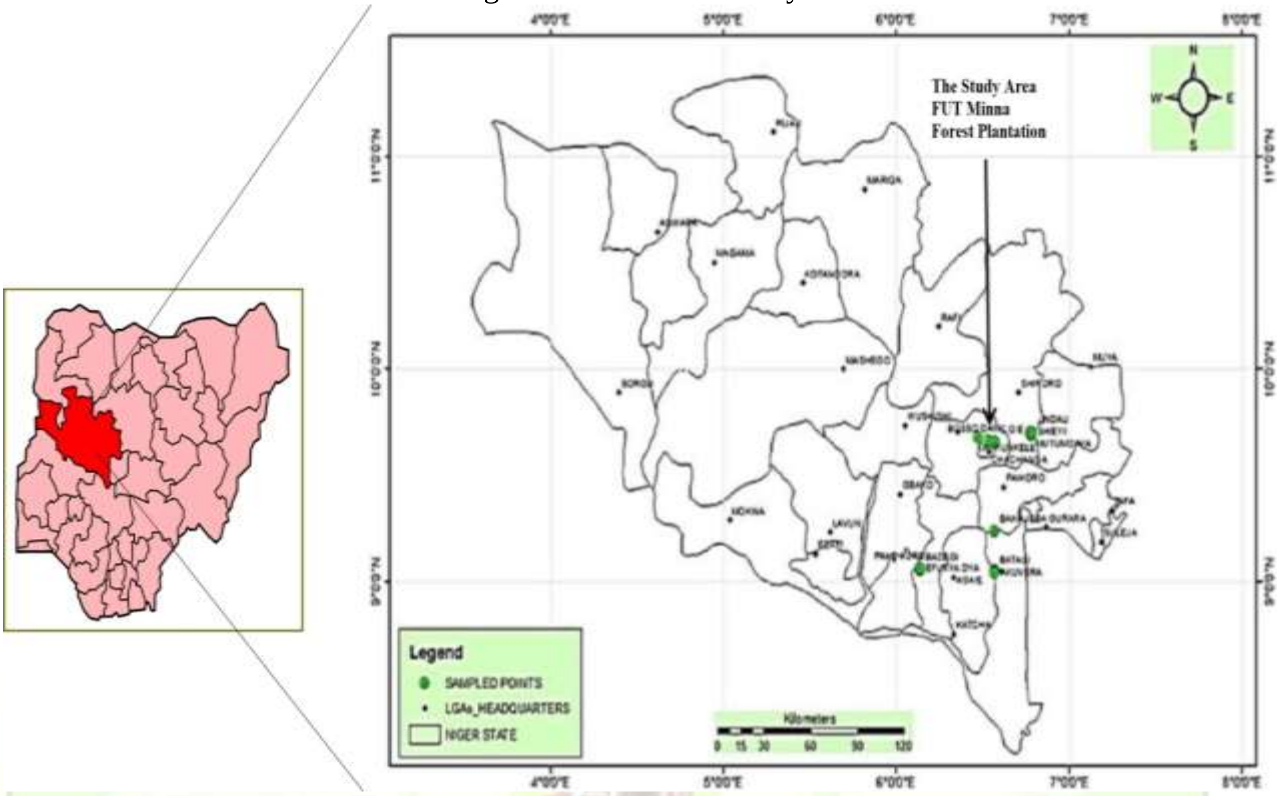

Figure 1: Map of Nigeria and Niger State showing the location of the study site

Laboratory Analysis

The air-dried soil samples were gently crushed and passed through a 2 mm sieve prior to analysis. The processed soil samples were analysed according to standard laboratory procedures as outlined in IITA (2015) for particle size distribution using Bouyoucos hydrometer method, pH was measured in a solution using 1:2.5 soil to water ratio, organic carbon (C) was determined using Walkey and Black's wet oxidation method, total nitrogen was determined using the Macro Kjeldahl technique, available phosphorus (P) was extracted using the Bray P1 method. Exchangeable bases, calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) were extracted with 1M ammonium acetate solution buffered at pH 7.0, thereafter, exchangeable potassium and sodium K and Na were determined on a flame photometer.

