African Journal of Environmental Science and Technology Vol. 5(9), pp. 748-754, September 2011
Available online at http://www.academicjournals.org/AJEST
DOI: 10.5897/AJEST11.038
ISSN 1996-0786 ©2011 Academic Journals

Full Length Research Paper

Creating a soil data base in a reconnaissance soil fertility study of an encroached forest reserve in Northern Nigeria for a reforestation programme

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Accepted 11 July, 2011

The reconnaissance soil fertility study of 10,000 ha partly encroached forest reserve located between latitude 11°47'N and 11°56'N and longitude 4°22'E and 4°32'E in Northern Nigeria was conducted in 2009 to generate a soil fertility data base of the reserve. The tracking of the forest reserve boundary was done using a Garmin 72 model global positioning system (GPS) receiver. The geographic coordinates were input into the computer to generate a digital map of the forest reserve. The entire forest reserve was divided into grids to guide in the location for soil sampling using the GPS/Geographic Information System (GIS) geospatial technique. Soil auger studies were made at 250 locations to site 60 sampling pits to collect soil samples for laboratory analysis of soil properties. Forest soils were classified into three groups using soil depth as a limiting parameter in the soil fertility assessment. The soils were sandy clay loam and the pH indicated a moderate to strong acid status with low content of organic matter, percentage nitrogen, available phosphorus, potassium, calcium and magnesium. A reforestation programme with the planting of acacia for soil rehabilitation was recommended for the reserve as the tree stands would serve to protect the land against erosive activity of wind and also serve in enriching the soil with nitrogen.

Key words: Soil fertility assessment, reforestation program, forest reserve, geographic information system.

INTRODUCTION

Reforestation had aptly been described as the tree planting process undertaken to replenish already harvested trees in existing forest land in order to ameliorate the soil fertility that had been degraded as a result of uncontrolled felling of forest trees (Moffat and Boswell, 1990; Jaiyeoba, 2001; Saarsalmi et al., 2010). The need for tree replanting has become desirable as rampant deforestation destabilized the ecosystem and caused increasing green house effects, soil erosion, loss of biodiversity and drastic climatic changes (Kassas, 1995; Bashir, 2010; Putatunda, 2010). It had previously been explained that forests absorb carbon dioxide through their photosynthesis cycle and increasing forests with reforestation and discouraging deforestation would help mitigate global warming (Rosillo-Calle and Hall, 1992; Yokoyama, 1997;.

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Several efforts have previously been made as discussed by Copperwiki (2010) for successful, sustainable and standardized afforestation and reforestation management as exemplified by projects executed by the Britain's Forestry Commission, the Jewish National Fund on the Yatri Forest and also the Green Wall of China which aimed to halt the expansion of the Gobi desert. The Yatri Forest project was a type whereby afforestation project had been successfully executed in harsh desert conditions to prevent further expansion of desert land.

The need for maximizing the use of available land resources with high yield tree species had become desirable and achieving this goal greatly depends on climate and soil conditions (Ravindranath et al., 2006; Wu et al., 2007). The scope of afforestation would extend beyond just planting of trees to planting of the right types of trees at the right places which would require soil fertility investigation to confirm the soil fertility status that would support the particular tree types (Moshki and

Lamersdorf, 2010). Soil fertility and management had been found essential to determine the type of forest trees to be planted as tree types influence soil properties (Ritter, 2009; Sartori et al., 2007).

Several methods of soil fertility investigation were employed in confirming the fertility status of soils (Assefa and Glatzel, 2010; Belachew and Abera, 2010). Some of the conventional methods of soil fertility investigation adopted in the past included locating study points randomly, zigzag direction and cutting of traverses at known regular intervals and these methods had not ensured the completion of soil fertility investigation within the specified time frame and the required degree of accuracy. The application of geospatial technology involving the use of Global Positioning System (GPS) and Geographic Information Systems (GIS) had greatly improved the old traverse techniques and forest soil fertility studies using remote sensing and GIS techniques had been reported (Solanke et al., 2005; Oza et al., 2006; Bhagat, 2009).

