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Evaluation of Chemical Soil Fertility under Different Land-Use Types in the Territory of Aru (Ituri, Democratic Republic of the Congo)

Kiza Kakado[a*], Solia Edondoto Sylvain[b], Aliango Uvon Blaise[c], Okungo Lotokola Albert[d]

[a]Assistant Lecturer, Shalom University of Bunia, Democratic Republic of Congo, Full

[b]Professor, Faculty Institute of Agronomic Sciences of Yangambi, Democratic Republic of Congo

[c]Assistant Lecturer, University of Bunia, Democratic Republic of Cong

[d]Full Professor, Faculty Institute of Agronomic Sciences of Yangambi, Democratic Republic of Congo

[a]Email: kkakado@gmail.com

[b]Email: sylvainsoliaac@gmail.com

[c]Email: blaisealiango@gmail.com

[d]Email: lotokungo@gmail.com

Abstract

This study assesses the chemical fertility of soils in the Territory of Aru (Ituri Province, DRC) under four land-use types, including tobacco cultivation (Nicotiana tabacum). Soil samples collected at depths of 0-30 cm were analyzed to determine pH (water and KCl), exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+), and cation exchange capacity (CEC). The results indicate that the soils are generally slightly to moderately acidic, with no significant differences among land-use types. Magnesium dominates the exchangeable bases, and the sum of bases remains globally satisfactory. However, CEC values are low (1.57-3.34 cmol(+)/kg), revealing limited nutrient retention capacity. The impact of tobacco cultivation appears moderate in the short term, but the low CEC and observed acidity indicate fragile soil fertility. Integrated management combining organic and mineral inputs is recommended to ensure the sustainability of local agricultural systems.

Keywords: Chemical fertility; land use; tobacco cultivation; pH; exchangeable bases; CEC; Aru; DRC.

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* *Corresponding author.*

1. Introduction

Agriculture in Sub-Saharan Africa remains characterized by low productivity, largely due to progressive soil degradation [9,13]. The reduction of fallow periods, cropping intensification, and inappropriate use of synthetic chemical inputs have contributed to nutrient depletion and declining soil organic matter. In this context, soil fertility is no longer considered solely in terms of physico-chemical properties but also as an ecological function integrating biological dynamics and biogeochemical cycles [3].

Different production systems imply contrasting fertility management strategies. Intensification strategies relying primarily on mineral fertilizers, when not accompanied by adequate organic inputs, may accelerate soil acidification, nutrient losses, and structural degradation [27]. Conversely, integrated soil fertility management approaches combine organic and mineral sources to sustainably maintain soil productivity [26].

The evaluation of chemical fertility particularly involves the study of the soil exchange complex, composed of clays and humic compounds carrying negative charges capable of reversibly adsorbing cations such as Ca^{2+}, Mg^{2+}, K^{+}, and N^{+} [8]. Soil pH, an indicator of hydrogen ion activity, directly influences nutrient availability and biological activity [7,10]. Cation exchange capacity (CEC), which reflects the total amount of cations a soil can retain, depends on clay mineralogy, organic matter content, and pH [6,22]. The sum of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) is an indicator of base saturation and soil nutritional balance [23]. The combined analysis of these parameters allows assessment of soil fertility status and vulnerability to acidification [24].

The objective of this study is to evaluate the fertility status of soils in Aru under different land use systems based on laboratory physico-chemical analyses. Specifically, the study aims to determine soil pH, cation exchange capacity, and exchangeable base contents in order to assess base saturation levels and soil nutritional balance. The results will provide a scientific basis for developing recommendations for sustainable and rational land management. We hypothesize that soil fertility levels are low due to the production systems adopted by farmers, particularly in tobacco cultivation.

2. Study Area, Materials and Methods

2.1. Study Area

The Territory of Aru is located in the northernmost part of Ituri Province (northeastern DRC) and covers approximately 6,749 km². The country is bordered to the north by South Sudan and to the east by Uganda. Its geographical location is specified by the following coordinates: 30°10′ and 31°30′ East longitude and 2°40′ and 4°05′ North latitude.

