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Spatial assessment of soil quality indicators under different agricultural land uses

Oyedele Adedayo Omowumi[1], Denton Oluwabunmi Aderonke[2], Olayungbo Adenike Anike[3], Ogunrewo Olubola Moronke[4]

[1, 2](Land and Water Resources Management programme /Institute of Agricultural Research and Training, Obafemi Awolowo University, Nigeria)
[2](Natural History Museum/ Obafemi Awolowo University, Nigeria)
[3](Department of Agricultural Sciences, College of Agriculture, Food sciences and Technology / Wesley University of Science and Technology, Nigeria)

***Abstract*:** *The physical, chemical and biological properties of a soil define soil quality which is fundamental for soil fertility. The objective of this study was to assess the spatial variability of these soil properties under four different agricultural land uses. The experiment was conducted at the Institute of Agricultural Research and Training,(IAR&T), Nigeria.The land uses evaluated were mono cropping system with cocoa, grazed land, fallow land and a mixed cropping system (horticulture). Samples were taken randomly at each location consisting of 25 georeferenced points each, and bulked to form 5 composite samples for each location.The result showed that the surface soil textures are loamy sand except for the cocoa plantation soils which was sand, all the soils showed alkalinity, ranging from a pHof 7.43 to 8.09. Total Nitrogen ranged from 1.16-1.81kg/ha, Available P ranged from 0.51-1.40 kg/ha while potassium ranged from 0.15-0.25 Cmol/kg. Average microbial biomass C was from 129.18 to 200.04μgCg^{-1} while the average microbial biomass N was from 12.74 to 19.84 μgNg-^{1}. Soil surface maps generated indicate that the soils are deficient in characteristics required for optimal production.This method can be used in determining relationships between agricultural land use and soil quality.*
***Keywords*:** *Land use, Soil properties, Soil quality, Spatial variation*

I. Introduction

Soils are characterized by a high degree of variability due to the interplay of physical, chemical, biological and anthropogenic processes that operate with different intensities and at different scales [1].Maintaining or improving soil quality can provide economic benefits in the form of increased productivity, more efficient use of nutrients and pesticides, improvements in water and air quality, and lessening of greenhouse gas emissions [2]. The dynamic soil nature describes the condition of a specific soil due to land use and management practices and it is measured by using various chemical, physical and biological indicators [3]. Assessing soil quality involves measuring soil physical, chemical, and biological properties and using these measured values to detect changes in soil as a result of land use change or management practices [4].

Maintenance of soil quality has been considered as a key component of agriculture sustainability and a goal of most farmers, environmentalists and government policymakers [5]. Studying land degradation through a soil quality approach, which reveals soil functioning within the ecosystem, is necessary for sustainable management of land resources [6]. Knowledge and assessment of changes (positive or negative) in its status with time is needed to evaluate the impact of different management practices. Selection of key indicators and their critical limits (threshold values), which must be maintained for normal functioning of the soil, are required to monitor changes and determine trends in improvement or deterioration in soil quality for various agro-ecological zones for use at district, national and global levels. Many soil indicators interact with each other, and thus, the value of one is affected by one or more of the selected parameters [7].

Human population pressures upon land resources have increased the need to assess impacts of land use change on soil quality [8]. Land-use can be referred to as the use into which a piece of land is put. It centers on the human activities that relate to a particular parcel of land. Land use varies from one place to another be it a country, state, city or local government area. Land use planning according to soil suitability is a well-known technology for long term sustainable land management. However change in time and space and the suitability use may also have to be reviewed [9]. Changes in soil properties due to use and management and their consequences to the environment and to the production capacity have been studied [9,10].Land use change, if not based on proper scientific investigation affects other physical, chemical, and biological properties of soil and leading to increased destruction and erosion [11].

Assessing soil quality involves measuring soil physical, chemical, and biological properties and using these measured values to detect changes in soil as a result of land use change or management practices [4]. Soil quality indicators may be used as an indirect measure of soil function, serving to assess soil quality or health and its direction of change with time, by linking functional relationships among measurable attributes and monitoring for sustainable land management, including environmental impacts [12, 13].For most natural environments such as soils, it is known that quantitatively soil properties within a site on the land scape are relatively similar. It is noted that spatial characterization of soil properties is necessary in order to locate homogenous areas to be carefully managed for agricultural sustainable development [14, 15, 16].

