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Fertility Levels of Soils under Selected Tree Vegetations for Efficient Agro-Forestry in Imo State, Nigeria

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***Abstract*—*In many parts of Nigeria, large areas of lands are dominated by tree crop vegetations for timber production and for fruits with land users not knowing the fertility status of soils in these vegetations.Continual evaluation of soil properties of these tree vegetations has become pertinent for agricultural sustainability. This study therefore was carried out to evaluate the fertility levels of soils under selected tree vegetations at National Horticultural Research Institute Okigwe, Imo State, Nigeria. Five tree vegetations that were over 20 years of establishment were selected namely: oil bean (Pentaclethra macrophylla Benth), African breadfruit (Treculia africana), mango (Mangnifera indica), Ogbonu (Irvingia gabonensis) and orange (citrus spp). In each of these tree vegetations, four soil samples were collected at uniform depths (0 – 20, 20 – 40 and 40 – 60 cm) at different locations using soil auger. The samples were analyzed using standard laboratory procedures. Data collected were statistically analyzed using analysis of variance. Results obtained showed that despite the ages of these vegetations, the soils were acidic, low in macronutrient and basic cation concentrations when compared to FAO standard. The highest exchangeable bases and organic matter (1.78%) was recorded on bread fruit vegetation. Therefore, there is need to increase the fertility status of these soils in these tree crop vegetations by adopting measures that will boost organic matter content of the soil irrespective of the duration of the vegetation and this will help in agro forestry and alley cropping.*

***Keyword*— Agro-forestry, Nutrient depletion, plant nutrients, Soil fertility, tree vegetations**

I. INTRODUCTION

To sustain optimum agricultural production and maintain environmental sustainability, soil needs proper nutrient management. (Ashenafi et al., 2010). This will enhance overall growth in the economy and food security (Burton et al., 2007, Muche et al., 2015,). It has been reported that land degradation, loss of soil fertility and productivity usually occur when natural forests are converted to cultivated arable lands and this has resulted to hunger, malnutrition and poverty (FAO, 2020). To achieve number 15 of the Sustainable Development Goal (SDG) that aimed at sustaining and restoring use of land resources for optimum food production, tree vegetations that occupy large areas of agricultural lands should be evaluated from time to time to determine the fertility status of the soil for crop production. (Tellen and Yerima, 2018). Through this, policy makers will be properly guided at adopting effective measures that will enhance soil fertility and agro-forestry activities especially in developing countries (IFPRI, 2010).

Land use system is one of the major factors that influence the physical, chemical and biological attributes of soil apart from other factors of soil formation such as relief, climate, parent material, time and organisms (Holden and Treseder 2013). Understanding changes in soil properties as a result of land use system such as forest vegetation will be useful in determining the quality and productivity of soil (Akpan-Ebe, 2017).

Many research works have provided information on understanding the interrelationship between the tree species (Myneni et al. 2001, Yang et al. 2010; Wang and Yang, 2007), soil microbial and soil physico-chemical properties of plantation fields (Landesman and Dighton, 2011). Also, previous works on varied forest soils have shown variations in the concentration of plant nutrients in tree crop vegetations (Landesmanand Dighton, 2011; Chandra et al., 2016).

National Horticultural Research Institute (NIHORT) Okigwe is a research institute that has large hectares of different tree plantation farms. Tree plantations are the source of global terrestrial carbon (Burton *et al.*, 2007) in which forest ecosystem plays a major role in carbon sequestration from increasing atmospheric carbon dioxide, as it covers the major portion of terrestrial land (Myneni et al., 2001). Little literature is available on soil fertility levels with respect to different tree vegetation covers in this part of Nigeria. The study therefore was aimed at evaluating the fertility levels of soils from different tree vegetations in Imo State, Nigeria.

II. MATERIALS AND METHODS

The study location

This research was conducted at National Horticultural Research Institute (NIHORT) Okigwe. The study area lies between latitude 5°87¹N and longitude 7°30¹E. The institute has a land area of about 810 hectares with mean annual rainfall of 2250 mm, mean annual temperature range of 27°-28°C and rainforest dominated the area with trees and shrubs. It has a sparsely vegetated shrubby rainforest with windward portions of hills having tall and varied plant species occurring in the district tiers. The main geological material is false bedded sandstones (Ajali formation). Major economic activities of people in the area is trading and farming.