The previous research in Medugu et al. (2010) had confirmed the role of afforestation programme in combating desertification in Nigeria and also in the research findings reported by Jaiyeoba (2001) in the evaluation of the performance of Eucalyptus and Pine plantations for soil rehabilitation in Nigeria Savanna environment. Ademoh and Abdullahi (2010) in Nigeria had discussed the use of *Acacia* species in soil rehabilitation and also in the economic values of production of binding resins products from it. The two species of Acacia trees *Acacia senegal* L. and *Acacia seyal* L. were reportedly planted in semi-arid conditions to prevent desert encroachment. Acacia is leguminous plant which in addition to enriching the soil with nitrogen also has the economic benefits of being used to produce acacia gum or gum arabic (Lupien, 2007). Furthermore, *Acacia* trees had been described as a natural shade tree and when planted properly could lower ground temperature and the nitrogen rich leaves when shed at the beginning of the rainy season could check soil erosion while the decomposition of the leaves would improve the fertility status of the soil.

The soil fertility studies for reforestation programme in the studied forest reserve was found desirable in order to replant with trees in proportion to the reserve areas where the original forest trees/shrubs had been illegally felled principally for arable crop production and for domestic fire wood use. The objective of the research was to carry out a soil fertility investigation of the encroached forest reserve for *Acacia* tree reforestation programme.

MATERIALS AND METHODS

Site description

The study site is situated between Latitude 11°47'N and 11°56'N and Longitude 4°22'E and 4°32'E, it is a 10,000 ha forest reserve located in Kebbi State in Northern Nigeria as shown in Figure 2. The climate is tropical with two distinct seasons of rainy and dry seasons. The annual rainfall varies between 650 and 1000 mm while the mean annual temperature is 26 and 33°C during the rainy and dry season respectively. The soils are Aridisols by the United States Soil Taxonomy Classification system. The soil investigation involved preliminary computer analysis, field work and the laboratory analysis.

Preliminary computer analysis and field work

The tracking of the boundary of the forest reserve was carried out with the use of the GPS Garmin 72 receiver and the data input into the computer to generate a digital map of the forest reserve. The entire forest reserve was divided into grids to guide in the location for soil sampling using the GPS/ GIS geospatial technique. The points for soil sampling indicated on the digital map were located on the ground with the use of the GPS receiver and soil samples taken from the sampling pits for laboratory analysis.

Collections of soil samples, packing and transportation to laboratory

Soil samples were collected from the three types of soils categorized according to depth. For soil depth category of 0 to 15 cm (Group A soils), samples were taken from surface layer to 15 cm while for soil depth category of 0 to 30 cm (Group B soils), samples were taken from surface to 15 cm and 15 to 30 cm and for soil depth category of 0 to 60 cm (Group C soils), samples were taken from surface to 15 cm, 15 to 30 cm and 30 to 60 cm. The soil samples were bagged in 350 cc sampling bag, labeled and transported to the laboratory for analysis.

Laboratory analysis

Soil samples were air-dried and sieved through 2 mm sieve and analysed following the laboratory procedures of Canadian Society of Soil Science (Carter, 1993). The particle size distribution was determined by the hydrometer method in which 50 g of sieved air dried soil was weighed into 250 ml beaker and 100 ml of calgon added and allowed to soak for 30 min. It was transferred to a dispersing cup and the suspension stirred for 3 min with mechanical stirrer. The suspension was transferred to a sedimentation cylinder and filled to the mark with distilled water. A plunger was inserted and used to mix the content thoroughly. The stirring was stopped and the time recorded. The hydrometer and thermometer were carefully lowered into the suspension and the readings taken after 40 s. Two hours after, another hydrometer and thermometer readings were taken and the hydrometer reading corrected for temperature by adding 0.36 g/L for every 1°C above 20°C and subtracting 0.36 g/L for every 1°C below 20°C.

The soil pH was determined in water using a glass electrode pH meter. Organic carbon was determined by oxidising soil sample with dichromate solution and later titrated with ferrous sulphate solution (Walkley and Black, 1934). The total nitrogen was determined using micro-kjeldahl method and the available phosphorus colorimetrically by the molybdenum blue method (Bray and Kurtz, 1945). The exchangeable cations were extracted by leaching 5 g of soil with 50 ml of ammonium acetate at pH 7. The potassium and sodium in the leachate were determined with a column model 21 flame spectrophotometer while the calcium and magnesium were determined with atomic absorption spectrophotometer. The exchangeable acidity was determined by adding barium chloride buffer solution to soil sample and titrated against 0.1 N HCl.