The spatial variability and geographical heterogeneity of physical and chemical properties of rangeland ecosystem soils are under physical and biological factors impact including topography, vegetation cover,soil microclimate, various grazing systems and rangeland management [17]. Technological advances in geographical information systems (GIS) have recently given land use planners as well as agriculturists a more efficient and effective way of handling large amounts of spatial data. The use of the global positioning system (GPS) and remote sensing in agriculture offers at least four advantages: (1) provision of data cheaply and quickly at a variety of resolutions; (2) use of repeatable methods; (3) provision of improved diagnostics for error detection and accuracy determinations; and (4) generation of information that can be used with the visualization tools in GIS to develop customized as well as tabular summaries [18].

Thus the objectives of this study was to assess the spatial variation of some soil physical, chemical and biological properties of four different agricultural land uses and generate soil surface maps of the sitesto determine soil quality, agricultural fertility and to make suggestions for improved crop production.

II. Materials And Methods

2.1 Sample sites

This study was carried out at four different locations of the Institute of Agricultural Research and Training (IAR&T), Ibadan (7° 23' N; 3° 51'E and 160 m above mean sea level), Nigeria (Fig. 1 and 2). The area is characterized by a tropical climate marked with wet and dry seasons. It is characterized by a bimodal rainfall pattern with rainfall peaks occur mostly in June and September. Annual temperature ranges from 21.3 to 31.2°C. Four different locations with different agricultural land use types which more or less exhibit the same ecological conditions were chosen for the study. Fig. 2 shows the base map of the whole institute and the various land use fraction from which soil samples were taken for analysis. The land use types considered were:

2.11 Cocoa plantation which is usually being maintained by manual weeding of the grasses and weeds from time to time. It is a mono cropping system with no other crop planted there asides cocoa and it has been in existence for over 50 years.

2.12 Grazed land which is being used for grazing purposes, it has mainly grasses and forages growing on it. Animals that graze on it include cows, sheep and goats. It is moderately grazed, as the animals are released onto the site for only 4-5 days a week

2.13 Fallow land which has not been put to any agricultural use but just has some weeds and grasses growing on it. It has been left fallow for about 15 years.

2.14 Horticultural land which has been used over the years for mixed cropping with the cultivation of horticultural crops and leafy vegetables. It has an area that is not heavily tilled with machinery and is being cropped both in the rainy season and in the dry season.

2.2 Determination of soil physical and chemical analysis

The samples were air-dried, crushed and allowed to pass through a 2 mm sieve. Particle size distribution was determined using hydrometer method [19]. Soil samples were analyzed for soil pH in both water and 0.01 M potassium chloride solution (1:1) using glass electrode pH meter [20]. Total nitrogen was determined by the macro-kjeldahl digestion method [21]. Available P was determined by the method described by Olsen [22]. Total N was determined by the Kjeldahl method [23]. Organic carbon content (OC) was measured by the Walkley-Black method [24]. Conversions between values of organic carbon and organic matter was made using Van Bemmelen factor of 1.724 on the assumption that, on average, SOM contains 58% of organic C. Exchangeable cations were extracted with 1 M NH_4OAC (pH 7.0) to determine K and Na using flame photometer and exchangeable Mg and Ca by atomic absorption spectrophotometer [25]. All the data analyzed were imported into GIS environment.

2.3 Soil microbial biomass analysis

The microbial biomass Carbon (MBC) was determined by fumigation extraction method. MBC was calculated from the relationship: MBC = EC - kEC, where EC is the difference between the amount of organic C extracted from the fumigated and non-fumigated soils and kEC is 2.64 [26]. Microbial biomass N (MBN) was calculated from the equation MBN = EN/kEN, where EN is the difference between the amount of organic N extracted from the fumigated and non-fumigated soils and kEN is 0.54 [27].

