International Journal of Development and Sustainability
ISSN: 2168-8662 – www.isdsnet.com/ijds
Volume 3 Number 2 (2014): Pages 393-403
ISDS Article ID: IJDS13100801

Soil suitability assessment of Haplustalfs for maize and groundnut in sub-humid environment of Nigeria

Lemuel Musa Maniyunda *, Mwagim George Gwari

Deparment of Agricultural Engineering, Kaduna Polytechnic, P.M.B. 2021 Kaduna, Nigeria

Abstract

Haplustalfs soils namely land unit 1 (LU1), land unit 2 (LU2) and land unit 3 (LU3) developed on loessial deposits, loess-over basement complexes and basement complex rocks respectively were evaluated for their suitability for maize and groundnut in sub-humid environment of Nigeria. Land qualities and crop requirement features considered in the study include crop growth pattern, soil fertility, water requirement of the crops and soil conservation. The suitability assessment approaches used in the evaluation were limiting condition, addition and multiplication methods. Most of the land units were marginally suitable (S3) for maize and groundnut using limiting condition and addition methods except LU2 that was moderately suitable (S2) for maize in addition method and moderately suitable for groundnut in LU2 and LU3 for limiting condition and addition methods respectively. The multiplication method rated the land units lower (S3 and N) than other methods, and was not a representation of the obtainable yield on the land units. None of these land units of Haplustalfs were highly suitable for the crops evaluated. Soil moisture retention capacity, nutrient availability and nutrient retention were critical factors that lowered the soil suitability classification and were considered critical to management for sustainable utilization of the soils studied.

Keywords: Soil suitability; Haplustalfs; Maize; Groundnut; Sub-humid environment

Cite this article as: Maniyunda, L.M. and Gwari, M.G. (2014), "Soil suitability assessment of Haplustalfs for maize and groundnut in sub-humid environment of Nigeria", *International Journal of Development and Sustainability*, Vol. 3 No. 2, pp. 393-403.

* Corresponding author. *E-mail address:* lemuelmusa@gmail.com

1. Introduction

The evaluation of land is normally carried out to determine their suitability for specific uses. The information obtained can be use for a more realistic land use recommendation and present their constraints (FAO, 1995; Abdulkadir, 1998; Braimoh, 2000). It also enables management guidelines in order to promote a more sustainable use of the soil and environmental resources. For assessing the suitability of soils for crop production, soil requirements for crops must be known. The requirements must be understood within the context of limitations imposed by the soil and other features which do not form a part of the soil but may have a significant influence on use that can be made of the soil (FAO, 1978). From the basic soil requirements of crops, numbers of soil qualities are directly related to crop yield performance. For most crops, soil characteristics have been identified for high, moderate, marginal and unsuitable levels. Beyond critical levels, crop performance is reducing unless some precautionary management measures are applied. Soil suitability classifications are based on matching requirements for crops and soil qualities (FAO, 1995). The suitability classes obtained from the matched characteristics are combined to obtain overall soil suitability classes through use of principle of limiting condition, addition and multiplication methods (Dent and Young, 1987; FAO, 1995).

The present shortage of good land for food production as caused by competing demand for other land uses such as industrialization, housing, grazing, fuel wood, cash crop and their degradation as caused by unsuitable land use practices (FAO, 1985; Raji, 1999) called for a reliable land evaluation. Land suitability analysis for crop is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. Land evaluation is a tool for land use planning for sustainable agriculture (Shahbazi et al., 2009; Perveen et al., 2012). Soil characterization and land evaluation for various land use is one of the strategies for achieving food security as well as sustainable environment (Esu, 2004). The starting point toward sustainable management is adequate information on land resources and their suitability but these are not in proper form in spite of several spots studied in Nigeria (Ogunkunle, 2004).