Sample collection

A reconnaissance visit was made to locate the study locations. Areas to collect the soil samples were guided by land use types under tree vegetations. Soil samples were collected using stratified random sampling from five different land use types dominated by tree crops that were over 20 years of age. The crops were oil bean plants (*Pentaclethra macrophylla Benth*), African breadfruit plants (*Treculia africana*), mango plants (*Mangnifera indica*), Ogbonu plants (*Irvingia gabonensis*) and orange orchard (*citrus spp*). A mini pedon was dug in each of the location and soil samples were collected at uniform depths from 0 – 60 cm at the intervals of 0 – 20, 20 – 40 and 40 – 60 cm depths using soil auger. Core sampler was used to collect undisturbed soils for bulk density and total porosity determination. The samples were air dried at room temperature and sieved using a 2mm sieve. After sieving, the selected soil physical and chemical properties were determined using standard procedures as stated in Table 1.

Laboratory analysis

Soil samples were analyzed at the Department of Soil Science and Technology, Federal University of Technology Owerri, Nigeria using the methods as stated in Table 1.

Table 1: Soil properties analyzed and the method used

Soil Property	Methodology
Particle Size Distribution	This was determined by hydrometer method according to the procedure of Gee and Or (2002).
Bulk Density	The bulk density of soil samples was determined by core methods according to Grossman and Reinsch (2002) using the formula Bulk density (BD) = $\frac{\text{weight of dry soil}}{\text{volume of dry soil}}$ …….. Eqn 1.
Total Porosity	This was calculated from the result of bulk density using the formula Total Porosity (TP) = $[1 - \frac{BD}{pd} \times 100]$ where pd = Particl*e* density (2.65 g/cm^3) and BD = bulk density.

Soil pH (H_2O)	This was determined using pH metre in soil / liquid suspension of 1 : 2.5 according to Hendershot et al., (1993)
Organic Carbon	Organic carbon was determined using chromic wet oxidation method according to Nelson and Sommers (1982).
Total Nitrogen	Kjeldahl digestion method using concentrated H_2S0_4 and Sodium Copper sulphate catalyst mixture according to Bremner and Yeomans (1988) was used.
C / N Ratio	This was by computation of organic carbon and total nitrogen values (Brady and Weil, 1999).
Exchangeable Mg and Ca	Ethylene diamine tetra acetic acid (EDTA) (Thomas, 1982) procedure was used to determine exchangeable Mg and Ca.
Exchangeable K and Na	1 N ammonium acetate (NH_4OAC) was used for the extraction and exchangeable K and Na was determined using flame photometer (Thomas, 1982).
Exchangeable Acidity	This was measured titrimetrically using 1 N KCl against 0.05N Sodium hydroxide (Mclean, 1982)
Effective Cation Exchange Capacity	This was calculated by the summation of all exchangeable bases and total exchangeable acidity
Base saturation	Base saturation was calculated by dividing total exchangeable base by effective cation exchange capacity and multiplying the quotient by 100

Statistical analysis

Data from analyzed soils were subjected to analysis of variance (ANOVA). Significant means were determined using Least Significant Difference (LSD) at 0.05 probability level.

III. RESULTS AND DISCUSSIONS

Soil physical properties of the study area

Soil particle size distribution in the five tree vegetations are presented in Table 2. Sand fractions dominated the area and this could be due to the geological material (false-bedded sand stone) that formed the soil (Soil Survey Staff, 2006). Sand decreased down the depth while clay fractions increased with increase in depth. Sand fractions ranged from 73.85 to 81.45% with the highest value (81.45%) recorded under citrus orchard. However, the vegetations did not significantly influence the sand content. Silt content ranged from 11.64 to 13.84% with the highest and lowest values recorded under African bread fruit vegetation and mango vegetation respectively. Clay content ranged from 13.11 – 6.44%. The tree vegetations significantly (p = 0.05) influenced the clay contents of the soils. There were variations in the textural class of the soil which varied from sand, sandy loam to loamy sand. This agrees with the previous works as recorded by Onwudike et al., (2015) that land use types changes the textural class of soils over time.