2.4 GIS analysis

The criteria listed in Table 2 formed the basis for the GIS datasets that were analyzed for soil nutrients while the microbial biomass C and N were graded based on the values obtained in the present study. The data were inputted into ArcGis and interpolated using the IDW (Inverse Distance Weighted) technique, this is a technique used to interpolate a surface from points. The GPS coordinates of each cluster point and corresponding nutrient values were interpolated and a raster image derived for each. After interpolation the raster data obtained was then reclassed using the reclassify module which is a spatial analyst tool in ArcGis to group into four classes i.e. low, slightly marginal, marginal and high based on the values in the raster data set (Fig.3-9).

III. Results And Discussion

The textural classifications of the study areas are presented in Table 1.The spatial variability of particle size distribution plays an important role in crop production as they impact the soil texture, soil quality and soil erosion [18]. The result showed that the surface soil textures are all loamy sand except for the cocoa plantation soils which was sand. Cocoa is grown on a wide range of soil types and the standards for soil suitable for cocoa vary considerably [28], and since it is a tap rooted plant it requires deep well drained soils [29].

The soil reaction in terms of soil pH as presented in Fig.3was tested in water; the surface soils from the four agricultural land use patterns showed alkalinity, ranging from an average of 7.43 to 8.09.The pH of the cocoa plantation and the grazed land showed moderate alkalinity while the fallow land and mixed cropping land showed slight alkalinity. The alkalinity observed in the study areas suggests a stressed and degraded ecosystem.
Total Nitrogen (TN) was also greatest in cocoa plantation soil and decreased in the order of grazed land, fallow land and cultivated land it ranged from 1.16 to.1.81kg/ha. The Nitrogen content in the area being used for horticultural purposes was slightly marginal with a range of 1.13 to1.54%. This could be as a result of the kind of crops being planted in the area such as leafy vegetables and other forms of vegetables which do not require much fertilizer inputs and also various human activities and agricultural practices carried out at the site, while the other land uses i.e. the fallow land, grazed land and cocoa plantation had marginal Nitrogen content with a range of 1.54 to 1.94% (Fig.4).Disturbing soil surface and its natural conditionsleaves negative impacts on soil structure and infiltration rate,increases runoff, and leads to the loss of large amounts ofnitrogen from soil surface [11].

Available P (AvP) ranged from 0.51to 1.40 kg/ha and was highest in cultivated land and lowest in grazed land. The phosphorus content was marginal in most of the land uses under observation with a range of 1–2 ppm, a little boost in the form of fertilizers could help in increasing the fertility of the areas. The grazed land was particularly low in phosphorus compared to the other areas, this could be as a result of the lack of farming activities on such land asides pasture grasses. High content of phosphorus could just be spotted in certain areas (Fig.5).

The exchangeable bases analyzed were low in all the land use types and it ranged from K (0.18 to 0.24 kg/ha), Ca (0.49 to 1.18 kg/ha), Na (0.33 to 0.34 kg/ha) and Mg (1.67 to 2.56 kg/ha). The potassium content was predominantly marginal in all the land use types with a range of 0.15 to 0.25 Cmol/kg, with just a part of the fallow land being less than 0.15 Cmol/kg while part of the cocoa plantation had high amounts of potassium (Fig.6). The high amounts observed in the cocoa plantation could be as a result of the soil not been actively cultivated and the other areas could be subjected to fertilizer use so as to boost the potassium content.Continued nutrient export without K supply will lead to depletion in the soil that, depending on K storage, may take from 3 to10 years [30].

Organic carbon (Oc) ranged from 1.84 to 3.29kg/ha, it was greatest in cocoa plantation soil and decreased in the order of grazed land, fallow land and cultivated land. The organic carbon content in most of the areas were found to be just marginal between 2 to 3% with a few spots low in organic carbon while a small portion of the cocoa plantation had high deposits greater than 3%. This could be as a result of leaf litter and other organic materials at the cocoa plantation (Fig. 7).