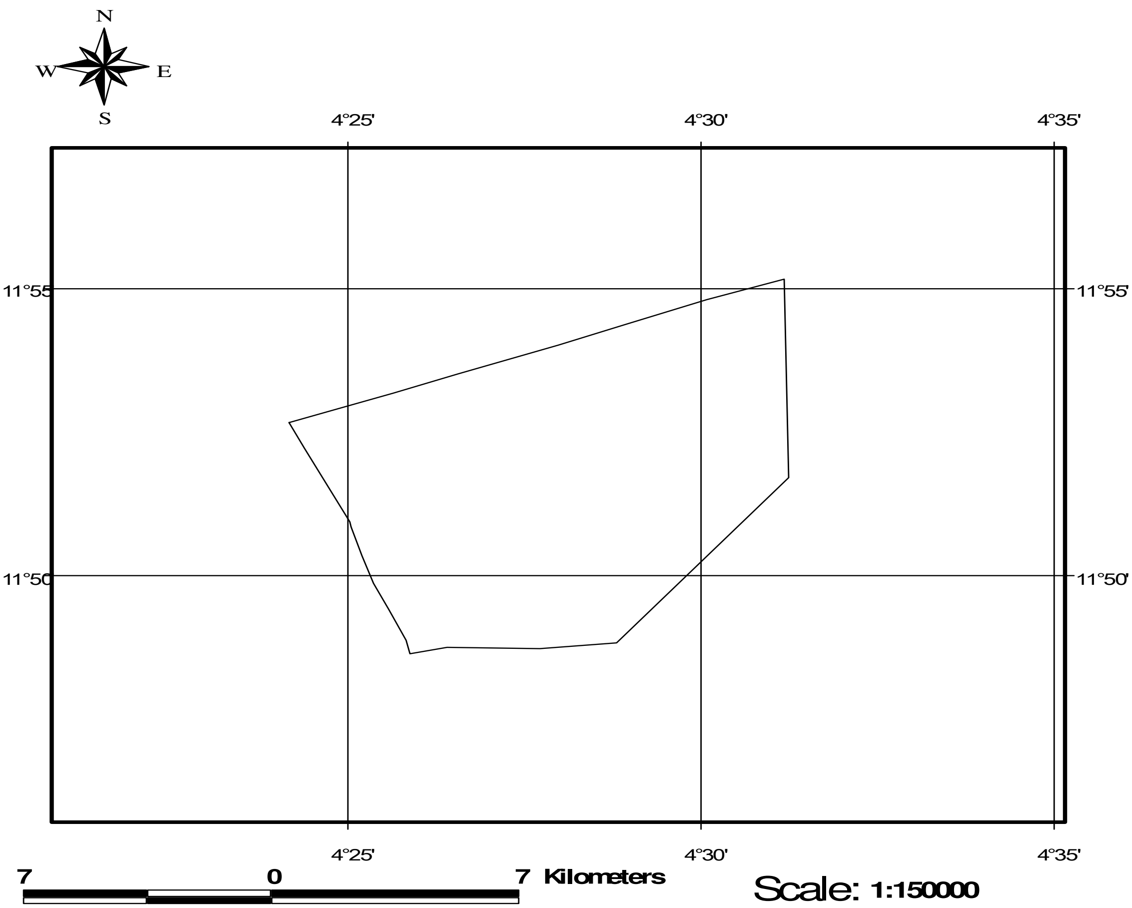

Figure 1. Digital boundary map of the forest reserve.

Creation of attribute table and link to digital map

In creating the attribute table, the soil parameters which included the coordinates specifying the latitudes and longitudes of all the sampling point locations and the soil properties were entered as a table in Excel software and saved in a dBASE IV (DBF 4) format. The table was automatically linked to the digital map generated from the data and ArcView, statistical analysis run to calculate the minimum and maximum values to obtain the average values of soil properties for each of the three soil depth categories of 0 to 15 cm depth (Group A soils), 0 to 30 cm depth (Group B Soils) and 0 to 60 cm depth (Group C Soils).