There was significant difference (p = 0.05) on soil bulk density and total porosity with respect to these vegetation. Soil bulk density ranged from 1.49 – 1.56 g/ cm^3 with the highest value (1.56 g/cm^3) recorded under mango vegetation and the lowest value (1.49 g/cm^3) recorded under citrus orchard and oil bean vegetation. Similarly, soil total porosity ranged from 41 - 43.70% with the highest value (43.70%) recorded under African bread fruit vegetation and the lowest value was under mango vegetation. It was observed that increase in bulk density reduced soil total porosity which is in line with Onwudike and Onwubiko (2020) and Nadian et al., (2005), that there is a negative correlation between soil bulk density and total porosity.

Variations in the textural class of these soils could be attributed to litter fall and decomposition of these letters by soil microbes which directly increase soil organic matter and this plays vital role in soil fertility and structural stability of the soil, profile mixing and other biogeochemical nutrient dynamics (Nsalambi et al., 2010). Significant effect on soil bulk density could be due to litter fall and its decomposition since organic matter reduces the compaction of soil and improves soil porosity (Marcet et al., 2006).

Table 2: Soil physical properties of the area

Location	Depth cm	Sand %	Silt %	Clay %	Textural Class	Bulk density g/cm3	Total Porosity %
Oil bean vegetation	0 - 20	83.32	14.24	2.44	Loamy sand	1.44	45.5
Oil bean vegetation	20 - 40	69.12	13.44	17.44	Sandy loam	1.49	43.7
Oil bean vegetation	40 - 60	69.12	11.44	19.44	Sandy loam	1.55	41.4
Mean		**73.85**	**13.04**	**13.11**	**Sandy loam**	**1.49**	**43.53**
Ogbonu vegetation	0 - 20	90.12	9.44	0.44	Sand	1.49	43.6
Ogbonu vegetation	20 - 40	73.12	16.32	10.56	Sandy loam	1.57	40.69
Ogbonu vegetation	40 - 60	70.12	12.44	17.44	Sandy loam	1.5	43.3
Mean		**77.79**	**12.73**	**9.48**	**Sandy loam**	**1.52**	**42.53**
Mango vegetation	0 - 20	81.12	14.44	4.44	Loamy sand	1.61	39.10
Mango vegetation	20 - 40	78.72	13.84	7.44	Sandy loam	1.54	41.80
Mango vegetation	40 - 60	84.12	6.64	9.24	Loamy sand	1.53	42.10
Mean		**81.32**	**11.64**	**7.04**	**Loamy sand**	**1.56**	**41.00**
African Breadfruit vegetation	0 - 20	76.12	18.44	5.44	Sandy loam	1.42	46.4
African Breadfruit vegetation	20 - 40	85.12	9.64	5.24	Loamy sand	1.52	42.8
African Breadfruit vegetation	40 - 60	75.12	13.44	11.44	Sandy loam	1.53	41.9
Mean		**78.79**	**13.84**	**7.37**	**Sandy loam**	**1.49**	**43.70**
Citrus orchard	0 – 20	86.12	11.44	2.44	Loamy sand	1.47	44.1
Citrus orchard	20 – 40	81.12	14.44	4.44	Loamy sand	1.53	42.1
Citrus orchard	40 – 60	77.12	10.44	12.44	Sandy loam	1.53	41.9
Mean		**81.45**	**12.11**	**6.44**	**Loamy sand**	**1.51**	**42.70**
LSD(0.05)		**Ns**	**6.29**	**6.99**		**0.01**	**3.30**