In this study, the mean values for microbial biomass C (MBC) ranged from 129.18 to 200.04 μgCg^{-1}while the mean microbial biomass N (MBN) ranged from 12.74 to 19.84 μgNg^{-1}. The results of the soil microbial biomass analysis also indicate that the cocoa plantation soil contains the highest MBC and MBN while the fallow land contains the lowest.The surface maps for the MBC and MBN were graded based on the values obtained in the study, this is shown in Fig. 8 and 9 respectively.The cocoa plantation was found to have the highest MBC with a part of it also having high values for MBN. This could be as a result of the leaf litterswhich contributed to the formation of organic matter. As seen in the surface maps, high values of organic carbon, K and available P were spotted in some areas of the cocoa plantation site and these could have contributed to the higher values of MBC and MBN.Soil organic matter rejuvenates degraded soils and increases biomass production [31] and differences in the quantity and quality of substrate inputs via varying litter and root types and associated nutrient specificity can be crucial drivers to influence the soil microbial biomass

[32,33].This study suggests that mono-cropping with cocoa has a better soil quality than the other agricultural land uses.

IV. Conclusion

Generally, the soils in the area are marginally suitable for agricultural production but employment of management techniques will improve agricultural productivity and optimal production. The chemical and biological characteristics of the sites as shown on the surface maps indicated that the soils are deficient in nutrients required for optimal production, although the cocoa plantation land seems to be more suitable compared to the other lands. Therefore, sustainable agricultural production in the study area can only be possible through the use of external inputs such as organic and inorganic fertilizer application in addition to appropriate management techniques to augment the natural endowment in the area.

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Table 1: Soil texture of different agricultural land use

Land use type	Sand (%)	Silt (%)	Clay (%)	Texture class
Cocoa plantation	88.8	4.0	7.28	Sand
Grazed land	84.3	6.64	9.04	Loamy sand
Fallow land	86.7	5.60	7.68	Loamy sand
Cultivated land	85.8	6.40	7.84	Loamy sand

Table 2: Critical limits of nutrients

S/No	Criteria	Low	Slightly Marginal	Marginal	High
1.	Nitrogen (%)		1.13-1.54	1.54-1.94	
2.	Phosphorus (ppm)	<1		1-2	>2
3.	Potassium (Cmol/kg)	<0.15		0.15-0.25	>0.25
4.	Organic Carbon (%)	<2		2 -3	>3
5.	pH			5 - 8	>8

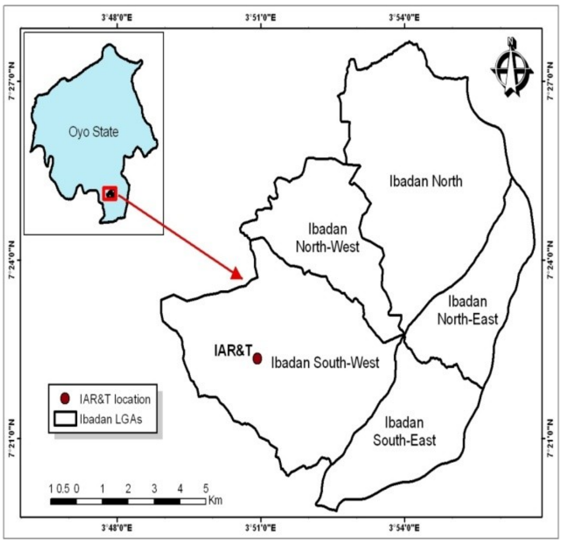

Figure 1: Oyo state showing core Local Government Areas and location of study area