Land Suitability Evaluation

Suitability evaluation was performed for production of alfalfa using square root method (Khidir, 1986) as expressed in equation (1) below:

$$I_i = R_{min} \text{ x } \sqrt{\frac{A}{100} X \frac{B}{100} X \frac{C}{100} \ldots \ldots} \quad \text{equation (1)}$$

where, *Si*= suitability index, R_{min}= connotes the factor that has minimum weight; and A, B, C… are ratings of other factors besides the minimum.

The parameters used for the evaluation includes climate, soil physical characteristics, wetness (drainage), topography, nutrient availability and nutrient retention capacity of the surface soil (Tenka and Balogun, 2019). These characteristics were matched with soil and environmental requirements for cultivation of alfalfa (Table 1). Final suitability for each crop was defined by applying the computed index values converted to its corresponding land suitability classes. According to suitability ranking of Sys *et al*. (1991), land suitability index from 0 to 12.5% connotes permanently not suitable (N2), 12.5 to 25% is currently not suitable (N1), 25 to 50% is marginally suitable (S3), 50 to 75% is moderately suitable (S2) and 75 to 100% is highly suitable (S1).

Table 1: Land Suitability classification factors for alfalfa as defined in Sys *et al*. (1993).

	Rating				
Land characteristics	S1 100%	S2 85%	S3 60%	N1 40%	N2 25%
Rainfall(mm)	1100-1400	1400-1600	> 1500		
	1100-800	800-600	600-400	-	< 400
Temperature(°C)	25 – 28	28 – 32	32– 40	-	> 40
Topography (t):					
Altitude(m)	0-4,000	-	-	-	-
Slope gradient(%)	0-4	4-8	8-16	16-30	> 30
Wetness (w):					
Drainage	Good to moderate	Imperfect	Poor and aeric	Poor, drainable	Poor, not drainable
Soil physical characteristics (s)					
Texture	Heavy and medium	Medium	Light	-	
Soil depth(cm)	200-150	150-50	50-1	-	-
Soil Fertility characteristics (s)					
pH	7.4-6.0	6.0-5.5	5.5-5.2	<5.2	-
	7.4-8.0	8.0-8.2	8.2-8.5	-	> 8.5
Organic carbon (kg^{-1})	> 20	20-12	12-8	< 8	-
CEC (cmol kg^{-1})	> 24	24-16	< 16 (-)	< 16 (+)	-
Base saturation (%)	> 35	35-20	< 20	-	-

Note: S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, N1 = currently not suitable, S2 = permanently not suitable

Results and Discussion

Soil Morphological Characteristics

The surface soil was characterized by dark yellowish brown (10YR 3/4) colour overlaying shades of yellowish red (5YR 5/6) and strong brown (7.5YR 4/6) at the subsoil (Table 2). Yellowish brown colour exhibited at the topmost horizons might be an indication of presence of hydrated Fe compounds such as. limonite or goethite in those strata. The soil was moderately deep and imperfectly drained due to presence of a plinthic layer starting from 70 cm depth. The plinthic horizon may hinder free de-percolation of water, more so, that the site was relatively flat.

The surface horizon had weak fine crumb underlain by sub-angular blocky structure in the subsurface while the plinthic layer was poorly structured (massive). In terms of morphological characteristics, the two topmost horizons may favour rooting and normal growth of the alfalfa crop with provision of adequate drainage. Its effective soil depth (70 cm) could permits good distribution of the alfalfa roots and provides adequate volume for storage of nutrients and moisture for crop use.