Several approaches have been used for land evaluation, these include Boolean logic, Fuzzy set method; limiting conditions; arithmetic procedure, productivity evaluation (Burrough et al., 1992; Braimoh, 2000; FAO, 1995, Maniyunda, 1999; Raji, 1999). The productivity of soils in Nigerian savanna region is decreasing due to their fragile nature. These lands have been utilized intensively for all purposes at the expense of their suitability resulting in degradation and altering of the natural ecological conservatory balances (Ande, 2011; Senjobi, 2007). Therefore, there is need to use the soils in a sustainable way to avoid their degradation. The competing demand on soils and the degradation on the environment necessitated the present study. The objectives of the study therefore was to assess some of the methods used in land suitability evaluation and to determine which of the methods is suitable and realistic to the soil environment of the sub- humid region of Nigeria using maize and groundnut crops.

2. Materials and methods

2.1. Description of study area

The study was carried out in Funtua on the far south of Katsina state and situated between latitude 11^{o} 33^{1} 07.4” to 11^{o} 33^{1} 54.2” N and longitude 07^{o} 14^{1} 08.6” to 07^{o} 14^{1} 16.8” E. The area is in the Northern Guinea Savanna vegetation zone of Nigeria (Figure 1). It is situated within sub-humid environment closer to the semi-arid agro climatic region (Ojanuga, 2006). The area has 5 months of rainfall with mean annual rainfall of 781mm, while the mean atmospheric temperature range between 15-35.3^{0}C (Kowal and Knabe, 1972). The crops commonly grown in the area include; cotton, millet, sorghum, tomato, onion, cowpea, groundnut, maize, rice, and sugarcane.