From a physiographic perspective, the region is predominantly characterised by plateaus, with an average altitude of 1,300 metres. These plateaus are extensively covered by savannah vegetation. According to the Köppen classification, the region falls within the Aw3 tropical climate type, distinguished by a pronounced dry season [4]. The region experiences two distinct seasons: a dry season, which extends from November to February, and a rainy season, which commences in March and concludes in October. The mean annual temperature is approximately 25°C.

Figure 1 presents the ombrothermic curve of the territory for the period 2000-2025, illustrating the seasonal dynamics of precipitation and temperature.

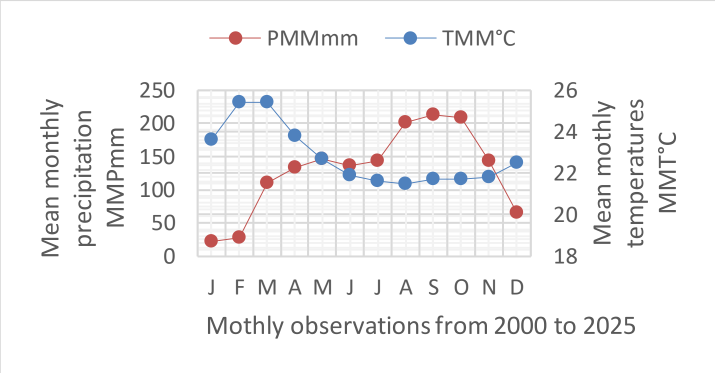

Figure 1: Ombrothermic diagram showing mean monthly precipitation and temperature in the Aru Territory for the period 2000-2025 (Source: NASA POWER Data Access Viewer)

The mean ombrothermic curve for the period 2000-2025 was analysed, revealing a tropical climate characterised by pronounced rainfall seasonality. Precipitation levels, which are minimal in January and February, undergo a progressive increase from March onwards, reaching a maximum between August and October, with the highest values recorded in September. Rainfall then declines towards the end of the year, indicating a unimodal rainfall regime characterised by a principal rainy season and relatively dry conditions at the beginning and end of the year. The mean monthly temperatures range from 21 to 26°C, exhibiting low annual thermal amplitude. Maximum values are observed in February-March, with a slight decrease between June and August, corresponding to the period of intensified rainfall. Collectively, these patterns substantiate the temperate and seasonally humid nature of the climate, whose variability exerts a substantial influence on regional hydrological and environmental dynamics [28].

Vegetation is dominated by wooded and herbaceous savannah, interspersed with gallery forests of notable ecological importance. Climatic and ecological conditions strongly influence agro-environmental dynamics in the region.

The Territory of Aru is composed of eight decentralised administrative entities, including seven chiefdoms and one sector, which together comprise a total of forty-seven *groupements*. The chiefdoms are Aluru (administrative centre: Adranga), Kakwa (Ingbokolo), Kaliko Omi (Mado), Lu (Yuku), Otso (Otse), Nio Kamule (Ondolea), and Zaki (Nderi). In addition to these chiefdoms, the Ndo sector, headquartered in Alo, constitutes part of the territorial administration. The Aru Territory is organised into administrative subdivisions, which are delineated in the territorial organisation [5].

2.2. Materials

The field equipment employed in this study encompassed instruments for measurement, sampling, sample handling, and data recording. A 50-metre measuring tape was utilised to delineate pedological profiles and sampling intervals, while a Global Positioning System (GPS) device was employed to record the geographical coordinates of sampling sites and to orient the transects. The execution of clearing and excavation operations necessitated the utilisation of a machete and a shovel, whereas a stainless-steel knife was employed for the purpose of soil sampling, with the objective of averting contamination.