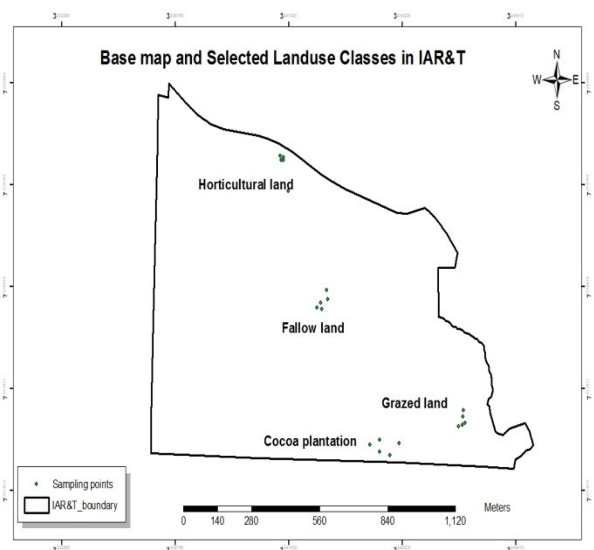

Figure 2: Base Map of selected agricultural Land use Classes in IAR&T

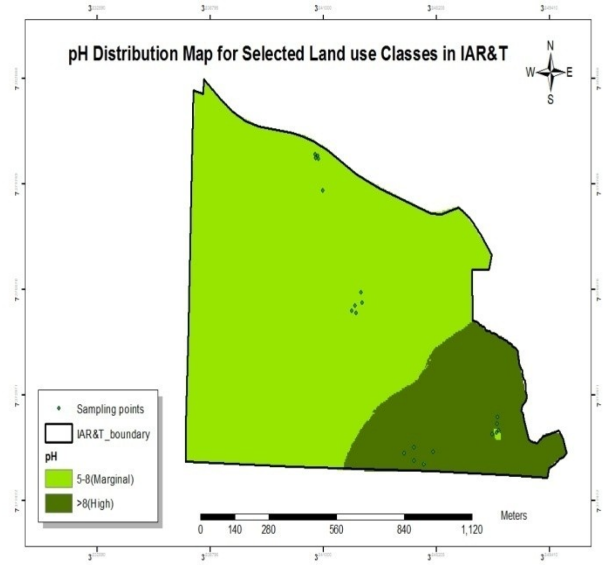

Figure 3: pH Distribution Map for the selected agricultural land use classes in IAR&T.

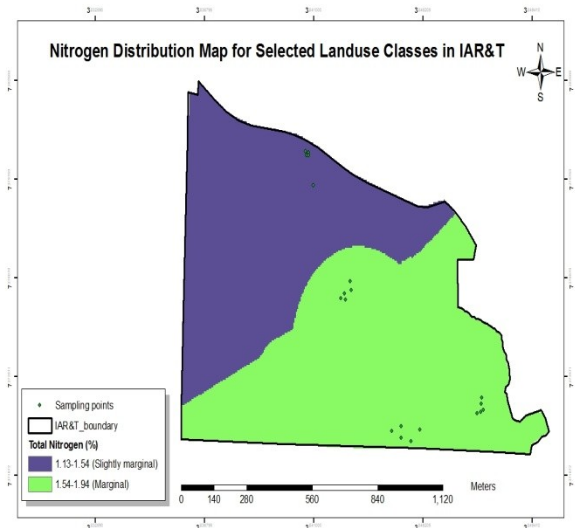

Figure 4: Nitrogen Distribution Map for the selected agricultural land use classes in IAR&T.

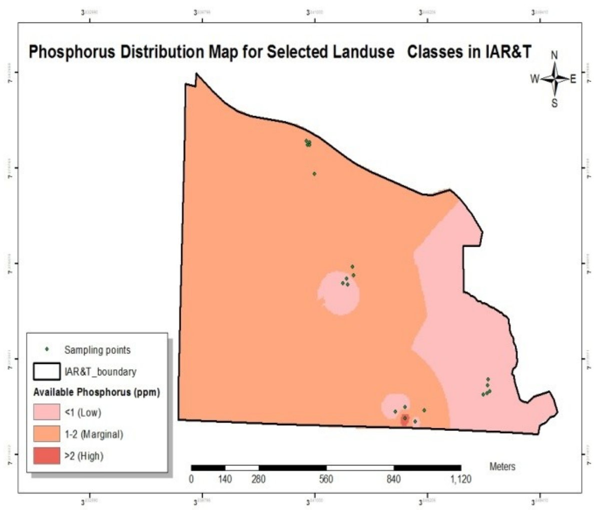

Figure 5: Phosphorus Distribution Map for the selected agricultural land use classes in IAR&T.