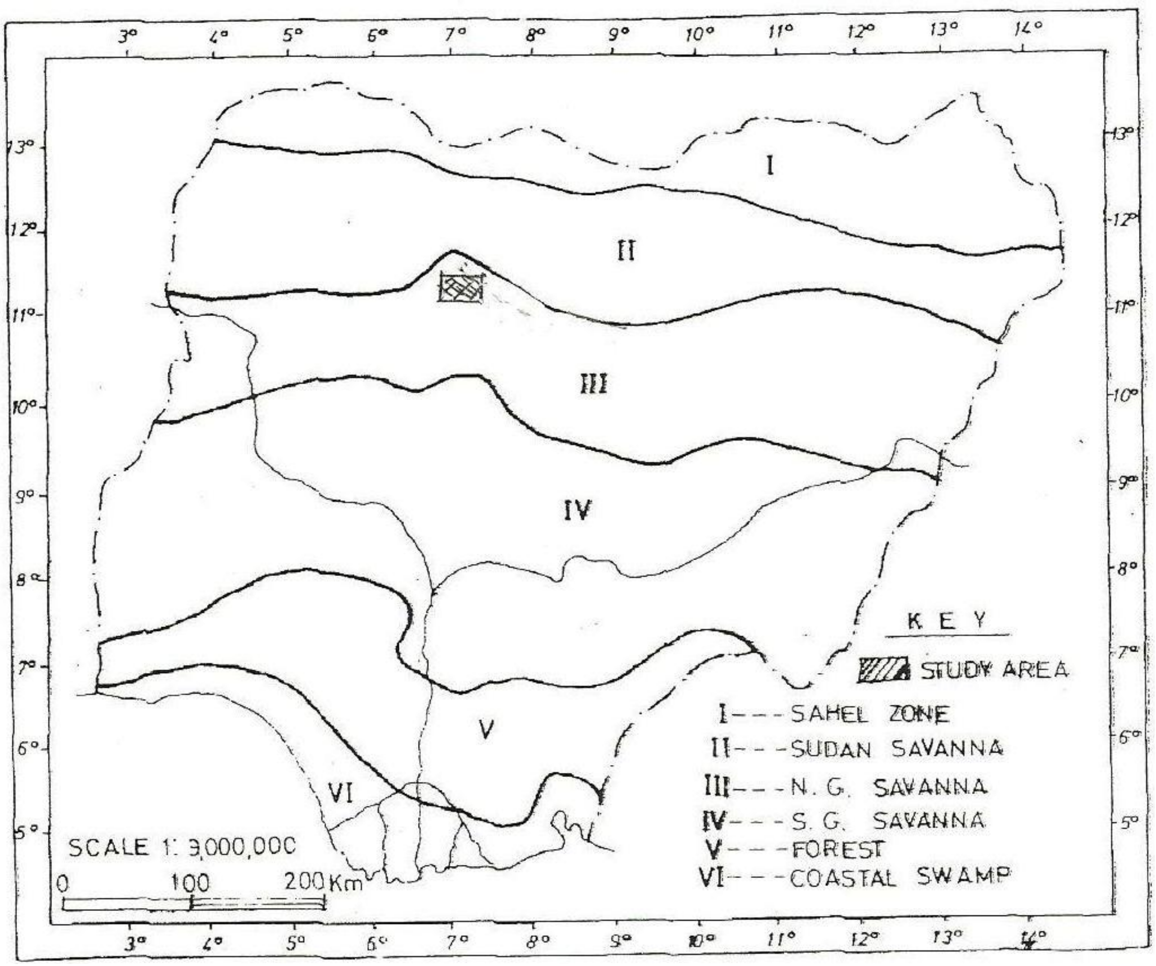

Figure 1. Ecological map of Nigeria showing location of study area

2.2. Field studies

Two profile pits were dug on each of the identified three soil units and soil samples were collected from genetic horizons within each soil profile pit. Soil morphological properties were observed and described in the field following USDA Soil Survey Manual procedure (Soil Survey Division Staff, 1993). Particle size distribution was estimated by the hydrometer method to determine soil texture (Gee and Bauder, 1986). Available water holding capacity (AWHC) was determined by calculating the difference in moisture content at field capacity and permanent wilting point (Klute, 1986). Soil pH was determined in a 1:1 soil/water ratio with soil pH metre and the electrical conductivity ECe was determine at 1:2.5 soil water ratio. The base saturation percentage (BS) was calculated from the percentage ratio of total exchangeable bases (Ca, Mg, K, Na) (Thomas, 1982) to Cation exchange capacity (CEC) was determined by neutral (pH 7.0) NH_4OAc saturation method (Rhoades, 1982). CEC of clay fraction was calculated using the method proposed by Sombroek and Zonneveld (1971) as follows.

$$\text{CEC (clay)} = \frac{\text{CEC (soil)} - (3.5\%\ \text{OC})}{\%\ \text{clay}} \times 100\% \qquad (1)$$

Organic carbon was determined by Walkley - Black dichromate wet oxidation method (Nelson and Sommer, 1982).

2.3. Assessment of soil suitability for crops

Data for the requirements of both maize and groundnut were obtained through the review of various literatures on their morphological characteristics, water requirement and the soil physicochemical requirements (Sys et al., 1993; FAO, 1995. The information for the soil units' characteristics and crop requirement were matched for each quality to obtain suitability rating (FAO, 1995). The overall soil suitability classes were obtained using techniques including; principle of limiting condition and arithmetic procedures (addition and multiplication methods) (Dent and Young, 1987; FAO, 1995).

2.3.1. Principle of limiting condition

The method used the most extremely suitability limiting classes of the individual qualities to produce the overall suitability class for each soil unit (FAO, 1995).

2.3.2. Arithmetic procedure (addition method)

It used working rules drawn up as to the number of moderately suitable (S2) and marginally suitable (S3) assessments to lower the overall suitability class. For number of S2 assessment of 0 or 1, the soil was assigned highly suitable (S1) class, 2 to 4 assigned S2 and 5 or more assigned S3 class. While for number of S3 assessment of 0 or 1, the soil was assigned S2, 2 or 3 assigned S3 and 4 or more assigned not suitable (N) (FAO, 1995).

2.3.3. Arithmetic procedure (multiple method)

The method converted individual ratings to numerical factors and multiplied the values together.

- The numerical values are as follows: S1 = 1.0, S2 = 0.8, S3 = 0.5, N= 0.0.
- The numerical values for the overall suitability classes are as follows: 0.8 to 1.0 = S1, 0.4 to < 0.8 = S2, 0.2 to < 0.4 = S3, 0.0 to < 0.2 = N (FAO, 1995).