Soil samples were placed in durable polyethylene bags (20 × 30 cm and 25 × 50 cm), transported in pedologist field cases, and subjected to preliminary weighing using a portable balance. Field data were meticulously recorded in a field notebook, accompanied by labeling sheets that indicated the site, date, profile number, horizon, depth (cm), and sample identification number.

a. Soil Sampling Design and Preparatory Work

The experimental design was based on two factors: land use as the primary factor and soil depth as the secondary factor. Four land-use types were considered: a site formerly cultivated with tobacco (Nicotiana tabacum), a site where tobacco had been replaced by other crops, a site currently under tobacco cultivation, and a site never cultivated with tobacco.

Subsequent to the selection of the site, preparatory activities encompassed the demarcation of the study area and its subdivision into plots, in addition to the staking out of the sampling lines using machetes, ropes, measuring tapes, GPS devices, and wooden stakes. The soil samples were collected using a diagonal sampling approach to ensure representative spatial coverage within each plot.

Each plot measured 50 m × 50 m (0.25 ha), with a 10 m buffer zone on each side in order to minimise edge effects. Within each plot, three pedological pits were excavated at 12.5 m intervals.

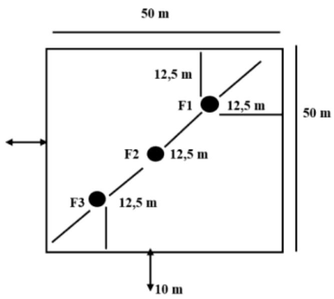

Figure 2: The following schematic representation illustrates the soil sampling design under four land-use systems

b. Soil Sampling and Sample Preparation

Soil sampling was conducted in accordance with a layout that took into account areas exhibiting varying degrees of tobacco cultivation intensity, in addition to control pits situated within regions not utilised for this specific crop. A total of sixteen pedological pits, measuring 1 m × 1 m × 0.5 m, were excavated, with three pits established per land-use type. The pits were oriented along an east-west axis in accordance with methodological recommendations. The depth of sampling was determined on the basis of root density and the presence of humus, which was identifiable by its darker colouration. Soil samples were collected at three depth intervals: 0-10 cm, 10-20 cm, and 20-30 cm, across the four land-use types (formerly cultivated with tobacco, converted to other crops, currently cultivated with tobacco, and never cultivated with tobacco).

For each land use category, individual samples were collected in triplicate (i.e. faces a, b, and c), resulting in a total of 144 samples per land use category. In total, 48 samples were allocated for chemical analyses, while 96 samples were designated for particle size analysis and pH determination (faces a and b). These samples were subsequently transported to the UCG laboratory in Butembo for physico-chemical analysis.

In the laboratory at Shalom University in Bunia, the samples were subjected to a series of preparatory procedures. These included the process of air-drying, gentle crushing to disaggregate clods, sieving through a 2 mm mesh to obtain the fine earth fraction, and final packaging prior to laboratory analysis.

Figure 3. The following essay will explore the spatial distribution of land-use types in the Aru Territory.

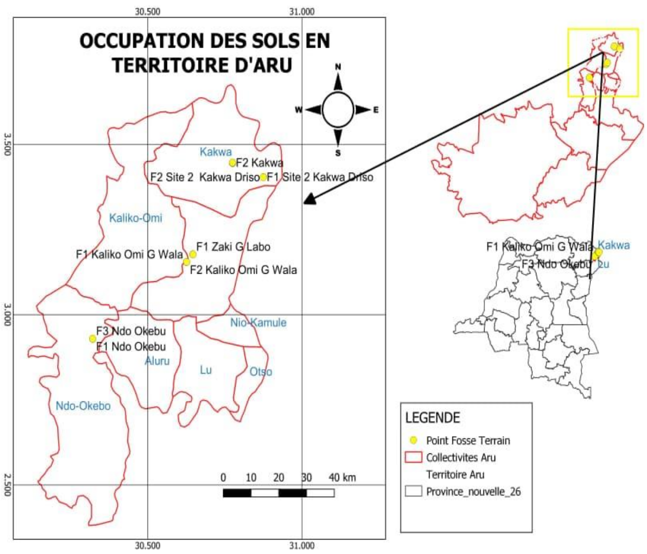

Figure 3: The following map illustrates the Aru Territory within the province of Ituri in the Democratic Republic of the Congo

