FORMS AND DISTRIBUTION OF POTASSIUM IN SOILS PLANTED WITH PLANTAIN (*MUSA SPP.)* IN UNIVERSITY OF BENIN, NIGERIA.

BY

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DEDICATION

I dedicate this project to God Almighty, whose grace, wisdom, and strength have guided me through every stage of this academic journey. Without His divine help, this accomplishment would not have been possible.

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TABLE OF CONTENTS

PAGE

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLES

TABLES TITLE PAGES

LIST OF ABBREVIATIONS

ABBREVIATIONS	INTERPRETATION
cmol/kg	Centimole per Kilogram
mg/kg	Miliigram per kilogram
K	Potassium
P	Phosphorus
Ca	Calcium
Mg	Magnesium
g/kg	Gram per kilogram
cm	Centimetre
NH_4OA_c	Ammonium acetate
g	Gram

ABSTRACT

Different forms of Potassium (K) could exist in soils, contributing to total K pool. The study aims at evaluating the forms and distribution of K in soils planted to plantain in University of Benin, Nigeria. Soil samples were collected in April, 2025, from four (0 - 30, 30- 60, 60 - 90 and 90 - 120 cm) depths in three replicates, making a total of 12 samples, the samples were air-dried, crushed, passed through 2 mm sieve and analyzed for some chemical and physical properties, using standard operating methods. Water soluble, exchangeable, difficultly exchangeable, fixed and total K forms, were determined in 1:10 soil:xtractants ratio diluted to 25 ml volume, while the relationship between some physical and chemical properties and forms of K were determined using simple linear correlation. The result showed that sand was the dominant soil separate with grand mean values of 71.37%, while the pH (H_2O) showed slightly acidic soil reaction, and ranged between 5.00 - 5.15 with grand mean value of 5.06. The water soluble and exchangeable K were very low and ranged between 0.01 - 0. 03 and 0.01 - 0.05 cmol/kg with grand mean value of 0.02 and 0.03 cmol/kg respectively. Highest value of 0.10 cmol/kg at 30 - 60 cm soil depth and 0.07 cmol/kg at 60 - 90 cm soil depth with a grand mean values of 0.06 and 0.08 cmol/kg was obtained for difficultly exchangeable K and fixed form of K, respectively. Positively and negatively significant relationships was obtained between some soil physical and chemical properties, and different forms of K, indicating the influence of soil properties on forms, distribution and availability of K. Water soluble and exchangeable forms of K were very low in the soils studied

INTRODUCTION

1.0 CHAPTER ONE

Potassium (K), an essential macronutrient for plant growth, cycles through four interconnected pools in soils: soluble potassium (freely dissolved K^+ ions), exchangeable potassium (electrostatically adsorbed to soil colloids), non-exchangeable potassium (fixed in clay interlayers), and structural potassium (embedded in primary minerals). These pools exhibit distinct biogeochemical behaviors, with structural potassium constituting over 90% of total reserves yet largely inert on agronomic timescales. Soluble potassium, while immediately plant-available, is highly vulnerable to leaching in sandy soils, whereas exchangeable potassium serves as a rapid-reserve reservoir replenishing soluble pools via cation exchange (Mujalde *et al.*, 2023). The distribution of potassium pools is primarily governed by soil parent material. Igneous or metamorphic rocks like shale yield soils with abundant structural potassium (15,000–35,000 ppm), while sandstone-derived soils retain minimal reserves. Clay mineralogy further modulates K dynamics: 2:1 clays (e.g., vermiculite) fix potassium during dry periods, whereas 1:1 clays (e.g., kaolinite) exacerbate leaching. Climate imposes additional constraints—high rainfall accelerates leaching in sandy soils but enhances mineral weathering in clays. Topography drives spatial redistribution, with erosion depleting uplands and enriching lowlands with potassium-bearing sediments. Land management dramatically stratifies distribution; no-till systems concentrate over 75% of exchangeable potassium in the top 0–5 cm, limiting subsoil accessibility for deep-rooted crops (Bell *et al.,* 2022).

Bioavailability hinges on equilibria between pools, mediated by soil pH and organic inputs. Acidic conditions enhance mineral dissolution but increase leaching, while alkaline soils promote fixation. Organic amendments like biochar expand cation exchange capacity, elevating exchangeable potassium by up to 58% (Liu *et al.*, 2023). Deficiency manifests as marginal chlorosis, necrotic spotting, and weak stalks when exchangeable potassium drops below critical thresholds (e.g., <64 mg kg^{-1} for soybeans), depressing yields by 8–20% (Liu, *et al.,* 2023). Several studies have accessed K availability and availability and dynamics in soils (Efenudu and Egharevba, 2024). However, there is limited information on forms and distribution of K in agronomic soils, planted to plantain within university of Benin. Hence this study.