3. Results and discussion

3.1. Soil properties and classification

The soil physical and chemical characteristics obtained from the land units are presented in Table 1. The Soils were moderately deep to very deep. Soils on loessial deposit were very deep and ranged between 150 and 152 cm and soils on basement complexes were least with range between 68 and 113 cm. The soils were predominantly medium textured with silt loam surface horizons and clay loam dominated in the subsoil, and was similarly reported by Malgwi et al. (2000) in Samaru, Nigeria. Soil structure was dominated by blocky structure and observed to be more developed in soils on loessial deposit. The subsoil horizons of soils on loess over basement complex rocks were structure less (massive). Drainage condition was poor in soils on loessial deposit, but soils on basement complex and loess over basement complex rocks were moderately to well drained. Available water holding capacity values were considered adequate to support plant growth (FAO, 1979) and the mean values increased in the order of soils on basement complex rocks, loess over basement complexes and highest on loessial deposit.

Table 1. Physicochemical Characteristics of the Land Units

Characteristics	**Units**	**LU 1**	**LU 2**	**LU 3**
Soil Depth	cm	150-152	125-150	68-113
Soil texture	Class	SiL /CL SL,	SiL/CL GSL,	SiL/GSCL
Soil Structure	Class	Sbk	Sbk/M	Sbk
Avail. WHC	%	14.3/15	10.1/12.7	7.7/12.0
Drainage condition	Class	Poor drain.	Imperf. drain.	Well drained
Slope	(%)	0-2	2-4	0-2
Soil Reaction (pH)	-	5.4/5.3	5.6/5.4	5.7/5.3
Base Saturation	%	36.1	37.8	45.1
Organic Carbon	gkg^{-1}	7.68	8.68	8.78
Elect. Conductivity	dSm^{-1}	1.79	1.41	1.47

/ = Surface against subsoil property
Sbk = Subangular blocky structure
M = Massive structureless
GSL= Gravelly sandy loam
SL = Sandy loam
SiL = Silty loam
CL = Clay loam
GSCL = Gravelly sandy clay loam.

The soil reaction varied between pH 4.9 and 5.8 and rated very strongly to moderately acid. Exchangeable Ca dominated the exchange sites followed by Mg and K with Na being least. Total exchangeable bases, total exchange acidity and cation exchange capacity were lowest in soils on basement complexes, followed by loess over basement complexes and highest in soils on loessial deposits. Organic carbon was generally low in the soils with mean values of 4.7, 4.9 and 4.2 gkg^{-1} for soils on basement complexes, loess over basement complexes and loessial deposit respectively. Several researchers have reported low content of organic carbon in the Nigerian savanna (Raji and Mohammed, 2000; Malgwi et al., 2000; Yaro et al., 2007). Electrical conductivity values were low with values less than 0.07 dSm^{-1} and rated non saline.

The morphological, physical and chemical characteristics of the soils in this study influenced their classification as Alfisol at Order level. The soils were classified as Haplustalfs at the Great group level due to CEC of clay by (NH_4OA_C) was more than 16cmol (+) kg^{-1} in most of the argillic horizon and greater than 35% base saturated (Soil Survey Staff, 2010).

3.2. Suitability assessment

The crop requirement qualities for both maize and groundnut are presented in Table 2. The land units' characteristics and the crop requirement qualities were matched to obtained the suitability classes. The land units were all rated marginally suitable (S3) for maize using the principle of limiting condition and attributed to the high nutrients requirement of maize. Moisture and drainage conditions of the soils were other critical factors that affected the suitability for maize production. The addition method also rated the land units as S3 except for LU2 that is moderately suitable (S2). Rating of the land units were all lowered by nutrients requirement of the crops. The land units (LU1 and LU3) were rated as not suitable (N) using the multiplication method except LU2 as S3 (Table 3).

The rating of land units for groundnut showed that moisture, drainage and nutrients availability lowers the land units suitability as S3 for LU1 and LU3, and LU2 as S2 using the principle of limiting condition. Similarly, addition method also rated the LU1 and LU2 as S3, and LU3 as S2. Multiplication method further rated the land units 1 and 3 as S3 and LU2 as N (Table 3). The suitability rating using multiplication method rated LU2 as not suitable and was different from the rating by limiting condition and addition methods (S3). The rating by multiplication did not reflect the actual land use situation on the field as groundnut was cultivated during the previous season.