2.3. Laboratory Analytical Methods

The collected samples represented soils from four land-use categories: a site formerly cultivated with tobacco (Nicotiana tabacum) (T1), a site where tobacco had been replaced by other crops (T2), a site currently under tobacco cultivation (Nicotiana tabacum) (T3), and a site not yet cultivated with tobacco (T0). Laboratory analyses were conducted to determine three physico-chemical parameters in relation to the four land-use types.

The pH of the soil (pH H_2O) was measured using a pH meter equipped with a glass electrode and a reference electrode, in a soil-to-water suspension at a ratio of 1:2.5 (10 g of soil in 25 mL of distilled water). This procedure was conducted in accordance with the methods outlined in [15,21]. In the present study, the extraction of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) was conducted through the utilisation of a 1N ammonium acetate solution at pH 7. This method involved shaking soil samples with the aforementioned solution, resulting in saturation of the exchange complex with NH_4^+ ions and the subsequent quantitative displacement of the adsorbed cations. The concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined by atomic absorption spectrophotometry, while potassium (K^+) and sodium (Na^+) were measured by flame emission spectrophotometry. Following the removal of excess NH^+_4, as verified using Nessler's reagent, cation exchange capacity (CEC) was determined by distillation using the Büchi method, in accordance with standard protocols [21]. The effect of differing land-use types on soil parameters was assessed using one-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) post hoc test for multiple comparisons [29,1]. Prior to analysis, normality and homogeneity of variances were verified. In instances where these assumptions were not met, the data were log10-transformed or analysed using the non-parametric Kruskal-Wallis test, with Wilcoxon post hoc comparisons where deemed necessary ($p < 0.05$). The statistical analyses were conducted utilising the Jamovi software (version 2.3.2), the JASP software (version 0.18.3.0), and the R software (version 4.5.0).

3. Presentation and Discussion of Results

3.1. Soil pH (pH-H_2O)

As illustrated in Table 1, the variation in soil pH (pH- (H_2O) is presented as a function of the investigated land-use types and soil depth intervals. The objective of this analysis is to emphasise both spatial and vertical disparities in soil reaction within the designated study area. This is done to evaluate their ramifications for soil chemical fertility and the implementation of sustainable land management practices.

Table 1: The variation of soil pH (pH-(H_2O) is examined according to land-use type and soil depth (0-10, 10-20, and 20-30 cm)

Legend: T_0: Control (never cultivated with tobacco); T_1: Previously cultivated with tobacco; T_2: Site where tobacco has been replaced by other crops; T_3: At present, the cultivation of this species is for the purpose of producing tobacco (Nicotiana tabacum).

Land-use types / Soil depth (cm)	Ndo Okebu (T_0)	Zaki (T_1)	Kaliko Omi (T_2)	Kakwa (T_3)	p-value
0-10	6.12	6.50	5.65	5.883	0.0187*
10-20	6.08	6.44	6.17	5.547	
20-30	5.97	6.55	5.39	5.463	
Mean	6.05	6.50	5.74	5.630	–
Standard deviation	0.14	0.22	0.46	0.290	–
CV (%)	2.27	3.63	7.79	5.173	–
p-value (depth effect)	0.901	0.837	0.309	0.929	