ns = not significant

Soil chemical properties of the study area

Tree vegetations significantly (p = 0.05) influenced the pH of the soil (Table 3) but did not significantly affect soil organic matter, total nitrogen and C/N ratio. However, the highest pH value (5.66) was recorded under African breadfruit vegetation while the lowest value (5.48) was under citrus orchard. The highest soil organic matter (1.78%) was recorded under breadfruit vegetation as compared to the lowest value (0.87%) under mango vegetation. Also, the highest total nitrogen (0.12%) was recorded under oil bean and African breadfruit vegetations as compared to the lowest value (0.09%) under mango vegetation. African breadfruit vegetation had the highest C/N ratio (10.91) as compared to the lowest C/N ratio (5.48) under ogbonu vegetation. The C/N ratio of soil or organic material indicates the availability of nitrogen in the organic matter. According to Hadas et al. (2004), C/ N ratio below 10 is considered normal for optimum microbial activity and organic matter decomposition in the soil. The C/ N ratio of these soils are within the range for microbial activity.

Tree vegetations significantly (p = 0.05) affected total exchangeable Ca and Mg when compared to the five vegetations. However, there was no significant difference on total exchangeable K and Na. The highest exchangeable Ca (2.22 cmol/kg) and exchangeable Mg (0.75 cmol/kg) was recorded under oil bean vegetation as compared to the lowest values of exchangeable Ca (0.36 cmol/kg) and Mg (0.23 cmol/kg) which were recorded under mango and oil bean vegetations respectively. Similarly, the vegetations did not significantly influence total exchangeable K and Na in the five vegetations.

Tree vegetations significantly (p = 0.05) influenced total exchangeable acidity, total exchangeable bases and effective cation exchange capacity. The highest total exchangeable acidity (2.17 Cmol/kg) and lowest value (1.23 Cmol/kg) was recorded under oil bean and mango vegetations respectively. Similarly, citrus orchard and mango vegetation recorded the highest total exchangeable bases (4.70 Cmol/kg) and lowest value (1.35 Cmol/kg) while the highest value of effective cation exchange capacity (6.59 Cmol/kg) and lowest value (2.58 Cmol/kg) was recorded under citrus orchard and mango vegetations respectively. Base saturation was moderate in all the vegetations according to Esu (1991) and the values ranged from 48.0 – 75.6% with the highest value recorded under African breadfruit vegetation while the lowest value (48.0%) was found under mango vegetation.

Soils of these vegetations were acidic, low in organic matter, total nitrogen, exchangeable bases and moderate in percentage base saturation when compared with FAO (2006) and Esu (1991) fertility ratings. Soils under citrus orchard were more acidic than other vegetations due to the lower litter fall when compared to oil bean, African breadfruit and mango vegetations that had high thickness of litter fall due to their ability to shade leaves during dry season. The significant effect on total exchangeable bases (Mg and Ca) and base saturation could be attributed to litter falls which after decomposition, increases basic cations. Similarly, soil organic matter from the decomposition of litter fall could be contributed to the significant effects on effective cation exchange capacity since previous works of Onwudike et al., (2015) revealed a significant positive correlation between soil organic matter with effective cation exchange capacity and base saturation.

Table 3: Soil chemical properties of the studied locations

ns = not significant, OM = organic matter, TN =Total nitrogen, TEA = total exchangeable acidity, TEB = total exchangeable