None of the land units were observed to be highly suitable (S1) for both maize and groundnut. This may be attributed to low moisture retention, poor drainage, soil degradation and low fertility status as shown by the base saturation of less than 50% in all the land units along with low organic matter. Several soil suitability studies have also find out that soils of tropical savanna region are mostly not rated highly suitable (S1) (Olowolafe and Patrick, 2001; Maniyunda et al., 2007; Ande, 2011) and were associated with high rate of soil weathering and degradation affecting soil qualities. The low moisture retention (LU3), poor drainage (LU1) and low fertility status can be improved by the application of organic matter from crop residues and animal manure (Abdulkadir, 1998; Odunze, 2006). Mineralization of organic matter would add more nutrients, improve soil structure and increase both moisture retention capacity and drainage of the soils. To improve crop production, nutrient should be applied by burying right quantity of fertilizer.

Table 2. Land Use Requirement Rating for Studied Crops

Land Quality	Diagnostic Factor	Unit	Factor Rating			
			S1	S2	S3	N
Maize Rooting Condition (r)	Soil depth	cm	>120	50 –120	30-50	<30
Soil Workability (w)	Soil texture	class	SL, L	SCL, SiL	L, CL, SiCL	S, SC, SiC, C
Soil Workability (k)	Structure	class	Mod. developed	Mod. developed	Weakly developed	Structure less
Oxygen availability (g)	drainage	class	Well drained	Mod. well drained	Imperfectly drained	V. poor drained
Moisturea Availability (m)	AWHC	%	>15	10-15	7-10	>6
Erosion Hazard (e)	Slope	%	0-2	2-4	4-6	>6
Nutrient availability (a)	Reaction pH	-	6-7	5.5-6.0, 7.0-7.5	5.0-5.4, 7.6-8.0	<5, >8
Nutr. retention cap. (n)	PBS	%	>70	50 - 70	30 - 50	<30
Nutr. retention cap.(n)	OC	gkg^{-1}	>20	15 – 20	8 -15	<8
Excess salt (s)	ECe	dSm^{-1}	0-3	3-6	6-8	>8
Groundnut Rooting Condition (r)	Soil depth	cm	>100	70-100	40-70	<40
Soil Workability (w)	Soil texture	class	SL, SiL	SiCL, CL	S, SC, SiC	C
Soil Workability (k)	Structure	class	Mod. developed	Mod. developed	Weakly developed	Structure less
Oxygen availability (g)	drainage	class	Well drained	Mod. well drained	Imperfectly drained	Poorly drained
Moisture availability (m)	AWHC	%	>12	9-12	6-9	<6
Erosion Hazard (e)	Slope	%	0-2	2-5	5-8	>8
Nutrient availability(a)	Reaction pH	-	5.8-6.2	5.5-5.7, 6.3-6.5	5.0-5.4, 6.6-7	<5, >7
Nutr. retention cap. (n)	PBS	%	>50	35-50	25-35	<25
Nutr. retention cap. (n)	OC	gkg^{-1}	>12	8 –1 2	5 – 8	<5
Excess salt (s)	ECe	dSm^{-1}	0-2	2-3	3-4.5	>4.5

Table 3. Overall Suitability Classes for Maize and Groundnut

Method Use	LU1	LU2	LU3
Maize Principle of limiting condition	S3gan	S3n	S3wmn
Addition method	S3gan	S2n	S3wmn
Multiplication method	N	S3	N
Groundnut Principle of limiting condition	S3ga	S3gan	S3m
Addition method	S3ga	S3gam	S2m
Multiplication method	S3	N	S3m.

Addition method of the arithmetic procedure more appropriately assessed suitability of the three soil units than the principle of limiting condition and multiplication method to the actual field situation for the crops. This finding is similar to the reports of Kparmwang et al. (1998) and Maniyunda et al. (2001) for arable cropping in sub-humid agro climatic zone of Nigeria.

4. Conclusion

Three land units classified as Haplusalfs based on USDA Soil Taxanomy system were evaluated for their suitability for maize and groundnut production under rainfed condition. Most of the land units were marginally suitable for both crops using the limiting condition and addition methods, except LU2 that was moderately suitable for maize in the addition method, Groundnut was also rated moderately suitable for LU2 and LU3 by principle of limiting condition and addition method respectively. The multiplication method rated the land units lower as S3 and N and was not a representation of the actual obtainable yield on the Haplustalfs studied. None of the soils were highly suitable as were affected by the poor drainage condition, low moisture retention, low organic matter and low to moderate base saturation of the Haplustalfs.