RESULTS

Table 1 showed the coordinates specifying the latitude and longitude of the forest boundary while Figure 1 showed the digital map boundary generated from the coordinates. Table 2 showed the coordinates of the sampling pits from which soil samples were taken for laboratory analysis of the physical and chemical properties while Figure 2 showed the representations of the 60 sampling pit locations on the digital map. Nine sampling pits were 0 to 15 cm depth while 27 and 24 sampling pits were 0 to 30 cm and 0 to 60 cm depth respectively. Table 3 showed the mean values of soil properties as generated with ArcView statistical analysis. The soil was sandy clay loam with the clay content having an average of 25%.

DISCUSSION

The latitude and longitude readings of the forest reserve boundary in Table 1 were taken with the global positioning system receiver which was a satellite linked device that gave the precise locations on the ground. This was used to generate the boundary map of the reserve in Figure 1. The principle was used in a previous research of a farm layout which was part of the digital farm map of a crop type museum (Adekayode et al., 2007).

The coordinates of the sampling pits as shown in Table 2 and the representation of the points in Figure 2 showed the application of GIS to obtain accurate location of soil sample points in the forest reserve for the determination of soil properties at different locations. This principle was

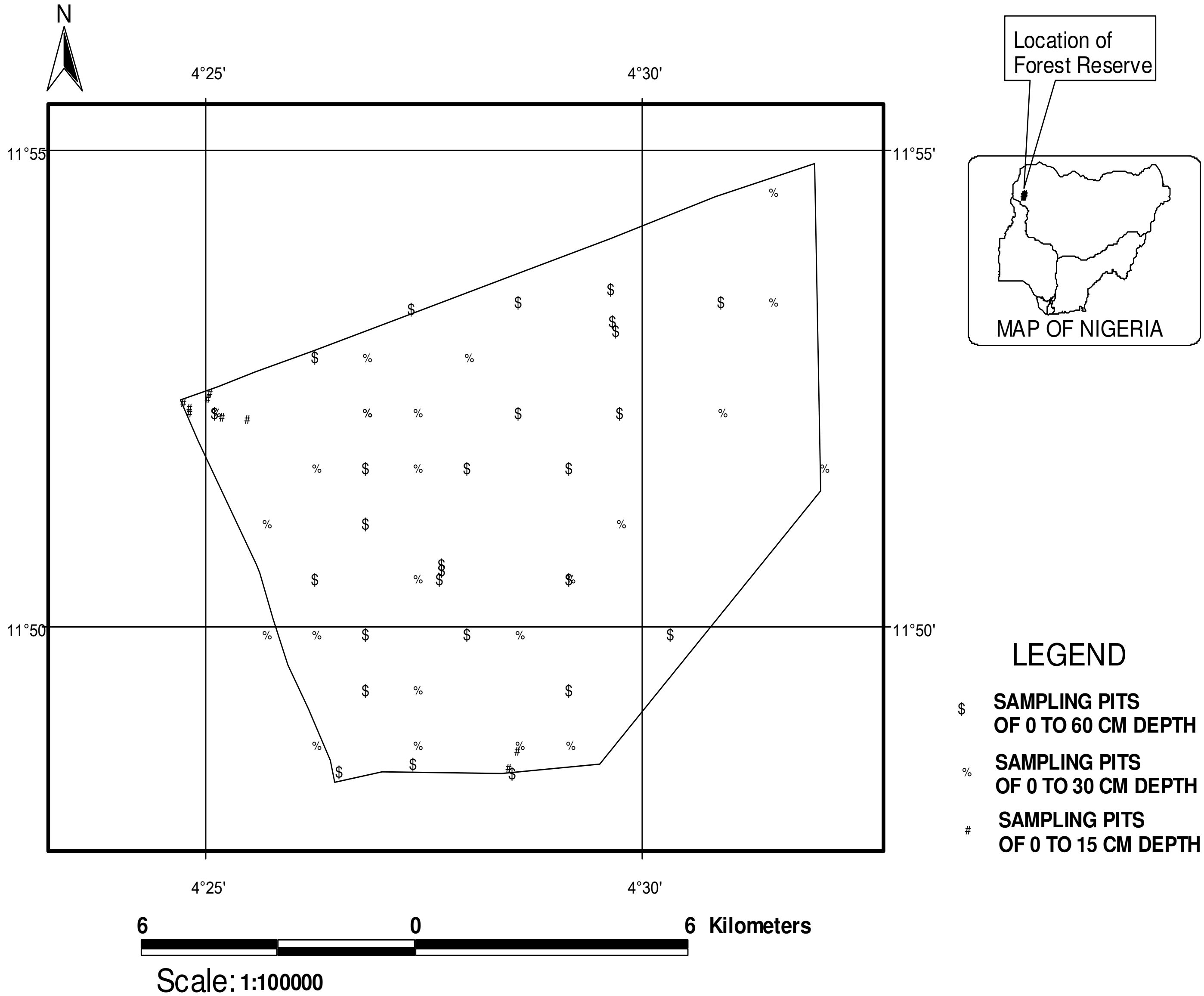

Figure 2. Map of the forest reserve showing locations of sampling pits with map of Nigeria and location of forest reserve in the inset.

Table 1. The coordinates of the forest boundary.

Boundary points	Latitude	Longitude	Boundary points	Latitude	Longitude
1	11.872391	4.403176	12	11.806707	4.485918
2	11.864977	4.406828	13	11.855968	4.529515
3	11.842722	4.418315	14	11.915204	4.528312
4	11.841300	4.418831	15	11.909216	4.508716
5	11.832878	4.421458	16	11.901658	4.488075
6	11.824518	4.424462	17	11.895715	4.471336
7	11.816641	4.428395	18	11.887013	4.445890
8	11.807432	4.432798	19	11.881212	4.429336
9	11.803468	4.433649	20	11.877390	4.418026
10	11.805174	4.443000	21	11.874895	4.410660
11	11.804927	4.466656	22	11.872391	4.403176

Table 2. The coordinates of the sampling pit locations.

Sampling pit (0-15 cm depth)	Latitude	Longitude	Sampling pit (0-30 cm depth	Latitude	Longitude	Sampling pit (0-60 cm depth)	Latitude	Longitude