The analysis of soil pH (pH-H2O) at depths of 0-10, 10-20, and 20-30 cm, presented according to land-use categories (Ndo Okebu T_0, Zaki T_1, Kaliko Omi T_2, and Kakwa T_3, indicates that the studied soils are generally slightly to moderately acidic. The mean values obtained were 6.05 for Ndo Okebu, 6.50 for Zaki, 5.74 for Kaliko Omi, and 5.63 for Kakwa. The vertical variability was minimal in Ndo Okebu (CV = 2.27%) and Zaki (CV = 3.63%), indicative of optimal homogeneity of soil pH throughout the profile. In contrast, Kaliko Omi exhibited greater variability (CV = 7.79%), with a decrease in pH to 5.39 at 20-30 cm, suggesting slight subsoil acidification. Kakwa exhibited intermediate variability (CV = 5.17%), with pH values decreasing from 5.883 (0-10 cm) to 5.463 (20-30 cm), which also indicated a tendency towards subsurface acidification.

3.2. Soil pH (pH-KCl)

The potential soil reaction, as determined by measuring pH-KCl, is an essential indicator of exchangeable acidity and the degree of saturation of the exchange complex with acidic cations. The evaluation of this parameter provides insight into soil acidity intensity beyond the current (active) reaction measured in water [7,21].

Table 2: Variation of soil pH (pH-KCl) according to land-use type and soil depth (0-10, 10-20, and 20-30 cm)

Legend: T_0: Control (never cultivated with tobacco), T_1: Formerly cultivated with tobacco T_2: Tobacco replaced by other crops, T_3: Currently cultivated with tobacco (*Nicotiana tabacum*).

Soil depth (cm)	Ndo Okebu (T_0)	Zaki (T_1)	Kaliko Omi (T_2)	Kakwa (T_3)	p-value
0-10	4.91	4.82	4.67	4.51	0.122
10-20	4.23	4.57	4.20	4.56	
20-30	4.62	4.53	4.10	4.32	
Mean	4.59	4.64	4.32	4.47	–
Standard deviation	0.36	0.17	0.31	0.17	–
CV (%)	7.62	3.70	6.91	3.81	–
p-value (depth effect)	0.346	0.584	0.293	0.422	

The pH-KCl values ranged from 4.10 to 4.91 across the various land-use types and soil depths, indicating that the soils are moderately to strongly acidic when exchangeable acidity is considered. The mean pH-KCl values were 4.59 for Ndo Okebu (T0), 4.64 for Zaki (T1), 4.32 for Kaliko Omi (T2), and 4.47 for Kakwa (T3). These values are systematically lower than those obtained in water (pH-H2O), reflecting the presence of exchangeable acidic cations (H+ and Al3+) on the soil exchange complex. The vertical variability was comparatively minimal in Zaki (CV = 3.70%) and Kakwa (CV = 3.81%), indicating a relatively uniform distribution of exchangeable acidity throughout the profile. In contrast, Ndo Okebu (CV = 7.62%) and Kaliko Omi (CV = 6.91%) exhibited slightly greater variability, particularly in the 10-20 cm and 20-30 cm layers, indicating localized differences in acidification processes within the subsoil. The absence of statistically significant differences among depths ($p > 0.05$) suggests that exchangeable acidity remains relatively stable throughout the upper 30 cm of the soil profile, regardless of land-use type.

Across all land-use types, pH-KCl values were consistently lower than pH-H2O values, resulting in negative ΔpH values ranging from 1.16 (Kakwa, T3) to 1.86 (Zaki, T1). This systematic difference indicates a predominance of negative charges on soil colloids and confirms the presence of appreciable exchangeable acidity within the exchange complex. The highest observed ΔpH in Zaki indicates higher reserve acidity, which may be associated with prior tobacco cultivation and resulting base cation depletion through nutrient uptake and leaching. The marked contrast between active acidity (pH-H2O) and potential acidity (pH-KCl) therefore highlights a substantial pool of exchangeable acidic cations, which may increase the risk of aluminium toxicity and limit nutrient availability under continued intensive cultivation without appropriate liming or soil amendments. The analysis of the ΔpH demonstrates that land use has a significant impact on both the current soil reaction and reserve acidity. This has important implications for the management of soil fertility in a sustainable manner.