However, application of crops residues, animal manure and fertilizers were recommended for the improvement of moisture retention, drainage condition and fertility status. These management practices will upgrade the suitability classes of the soils for higher yield in rainfed sustainable production of maize and groundnut in the study area.

References

Abdulkadir, A. (1998), "Soil types and their management in the southern Lake area, Nigeria", *Proceedings of the 12th National Irrigation and Drainage Seminar on Irrigation in Sustainable Agriculture,* 14-16th April, 1998, IAR, ABU, Zaria, Nigeria, pp. 334 – 348.

Ande, O.T. (2010), "Soil suitability evaluation and management for cassava production in the Derived Savanna area of Southwestern Nigeria", *International Journal of Soil Science,* Vol. 6, No. 2, pp. 142-149.

Braimoh, A.K. (2000), "Land Evaluating For Sorghum Based On Boolean and Fuzzy set methodologies", *Nigerian Journal of Soil Science,* Vol. 12, pp. 6 – 11.

Burrough, P.A, Macmillan, R.A. and Van Deursen, W. (1992), "Fuzzy classification methods for determining land suitability from soil profile observations and topography", *Journal of Soil Science,* Vol. 43, pp. 193-210.

Dent, D. and Young, A. (1987), *Soil survey and land evaluation*, George Allen and Unwin (publisher) Ltd. UK, pp. 140 – 156.

Esu, I.E. (2004), "Soil characterization and mapping for food security and sustainable environment in Nigeria", Proceedings of the 29th Annual Conference of the Soil Science Society of Nigeria, Dec. 6 – 10, University of Agriculture Abeokuta, Nigeria, pp. 20-24.

FAO (1978), *Production Year Book 1978*, Food and Agriculture Organization, Rome. Italy, pp. 116 -117.

FAO (1979), *Soil survey investigations for irrigation*. Soil Bulletin, No. 42. Food and Agriculture Organization. Rome. Italy.

FAO (1985), Guidelines: *Land evaluation for irrigated agriculture*, Soil Bulletin, No. 55. Food and Agriculture Organization. Rome. Italy, pp 229.

FAO (1995), *Guidelines; Land evaluation for rainfall agriculture*. Soil Resources Management and Conservation Service, Land and Water Development Division Rome, FAO Soil Bulletin. 52, pp. 237.

Gee, G.W. and Bauder, Y.W. (1986), "Particle size analysis", In: Klute A. (ed). *Methods of Soil Analysis.* Part 1 Aragon. 9. Maidison, WI. USA, pp. 383 –411.

Klute, A. (1986), Water retention. Laboratory methods. In Klute A. (ed) *Methods of soil analysis.* Part 1 Agron . 9. Midison, Wi. USA, pp. 635 – 662.

Kowal, J.M. and Knabe, D.J. (1972), *An Agro climatologically Atlas of Northern State of Nigeria*, ABU., Zaria, Nigeria, pp. 111.

Kparmwang ,T., Abubakar, A.S., Raji, B.A. and Chude, V.O. (1998), "The suitability of the Micro Topography land features of the river Galma Fadama at Zaria for arable cropping", *Soil management for sustainable agriculture and environmental harmony,* 24th Annual conference of Soil Science Society of Nigeria. ATBU Bauchi, Nigeria.

Malgwi, W.B., Ojanuga, A.G., Chude, V.O., Kparmwang, T. and Raji, B.A. (2000), "Morphological and physical properties of some soils at Samaru, Zaria, Nigeria", *Nigerian Journal of Soil and Environmental Research,* Vol. 1, pp. 58-64.

Maniyunda, LM. (1999), *Pedogenesis on loess and basement complex rocks and their suitability for arable crops at Funtua, Subhumid tropics, Nigeria*. M.Sc thesis (Unpublished), pp. 107.