Location	Depth Cm	pH (H_2O)	OM %	TN %	C/N	Ca	Mg	K Cmol/kg	Na	TEA	TEB	ECEC	BS %
Oil bean vegetation	0 – 20	5.64	2.37	0.17	6.89	1.30	0.41	2.72	0.66	1.54	5.09	6.63	76.7
Oil bean vegetation	20 - 40	5.45	1.75	0.12	7.33	1.25	0.55	0.14	0.06	1.73	2.00	3.73	53.6
Oil bean vegetation	40 - 60	5.36	1.00	0.08	7.00	4.20	1.30	0.20	0.08	3.25	5.78	9.03	64.0
Mean		**5.57**	**1.71**	**0.12**	**7.07**	**2.25**	**0.75**	**1.02**	**0.27**	**2.17**	**4.29**	**6.46**	**64.8**
Ogbonu vegetation	0 – 20	5.66	1.72	0.14	7.89	1.10	0.40	0.47	0.14	1.66	2.11	3.77	55.9
Ogbonu vegetation	20 - 40	5.54	0.77	0.08	0.88	1.40	0.20	0.38	0.14	1.58	1.12	2.70	41.5
Ogbonu vegetation	40 - 60	5.51	1.62	0.12	7.66	1.15	0.35	1.97	3.86	1.69	7.33	9.02	81.3
Mean		**5.53**	**1.37**	**0.11**	**5.48**	**0.88**	**0.32**	**0.94**	**1.38**	**1.64**	**3.52**	**5.16**	**59.6**
Mango vegetation	0 – 20	5.68	0.27	0.06	6.80	1.70	0.20	0.27	0.09	1.40	2.56	3.96	65.4
Mango vegetation	20 - 40	5.47	1.13	0.10	8.64	0.30	0.20	0.05	0.05	1.21	0.60	1.81	33.1
Mango vegetation	40 - 60	5.44	1.20	0.11	8.96	0.30	0.15	0.36	0.09	1.08	0.90	1.98	45.5
Mean		**5.58**	**0.87**	**0.09**	**8.13**	**0.77**	**0.23**	**0.23**	**0.08**	**1.23**	**1.35**	**2.58**	**48.0**
African breadfruit vegetation	0 – 20	5.87	2.72	0.18	8.19	0.30	0.70	2.48	0.57	1.50	5.05	6.55	77.1
African breadfruit vegetation	20 - 40	5.48	1.44	0.10	18.22	0.50	0.30	3.12	0.71	0.55	4.63	5.18	89.6
African breadfruit vegetation	40 - 60	5.40	1.17	0.09	6.33	0.28	0.12	0.54	1.83	1.83	2.77	4.60	60.2
Mean		**5.66**	**1.78**	**0.12**	**10.91**	**0.36**	**0.37**	**2.05**	**1.04**	**1.29**	**4.15**	**5.44**	**75.6**
Citrus orchard	0 – 20	5.84	1.89	0.12	8.16	0.50	0.21	0.49	0.12	1.68	1.32	3.00	44.0
Citrus orchard	20 - 40	5.66	1.20	0.11	6.33	0.54	0.36	0.37	0.95	2.38	2.22	4.60	48.3
Citrus orchard	40 - 60	5.47	1.17	0.10	7.24	1.40	0.50	3.20	5.46	1.62	10.56	12.18	86.7
Mean		**5.48**	**1.42**	**0.11**	**7.24**	**0.81**	**0.36**	**1.35**	**2.18**	**1.89**	**4.70**	**6.59**	**56.7**
LSD(0.05)		**0.13**	**ns**	**ns**	**Ns**	**1.69**	**0.55**	**ns**	**Ns**	**1.07**	**5.08**	**4.85**	**33.9**

bases, ECEC = effective cation exchangeable capacity, BS = base saturation

Comparison of soil organic matter and C/N ratio in the studied vegetations

Results showing the comparison of soil organic matter and C/N ratio in the studied soils are presented in Figure 1. Results showed that African bread fruit vegetation had higher concentration of soil organic matter more than other vegetations. The sequence in the order of increase was African bread fruit vegetation> mango vegetation>oil bean vegetation> citrus orchard >ogbonu vegetation. Similarly, the bread fruit had higher C/N ratio than other vegetations. The sequence in the order of increase was African bread fruit vegetation > mango vegetation> oil bean vegetation > citrus orchard >ogbonu vegetation.

Comparison of the concentrations of exchangeable bases in the studied vegetations

The concentrations of exchangeable Ca was highest under oil bean vegetation while exchangeable K was highest under African breadfruit vegetation. Citrus orchard had higher exchangeable Ca while exchangeable Na was highest under ogbonu vegetation. These results showed that there are variations in the concentrations of soil nutrients in these vegetations and this could be due to the micro-climate associated with these vegetations and differences in the amount of litter accumulation and organic matter turnover.