3.3. Influence of Land-Use Type on Exchangeable Bases (Ca^{2+}, Mg^{2+}, K^+, Na^+)

Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) play a fundamental role in plant mineral nutrition and in maintaining soil structural stability. The distribution of these features can be understood as a reflection of the combined influence of parent material, pedogenetic processes, and agricultural practices. As illustrated in Table 3, the distribution of major exchangeable cations is presented according to land use type and soil depth intervals. This highlights the spatial and vertical variations observed in the study area.

Table 3: Distribution of exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and their sum according to land-use type and soil depth (cmol (+) kg^{-1})

Land-use type	Soil depth (cm)	Ca^{2+}	Mg^{2+}	K^+	Na^+	Σ Bases
T_0 (Ndo Okebu, Control)	0-10	3.82	5.49	8.03	1.79	19.13
	10-20	7.69	5.64	1.69	2.12	17.13
	20-30	6.63	9.49	2.65	1.80	20.56
T_1 (Zaki, Former tobacco)	0-10	11.66	9.69	2.14	2.06	25.55
	10-20	4.63	7.50	1.99	1.90	16.02
	20-30	5.85	13.04	3.51	1.84	24.24
T_2 (Kaliko Omi, Converted crops)	0-10	9.06	11.27	6.44	2.17	28.93
	10-20	9.32	9.53	2.34	1.98	23.17
	20-30	3.91	10.56	1.89	1.89	18.24
T_3 (Kakwa, Current tobacco)	0-10	7.47	11.46	5.98	2.14	27.04
	10-20	8.19	12.96	1.33	1.86	24.34
	20-30	5.75	14.48	1.46	1.96	23.64

The analysis of exchangeable cation distribution (Ca^{2+}, Mg^{2+}, K^+, and Na^+) indicates that magnesium (Mg^{2+}) is generally the dominant ion in most soil pits, particularly in the deeper horizons of Kakwa S2 (20.96 cmol (+) kg^{-1}), Kakwa (14.48 cmol (+) kg^{-1}), and Kakwa S1 (14.82 cmol (+) kg^{-1}). Calcium (Ca^{2+}) demonstrates comparatively elevated surface concentrations at specific locations, including Zaki (11.66 cmol (+) kg^{-1}) and Kaliko Omie (9.06-9.32 cmol (+) kg^{-1}). Nevertheless, its vertical distribution remains irregular, indicating processes of leaching or redistribution within the soil profile. Potassium (K^+) has been observed to exhibit surface accumulation, particularly at Ndo Okebu (8.03 cmol (+) kg^{-1}) and Kakwa S1 (7.31 cmol (+) kg^{-1}), followed by a decline with depth, suggesting its relative mobility and plant uptake. Sodium (Na^+) remains quantitatively low and relatively stable across all soil pits (approximately 1.79-2.17 cmol (+) kg^{-1}), indicating the absence of sodicity constraints.

This ionic dynamic is reflected in the sum of exchangeable bases (S), which ranges from 12.06 to 34.68 cmol (+) kg^{-1}, depending on site and depth. The elevated values recorded at Kaliko Omie (28.93 cmol (+) kg-1 at the surface) and at Kakwa (approximately 24-27 cmol (+) kg-1) indicate a substantial and relatively homogeneous base reserve. In the Zaki region, the sum of bases exhibits fluctuations (16.02-25.55 cmol (+) kg^{-1}), indicating a depleted intermediate horizon. The Kakwa S2 profile is distinguished by a very low surface value (12.06 cmol (+) kg-1) and marked accumulation at depth (34.68 cmol (+) kg-1). These characteristics are indicative of vertical cation migration or the influence of parent material. At Ndo Okebu, values remain moderate (17.13-20.56 cmol (+) kg-1), indicating moderate and relatively stable chemical fertility.The findings of this study demonstrate that the dominance of Mg^{2+} and the variability of Ca^{2+} and K^+ exert a direct influence on both the magnitude and vertical distribution of the sum of bases. Despite the presence of satisfactory base reserves in several sites, the observed imbalances in cation ratios, particularly Ca/Mg, and the pronounced vertical variations in certain profiles underscore the necessity of integrated soil fertility management.