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Table 2: Morphological properties of the soil

Horizon	Soil Depth (cm)	Colour of matrix (moist)	Structure†	Consistency‡ Moist	Wet	Boundaryɫ
Ap	0 – 30	Dark yellowish brown (10YR 3/4)	1fcr	Very friable	ns &np	cw
Bt	30 – 70	Yellowish red (5YR 5/6)	1msbk	Friable/ firm	s &sp	aw
Btv	70 – 100	Strong brown (7.5YR 4/6)	0ss	Firm	s &np	-

†2 = moderate, m = medium, c = coarse, abk = angular blocky, f = fine, cr = crumb, sbk = sub-angular blocky, 0ss- structureless; ‡ss = slightly sticky, np = non plastic, sp = slightly plastic, s = sticky, p = plastic; ɫcw = clear wavy, aw = abrupt wavy, aw = abrupt smooth

Physical properties

Sand dominated the mineral fraction in the soil reflecting the nature of the parent materials which weathered to produce the soils. Sand content ranged from 676 to 826 g kg^{-1} and decreased irregularly down the profile. Silt ranged from 70 to 180 g kg^{-1} while clay ranged from 104 to 154 g kg^{-1} and impacted on the soil loamy sand at the two topmost horizons and sandy clay loam in the subsoil (Table 3). Loamy sand favours cultivation of most arable crops and pasture.

Table 3: Physical properties of the soil

Horizon	Soil Depth (cm)	Sand	Silt ($g\ kg^{-1}$)	Clay	Textural class*	Bulk density ($g\ cm^{-3}$)	Total porosity (%)
Ap	0 – 30	806	70	124	SL	1.35	49
Bt	30 – 70	676	120	204	SL	1.72	35
Btv	70 – 100	696	90	214	SCL	2.52	5

**SL = sandy loam, SCL = sandy clay loam*

Bulk density was 1.35 g cm^{-3} at topmost horizon and increased to 2.52 g cm^{-3} at the densic subsoil horizon with high content of gravels. Bulk density value of the surface horizon fall within the favourable range (1.00 to 1.70 g cm^{-3}) established for most arable crops (Brady and Weil, 2002). This suggests that the epipedom was not compacted. Total porosity of the surface was moderate and reduced with increasing depth to very low due to the underlining plinthic horizon in the subsoil with possibility of creating perched water-table which may limit vertical root distribution to explore nutrients in the subsoil.

Chemical properties of the soil

The results of chemical properties of the soil are presented in Table 4. Soil reaction (pH) was moderately to strongly acid at the surface to strongly acid at the subsurface. The pH range may limit ready availability of some plant nutrients, especially phosphorus. Exchangeable acidity was low suggesting that the soil has low potential acidity. Organic matter plays significant role in holding soil nutrient, water and binding mineral component to enhance soil structure. Organic carbon (OC) content was low irrespective of the horizons, implying that the soil contains low reserves of organic matter. This could be explained in terms of long-term tillage practices, high rate of mineralization, removal of crop residue, and lack of application of organic amendments by the farmer (Malla *et al*., 2020). Therefore, intensive use of this soil for sustainable production will necessitate paying attention in ensuring recycling of crop residues. Total nitrogen (N) in the soil was very low. In tropical soils, organic matter has been reported to be the major source of soil N, accounting to about 95% (Pribly, 2010). However, low N may not be a constraint to growing of alfalfa, being a leguminous crop.

Available phosphorus (P) in the soil was very low. This nutrient is required in large amount, especially for roots development. Hence, there is need to apply phosphorus-containing fertilizer, such as single superphosphate, to make up the nutrient deficit in the soil.

Table 4: Chemical properties of the soil profile

Soil Depth	pH	OC	N	P	Ca	Mg	K	Na	EA	CEC	BS
(cm)	(H_2O)	(g/kg)		(mg/kg)	←		(cmol/kg)			→	(%)
0 – 30	5.6	4.17	0.14	7.20	0.96	0.40	0.43	0.29	0.05	3.87	54
30 – 70	5.5	2.65	0.11	1.04	1.28	2.64	0.07	0.17	0.06	7.07	59
70 – 86	5.4	1.33	0.08	1.26	1.36	2.40	0.05	0.16	0.05	6.68	60

Note: OC = Organic carbon, N = total nitrogen, P = available phosphorus, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium, EA = exchangeable acidity, CEC = cation exchange capacity, BS = base saturation,

Calcium content within the soil was low in all the horizons. Magnesium was medium to high. Potassium concentration was high in the topmost horizon but very low in the subsoil. Sodium was medium to high but its concentration in the soil was below the critical level of classifying the soil as sodic. Thus, the soil could be free from sodium hazards, having the highest exchangeable sodium percentage (ESP) value of 11.24%. The exchangeable sodium percentage is the amount of exchangeable sodium in relation to other exchangeable bases.