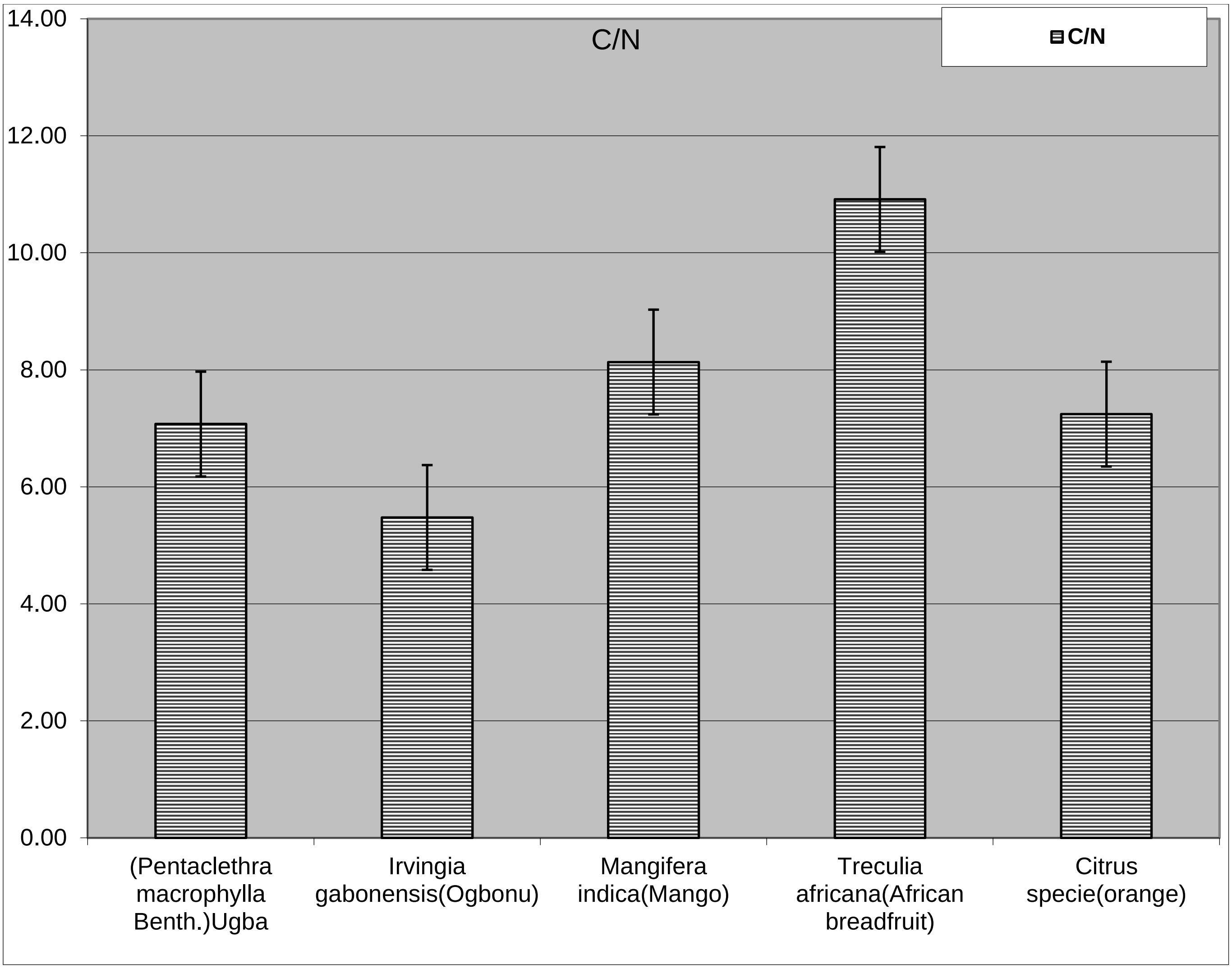

Fig 1: Comparing Soil organic matter and C/N ratio in the studied location

IV. CONCLUSION

The fertility status of soils under different tree vegetations that were established over 20 years at National Horticultural Research Institute (NIHORT) Okigwe, Imo State, Nigeria, was evaluated in this study. Results showed that the number of years tree crop vegetation stays is not an index in measuring the fertility status of the soil irrespective of the volume of litter fall. Soils under the studied tree crop vegetations were acidic, low in organic matter and exchangeable bases according to FAO standard. Evaluation of the fertility levels of soils under tree crop vegetations is vital in agro-forestry. Therefore there is need to boost the fertility levels of these soils through other agronomic practices such as alley cropping with legume crops and organic amendment without depending on the volume of litter falls. There is need to replicate this study in other agro-ecological zones for optimum crop production and food security.