1	11.872000	4.404000	1	11.870000	4.410000	1	11.870000	4.510000
2	11.871000	4.405000	2	11.880000	4.430000	2	11.910000	4.520000
3	11.872700	4.408700	3	11.860000	4.440000	3	11.880000	4.460000
4	11.870000	4.405000	4	11.840000	4.480000	4	11.870000	4.440000
5	11.873730	4.409190	5	11.870000	4.490000	5	11.850000	4.420000
6	11.868800	4.416480	6	11.890000	4.510000	6	11.830000	4.430000
7	11.869490	4.411540	7	11.870000	4.470000	7	11.820000	4.450000
8	11.806000	4.468000	8	11.860000	4.460000	8	11.860000	4.450000
9	11.809000	4.469700	9	11.890000	4.470000	9	11.850000	4.490000
			10	11.850000	4.440000	10	11.840000	4.480000
			11	11.840000	4.430000	11	11.840000	4.450000
			12	11.830000	4.440000	12	11.870000	4.410000
			13	11.820000	4.440000	13	11.860000	4.530000
			14	11.830000	4.500000	14	11.890000	4.520000
			15	11.860000	4.480000	15	11.830000	4.470000
			16	11.830000	4.460000	16	11.830000	4.420000
			17	11.820000	4.480000	17	11.880000	4.440000
			18	11.840000	4.454500	18	11.860000	4.430000
			19	11.841700	4.454880	19	11.870000	4.440000
			20	11.842670	4.454890	20	11.810000	4.480000
			21	11.892410	4.488310	21	11.810000	4.470000
			22	11.888870	4.448857	22	11.810000	4.450000
			23	11.886470	4.488570	23	11.810000	4.430000
			24	11.884910	4.489300	24	11.870000	4.450000
			25	11.805140	4.468730			
			26	11.805250	4.434620			
			27	11.806690	4.449270			

applied in previous research to map fertility levels across a farm to serve as basis for the application of farm inputs and also for establishing accurate location of yield data for the production of yield maps for yield monitoring (Ziadat, 2005; Sudhanshu et al., 2009).

Liaghat and Balasundram (2010) had discussed the use of GIS in precision farming to produce a production based farming system that was designed to increase long term, site-specific and whole-farm production efficiency, productivity and profitability. Song et al. (2009) in a research on the delineation of agricultural management zones using remotely sensed data concluded that remote sensing was a valuable tool for assessing the variation in soil properties and yield in arable fields. Hossain (2009) used the geographic information system to develop a site-specific geospatial database in assessing spatial land use/cover changes in a study site in Thailand while Adekayode (2006) used the soil data base on soil physical and chemical properties to generate the soil map of part of Owena Forest Reserve in Ondo State Nigeria.