3.4. Cation Exchange Capacity (CEC) as Influenced by Land-Use Type

As illustrated in Table 4, the mean CEC values were measured in the various soil profiles that were studied, with the measurements being taken according to depth and chiefdom (study sites). This analysis provides insight into the spatial and vertical variability of nutrient retention capacity and allows for the assessment of its potential implications for soil fertility and local agricultural productivity.

Table 4: Distribution of cation exchange capacity (CEC) according to land-use type and soil depth (cmol (+) kg^{-1})

Legend: T_0: Control (never cultivated with tobacco), T_1: Formerly cultivated with tobacco T_2: Tobacco replaced by other crops, T_3: Currently cultivated with tobacco (*Nicotiana tabacum*).

Soil depth (cm)	Ndo Okebu (T_0)	Zaki (T_1)	Kaliko Omi (T_2)	Kakwa (T_3)
0-10	3.83	1.00	1.54	1.89
10-20	3.38	1.62	1.59	1.99
20-30	2.82	2.08	1.93	1.89
Mean	3.34	1.57	1.68	1.92
Standard deviation	1.17	0.64	0.54	0.99
CV (%)	35.40	42.78	31.43	52.31

The results presented in Table 4 highlight both vertical and spatial variations of the analysed parameter across the different chiefdoms. At Ndo Okebu, a progressive decrease in CEC values with depth is observed, from 3.83 cmol (+) kg^{-1} at 0-10 cm to 2.82 cmol (+) kg^{-1} at 20-30 cm, indicating a greater concentration in the surface horizon. In contrast, the chiefdoms of Zaki, Kaliko Omi, and Kakwa demonstrate less pronounced depth-related variations, suggesting a relatively homogeneous distribution within the studied soil profile. The mean values demonstrate significant inter-site variation, with Ndo Okebu exhibiting the highest CEC (3.34 cmol (+) kg^{-1}), followed by Kakwa (1.92 cmol (+) kg^{-1}), Kaliko Omi (1.68 cmol (+) kg^{-1}), and Zaki (1.57 cmol (+) kg^{-1}).

The dispersion indicators indicate a degree of variability that can be categorised as moderate to high, with the specific value varying according to the geographical location. The standard deviation ranges from 0.54 to 1.17, while the coefficient of variation varies between 31.43% and 52.31%, with the highest heterogeneity observed at Kakwa. These findings reflect considerable pedological variability both vertically and between chiefdoms, suggesting the influence of local factors likely affecting the distribution of the studied parameter.

4. Discussion

The findings in the Aru territory are consistent with earlier research conducted on tropical soils subjected to agricultural intensification systems. The predominantly sandy texture observed across all land-use types constitutes a key factor influencing soil functioning. In their 2016 study, it was reported that sandy soils are characterised by low specific surface area and reduced cation exchange capacity (CEC), which limits their ability to retain essential nutrients [2]. The low CEC values recorded in the present study (1.57-3.34 cmol (+) kg^{-1}) confirm this structural constraint and are consistent with the findings on highly weathered tropical soils, where the dominance of low-activity clay minerals results in limited base retention capacity [22].

These characteristics suggest that the soils of the study area possess low buffering capacity and reduced resilience to nutrient depletion under continuous cultivation. In such systems, nutrient losses through leaching may be significant, particularly under high rainfall conditions typical of tropical environments [30]. Consequently, sustainable fertility management strategies such as organic matter incorporation, liming where necessary, and balanced fertilization are essential to maintain productivity and prevent further chemical degradation of the soils.