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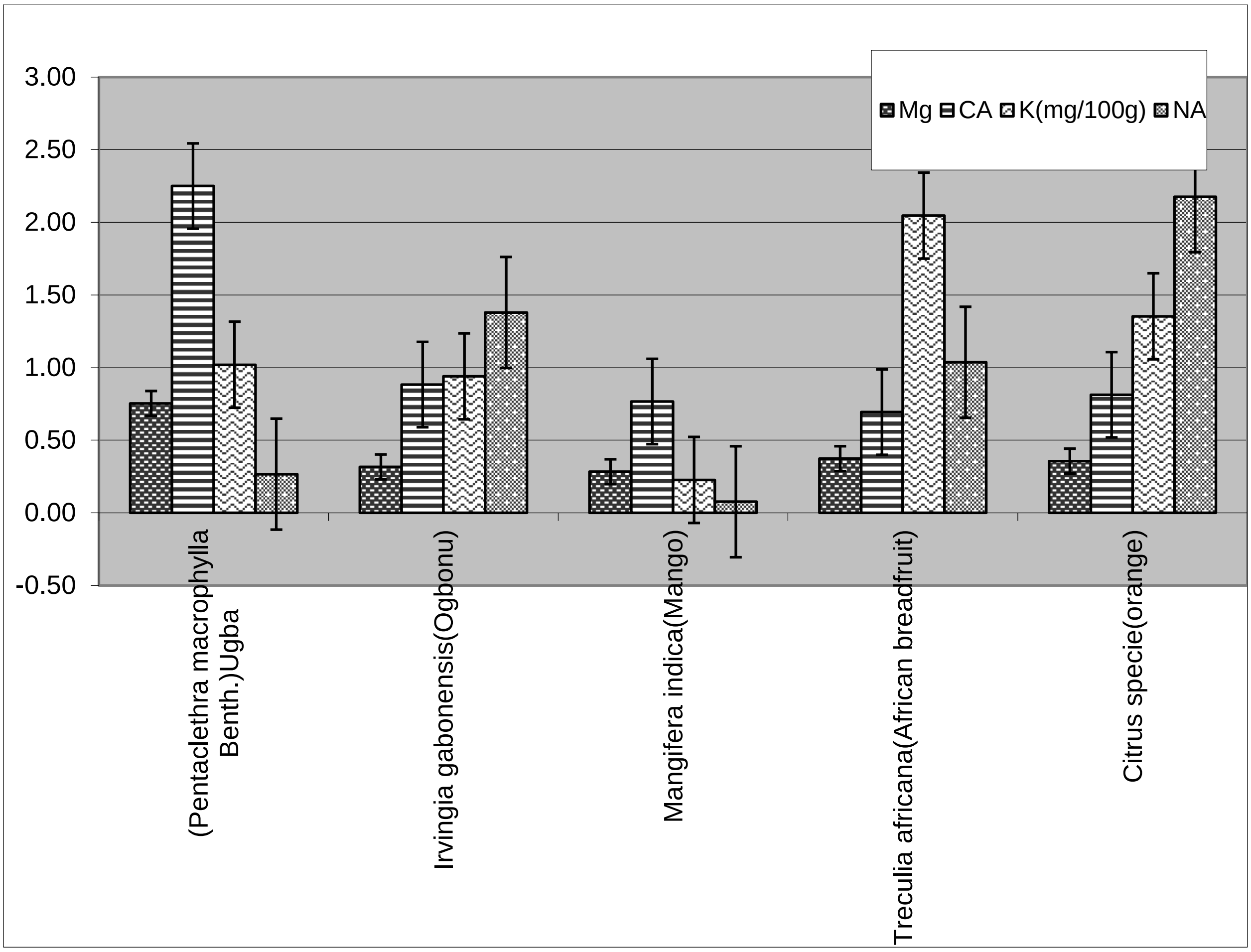

Fig 2: Comparing exchangeable bases in the studied location

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