Table 3 shows the mean values of soil physical and chemical properties was the result of ArcView statistical analysis of the soil properties entered as field in the attribute table. Soil samples from the sixty sampling pits were analyzed for the physical and chemical properties. Each soil property was entered as a field to calculate the maximum, minimum and the average values in relation to the various depths of 0 to 15 cm, 0 to 30 cm and 0 to 60 cm. The physical and chemical properties of soils in the forest reserve were similar and the limitation of Group 1 soils was the shallow depth being within 15 cm of the surface and this was caused by hard pan just below the surface. Such shallow sampling pits were mostly found in the north western part of the study area and this would make mechanical cultivation impracticable. The remaining part of soils in the forest reserve was 30 cm deep or even deeper. The generally low level of cations reflected the low level of organic matter which reflected in the low nutrient level as previous observation had revealed a direct relationship between organic matter and

Table 3. The mean values of soil physical and chemical properties.

Soil properties	Group A soils	Group B soils		Group C soils		
	(0 – 15 cm)	(0 – 15 cm)	(15 – 30 cm)	(0 – 15 cm)	(15 – 30 cm)	(30 – 60 cm)
Percentage gravel (%)	5.1	6.0	9.8	5.2	5.7	6.2
Percentage sand (%)	61	67	59	68	61	61
Percentage silt (%)	14	10	12	11	13	12
Percentage clay	25	23	29	21	26	27
Texture						
pH	5.1	4.9	4.9	4.8	4.7	4.6
Organic matter (%)	0.56	0.90	0.64	1.11	0.93	0.72
Available phosphorus (ppm)	3	2.7	2.3	2.6	2.5	2.4
Total nitrogen (%)	0.23	0.35	0.15	0.36	0.15	0.12
Sodium (cmol/kg)	0.17	0.16	0.20	0.15	0.16	0.11
Potassium (cmol/kg)	0.16	0.21	0.15	0.18	0.16	0.08
Calcium (cmol/kg)	1.23	1.42	1.40	1.38	1.36	1.25
Magnesium (cmol/kg)	0.58	0.68	0.62	0.71	0.66	1.02
Vegetation/land-use	Shrub	Shrub	Shrub	Shrub	Shrub	Shrub

nutrient availability to plants (Takata et al., 2007). The low level of nutrients showed the high degree of encroachment of the forest reserve by people for arable cropping whereas they did not make serious attempt to replenish the soil fertility with the addition of organic and inorganic fertilizers. The response of forest trees to soil nutrient content had been discussed in previous research (Liao, 1977; Alfaia et al., 2004; John et al., 2007). Tang and Robson (1993) in investigating the effects of pH on nodulation of *Lupinus* species observed that pH above 6 had a specific effect in the impairment of nodulation in Lupins and the lateral roots to be greatly reduced resulting in decreased uptake of iron and phosphorus while Ojeniyi and Agbede (1980) in investigating the effect of organic matter on the yield of tree crops in different ecological zones of Nigeria observed a positive correlation between soil organic matter and girth of *Gmelina arborea*. The nutrient requirement of some forest trees as reported previously in Nwoboshi (2000) stated the requirements for *G. arborea* to be 960 kg/ha Nitrogen, 371 kg/ha Phosphorus, 2425 kg/ha Potassium and 615 kg/ha Calcium while the requirements for *Tectona grandis* to be 640 kg/ha Nitrogen, 170 kg/ha Phosphorus, 719 kg/ha Potassium and 199 kg/ha Calcium. This corroborated the earlier research findings of Akinsanmi and Akindele (1995) while Adekayode (2005) had previously reported the potentiality of soil to support the growth of species of forest trees to be highly influenced by topography and parent materials.

Conclusion

The assessment of the fertility status of the forest reserve had been based on the soil data base of soil properties created. The soils generally had low fertility but which could be improved with the addition of both organic and inorganic manure and the productivity sustained with the planting of Acacia trees. The digital map of the forest reserve generated with GIS technique would allow a periodic review of the soil fertility status.

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