Site suitability evaluation for cultivation of Alfalf*a*

Means of climatic data for Minna, Niger State was used for the suitability evaluation. Land characteristics/quality of the site (Table 5) was matched with soil and environmental requirement for alfalfa (as earlier indicated in Table 1) to arrive at the actual and potential suitability classes (Table 6) for the site. Suitability rating of the factors vary with mean annual rainfall, slope gradient, altitude, drainage, soil texture, base saturation all ranked as highly suitable (S1). Other parameters such as mean monthly temperature, soil depth and pH were moderately suitable (S2), while organic carbon and CEC ranked as marginally suitable (S3).

Actual suitability implies fitness of the land for crop production on the basis of its present status without correcting the amendable limitations, particularly fertility attributes such as pH of the soil. Actual suitability classification revealed that the site was marginally suitable (S3) for cultivation of alfalfa in its current status, having aggregate index of 36%. Major limitation was pH (nutrient retention).

Potential suitability implies the assessment made on the basis that such fertility limitation as earlier indicated is corrected without incurring exorbitant cost. Such corrections form part of land use management decisions. When such management decision was imposed, suitability of the land was upgraded with land index of the site changed from 36 to 51% which corresponded to moderately suitable (S2) class for cultivation of alfalfa.

Table 5: Land qualities/ soil characteristics of the site

Land Characteristics / Quality	Value	Remark
Annual rainfall (mm)	1,151	Highly suitable (S1)
Mean monthly maximum temperature (°C)	31	Moderately suitable (S2)
Slope gradient (%):	1-2	Highly suitable (S1)
Altitude (m):	243.5	Highly suitable (S1)
Drainage	Well-drained	Highly suitable (S1)
Soil depth (cm)	63	Moderately suitable (S2)
Texture (topsoil)	Sandy loam	Highly suitable (S1)
pH (H_2O)	5.6	Moderately suitable (S2)
Organic carbon (g k^{-1})	3.60	Marginally suitable (S3)
Cation exchange capacity (cmol kg^{-1})	3.05	Marginally suitable (S3)
Base saturation (%)	56.83	Highly suitable (S1)

Table 6: Suitability evaluation of the site for alfalfa

	Suitability type	
FACTOR	Actual	Potential
Climatic regime of the environment (c):		
Annual rainfall	100	100
Mean monthly maximum temperature	85	85
Topography:		
Slope gradient	100	100
Elevation	100	100
Wetness (w):		
Drainage	100	100
Soil physical properties (s):		
Texture (topsoil)	100	100
Soil depth	85	85
Nutrient availability/retention (f):		
pH (H_2O)	85	100
Organic carbon	60	100
Cation exchange capacity (CEC)	60	60
Base saturation	100	100
Salinity and sodicity (n)		
Electrical conductivity	100	100
Exchangeable sodium percent (ESP)	100	100
Suitability Index (%)	**36**	**51**
Suitability Class	**S3sf**	**S2s**

Note: *S2 = moderately suitable, S3 = marginally suitable*
Limitations (restrictive features): s = soil physical characteristics, f = fertility (nutrient availability/ retention)

Conclusion

The site evaluated for the cultivation of the alfalfa had moderately deep soil, imperfectly drained in the subsurface and moderately acidic. Other soil fertility indicators such as soil organic C, content, total N, available P and exchangeable K were low which made the soil to be marginally suitable (S3) in its current state. For full potentials of the soil in the study area to be realised in meeting up the requirements of alfalfa and its sustainable production, it is recommended that farmers should correct soil acidity limitation by application of lime. Low organic C contentment can also be amended by management practices that will encourage returns of crop residues into the soil, such as application of organic fertilizers such compost. Soil fertility, particularly, available P and exchangeable K can be amended through application of mineral fertilizers. Since alfalfa is a leguminous crop with capacity to fix N to soil, application of little dose of N as starter will suffice.

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