With respect to the chemical reaction of the soil, the pH values measured in water (5,63-6,50) and in KCl (4.32-4.64) categorise the studied soils as moderately acidic, a condition that is characteristic of tropical environments subjected to intense leaching [21]. The absence of marked significant differences among land use types suggests that tobacco cultivation has not yet induced pronounced soil acidification. This observation stands in partial contrast to findings reporting progressive soil acidification under specialized tobacco-based systems in southern Africa, primarily associated with intensive nitrogen fertilizer application [19,18]. The observed discrepancy may be attributed to variations in cultivation duration, fertilization intensity, or local edaphoclimatic conditions. Nevertheless, repeated use of nitrogen fertilisers in soils with low CEC may, over the medium term, accelerate acidification processes [11,12]. This suggests a potential long-term risk if current management practices are maintained without appropriate corrective measures.

The distribution of exchangeable bases is indicative of the dominance of magnesium, as well as of vertical variability of calcium and potassium. This pattern is consistent with findings demonstrating that in tropical soils with variable charge, cation distribution is strongly influenced by soil pH and leaching processes [25]. The surface accumulation of potassium, as evidenced by specific locations, can be ascribed to recent fertiliser inputs and differential crop uptake. Furthermore, the vertical fluctuations of calcium suggest downward migration processes, which are particularly likely in coarse-textured soils. These observations are in agreement with analyses reporting the relative mobility of base cations in leached tropical environments [23].

The sum of exchangeable bases remains globally satisfactory in several profiles, indicating that the basic reserve has not yet been severely depleted. However, intensification systems relying primarily on mineral fertilisers show that base stability is contingent on the soil's capacity to retain cations and on the integration of organic inputs [27]. The present study posits that the low CEC suggests that this reserve may be unstable in the long term in the absence of integrated soil fertility management practices.

A comparison of the results with those obtained in other tropical regions suggests that the chemical fertility status of the region is still functional but structurally fragile. It has been demonstrated in the Democratic Republic of Congo that soil fertility dynamics are contingent on interactions among climate, vegetation, and management practices [16,17]. In the case of Aru, the relative homogeneity of parameters across land-use types suggests that inherent edaphic characteristics play a predominant role, while the specific impact of tobacco cultivation remains moderate at this stage.

In comparison with similar studies carried out in southern and central Africa, the present findings confirm that soils under tobacco cultivation may temporarily maintain an acceptable chemical balance. However, this equilibrium remains constrained by low nutrient retention capacity and moderate acidity. These observations are consistent with conclusions emphasising that soil fertility should be approached from a dynamic perspective integrating not only chemical parameters but also the system's capacity to withstand intensification pressures [3].

5. Conclusion and Recommandations

The present study set out to assess the influence of land use, particularly tobacco cultivation, on selected physico-chemical soil fertility parameters in the Aru territory.

The results indicate that the studied soils are generally slightly to moderately acidic, with relative pH stability across depths and land-use types. The potential acidity (pH-KCl) exhibited no significant disparities among the various land uses, indicating that tobacco cultivation has not yet resulted in substantial chemical modification of the soil exchange complex. Exchangeable bases revealed a dominance of magnesium and vertical variations in calcium and potassium, reflecting redistribution dynamics rather than direct effects of land use. The cation exchange capacity (CEC) was found to be low to moderate, thereby confirming a limited nutrient retention capacity.

In conclusion, the influence of tobacco land usage on the chemical parameters examined appears to be insignificant within the temporal and spatial framework that has been established. The soil fertility remains functionally adequate; however, signs of structural fragility are evident, particularly due to low cation exchange capacity (CEC) and moderate acidity.

It is therefore recommended to promote integrated soil fertility management combining organic and mineral inputs, to encourage regular soil testing in order to optimize fertilizer application rates, and to establish long-term monitoring programs to detect potential future changes. Such an approach would assist in the preservation of soil productive capacity whilst ensuring the sustainability of cropping systems in the Aru territory.

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