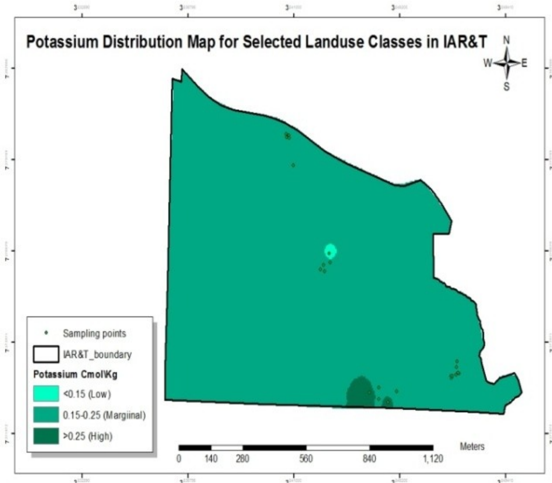

Figure 6: Potassium Distribution Map for the selected agricultural land use classes in IAR&T.

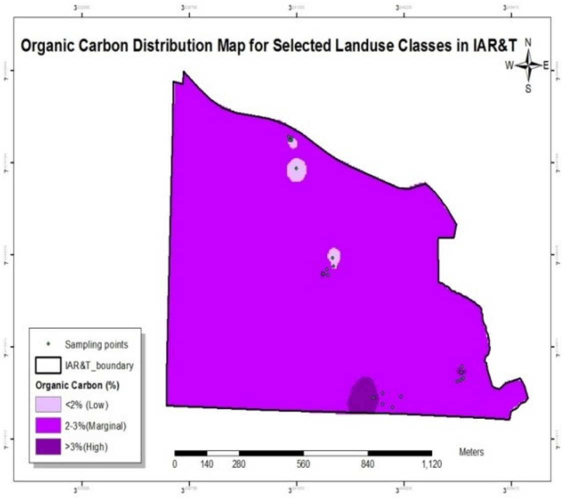

Figure 7: Organic carbon Distribution Map for the selected agricultural land use classes in IAR&T.

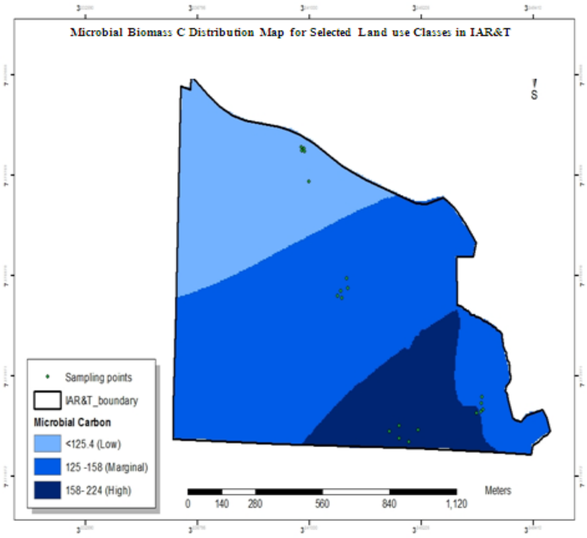

Figure 8: Microbial Biomass Carbon Distribution Map for the selected agricultural land use classes in IAR&T.

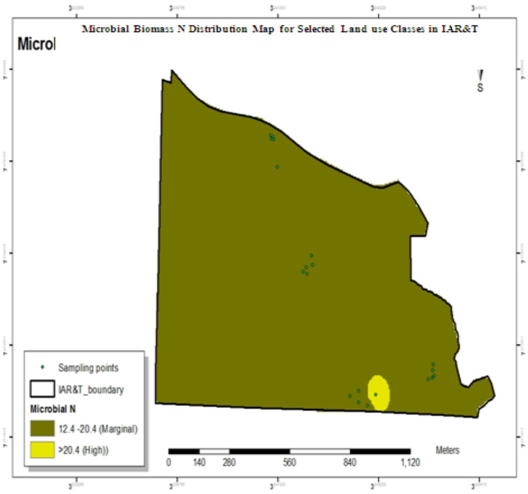

Figure 9: Microbial Biomass Nitrogen Distribution Map for the selected agricultural land use classes in IAR&T.