Maniyunda, L.M, Kparmwng, T., Raji, B.A. and Uyovbisere, E.O. (2001), "Assessment of soil suitability for cotton production at Funtua, Nigeria", *Journal of Engineering Tech. And Industrial Application,* Vol. 1, pp. 183 – 187.

Maniyunda, L.M., Malgwi, W.B. and Yaro, D.T. (2007), "Evaluation of the suitability of Galma River basin for irrigated agriculture", Proceedings of the 31st Annual Conference of Soil Science Society of Nigeria. 13th – 17th Novem., 2006, ABU Zaria Nigeria, pp. 23-28.

Nelson, D.W. and Sommers, L.E. (1982), "Organic carbon", In Page, A.L., Miller, R.H. and Keeney, D.R. (eds). *Methods of Soil Analysis.* Part 2 Agron 9. Madison WI, pp. 538-580.

Odunze, A.C. (2006), "Soil properties and management strategies for some sub–humid savanna zone Alfisols in Kaduna State, Nigeria", *Samaru Journal of Agricultural Research,* Vol. 22, pp. 3-14.

Ogunkunle, A.O. (2009), "Soil survey and sustainable land management", Proceedings of the 29th Annual Conference of the Soil Science Society of Nigeria, Dec. 6 – 10, University of Agriculture Abeokuta, Nigeria. pp. 12-16.

Ojanuga, A.G. (2006), *Agroecological zones of Nigeria Manual,* Berding, F. and Chude, V.O. National Special Programme for Food Security (NSPFS) Abuja, Nigeria and FAO, pp. 124.

Olowolafe, E.A. and Patrick, S. (2001), "Land evaluation for irrigated agriculture in a semi-arid area of Northern Nigeria", *Nigerian Journal of Soil Research*, Vol. 2, pp. 51 – 57.

Perveen, F., Nagasawa, R., Uddin, I. and Delowar H.K.M. (2012), "Crop – land suitability analysis using a multicriteria evaluation and GIS approach", available at: http://www.digitalearthisde.org/cms/upload/Paper%20and%20Abstract/Perveen.pdf (accessed 12/12/2012).

Raji, B.A. (1999), "Productivity evaluation of Quartizipsamment and Haplustults derived from contiguous sand dunes fields for rainfed Agriculture, pasture, and Forestry, NW, Nigeria", Proceeding of the 25th Annual Conference of Soil Science Society of Nig. 21st –25th Nov 1999, Lagos, Nigeria, pp. 53-61.

Raji, B.A. and Mohammed, K. (2000), "The nature of acidity in Nigerian savanna soils", *Samaru Journal of* Agricultural *Research,* Vol. 16, pp. 15-24.

Senjobi, B.A. (2007), Comparative assessment of the effect of land use and land type on soil degradation and productivity in Ogun Satae, Nigeria, Ph.D Thesis, University of Ibadan.

Shahbazzi, F., Jafarzadeh, A.A., Sarmadian, F., Neyshaboury, M.R., Oustan, S., Anaya- Ramero, M. and De La Rossa, D. (2009), "Suitability of wheat, maize, sugar beet and potato using MicroLEIS DSS software in Ahar area, Northwest of Iran", *American- Eurasian Journal of Agriculture and Environmental Science*, Vol. 5, No.1, pp. 45-52.

Soil Survey Division Staff (1993), *Soil Survey Manual,* Agric. Handbook. No 18. U.S. Gov. Print. Office. Washington, DC. Handbook No.18, pp. 437.

Soil Survey Staff (2010), *Soil Taxanomy. A basic system of soil classification for making and interpreting soil surveys,* 2nd Edition. Agric. Handbook. No 436. U.S. Gov. Print., Office. Washington, DC, pp. 346.

Sombroek, W.G. and Zonneveld, I.S. (1971), *Ancient dunefields and fluviatile deposits in Rima-Sokoto River Basin (NW Nigeria).* Soil Survey Paper No. 5. Soil Survey Inst. Wageningen, The Netherlands, pp. 109.

Sys, C., Van Ranst, E., Debaveye, J. and Beerneaert, F. (1993), *Land evaluation: Part III: Crop requirements*. Development Cooperation, Belgium.