1.1 Objectives of the study

The broad objective of the study was to determine forms and distribution of potassium in soils planted to plantain (*musa spp.)* in University of Benin, Nigeria. While specific objectives were to evaluate:

1. some physical and chemical properties of the soil
2. the forms and distribution of potassium in the soil
3. the relationship between some soil properties and forms of K in the soil

CHAPTER TWO

LITERATURE REVIEW

2.1 Potassium as an Element

Potassium (atomic number 19, symbol K) is a soft, silvery-white alkali metal characterized by extreme reactivity. (Haynes *et al.,* 2016) First isolated in 1807 by Sir Humphry Davy through electrolysis of potash (KOH), its name derives from "potash" (historically produced by soaking plant ashes in pots), while the chemical symbol "K" originates from kalium, the German term for alkali (Emsley, 2020). Possessing a single valence electron ([Ar] $4s^1$), potassium readily forms K^+ ions, exhibiting vigorous reactions: it ignites explosively in water to produce hydrogen gas and potassium hydroxide (KOH), and rapidly tarnishes in air, forming potassium peroxide (K_2O_2) and superoxide (KO_2) (Haynes *et al.,* 2016). Biologically, potassium is indispensable for nerve impulse transmission, muscle contraction, and cellular osmotic balance, regulated by the Na^+/K^+-ATPase pump. Industrially, over 90% of potassium compounds support agriculture as fertilizers (e.g., KCl, K_2SO_4), with niche applications including potassium nitrate (KNO_3) in gunpowder and liquid NaK alloy as a heat-transfer fluid (Zhang *et al.,* 2020).

2.2 Potassium in Soils

Potassium, an essential macronutrient for plant growth, exhibits complex dynamics within the soil system, existing in several distinct forms that vary significantly in their availability to plants. The most readily accessible form is dissolved potassium ions (K^+) present in the soil solution, though this pool typically constitutes less than 0.1% of the total soil potassium and is highly susceptible to leaching losses, particularly in sandy soils (Anderson *et. al.,* 2023). A larger and more significant reservoir for plant uptake is the exchangeable potassium pool, where K^+ ions are held by electrostatic attraction to negatively charged sites on clay minerals and organic matter; this pool, typically making up around 2% of total soil potassium, is in rapid equilibrium with the soil solution and is measured by standard soil tests (Sparks, 2015). A substantial portion of soil potassium, approximately 8%, is classified as fixed or non-exchangeable potassium. This potassium is trapped within the interlayer spaces of specific 2:1 clay minerals, such as illite and vermiculite, and can be slowly released into more available forms, particularly when soil solution concentrations are depleted by plant uptake or when root activity or microbial processes alter the local environment (Boostani *et al.*, 2024). The dominant form, comprising 90-98% of total soil potassium, is structural potassium. This potassium is locked within the crystal lattices of primary minerals like feldspars and micas, becoming available only over very long timescales through weathering processes and thus being essentially unavailable for practical agricultural purposes within typical crop cycles (Sparks, 2015).

The behavior and availability of potassium in soil are governed by dynamic equilibria between these pools and are strongly influenced by inherent soil properties. Clay mineralogy is paramount: soils rich in 2:1 phyllosilicate clays (e.g., vermiculite, illite, smectite) possess a high capacity to fix potassium into non-exchangeable forms, acting as both a reserve and a potential sink for applied fertilizer potassium. Conversely, soils dominated by 1:1 clays (like kaolinite) or oxides have much lower fixing capacities but also lower inherent reserves of slowly available potassium (Sparks, 2015). Other factors influencing potassium dynamics include soil pH, which affects fixation and release rates as well as potential cation competition (e.g., aluminum in acidic soils), soil moisture cycles (where wetting and drying can promote fixation), and the presence of competing cations like calcium, magnesium, and ammonium which can affect both adsorption and plant uptake (Sparks, 2015). Organic matter contributes positively by increasing CEC and thus the retention of exchangeable potassium, and also releases potassium upon decomposition (Anderson, 2023).

Effective management of soil potassium necessitates understanding these dynamics. Regular soil testing for exchangeable potassium is fundamental for determining fertilization needs, with critical thresholds varying by crop and soil type; for instance, long-term Chinese experiments indicate critical levels of approximately 159 mg kg^{-1} for wheat, 149 mg kg^{-1} for maize, and 94 mg kg^{-1} for rice (Chen *et al*., 2025). While potassium leaching is generally low in medium-to-fine-textured soils, it can be significant in sandy soils or under specific conditions like heavy rainfall on frozen or waterlogged ground. Plants may also exhibit luxury consumption, absorbing potassium beyond immediate needs when soil levels are high, leading to inefficient fertilizer. Crucially, excessive potassium application can be detrimental. Research from long-term Chinese field experiments demonstrates that over-application, particularly in soils already rich in potassium, can suppress yields in crops like wheat, likely due to induced nutrient imbalances such as magnesium or calcium deficiency (Chen *et al.,* 2025). Furthermore, high potassium levels, especially when applied as chloride salts, can reduce soil organic carbon, microbial biomass, and the abundance of beneficial soil bacteria and fungi, while also increasing salinity and chloride uptake in sensitive crops like pineapple (Chen *et al*., 2025). Conversely, optimal potassium nutrition strengthens plant cell walls, improves overall vigor and stress tolerance, and enhances resistance to diseases, as demonstrated in peppers where adequate potassium significantly increased resistance to *Rhizoctonia solani* root rot (Yilmaz *et al.,* 2025). Therefore, balanced potassium management, guided by soil testing and an understanding of soil-specific behavior, is essential for optimizing crop productivity, quality, and plant health while preserving long-term soil fertility and biological function.

2.3 The Potassium Cycle in Terrestrial Ecosystems

The potassium cycle represents a fundamental biogeochemical process as shown in Figure 1, yet it is often overshadowed by the cycles of nitrogen and phosphorus. Unlike these elements, potassium does not form stable organic compounds; its cycle is predominantly geochemical and biological, driven by the weathering of primary minerals, its uptake by plants, and its return to the soil system through residue decomposition and leaching losses (Sparks, 2015). The cycle begins with the slow geogenic release of structural potassium from minerals such as K-feldspars and micas. This process, accelerated by carbonic and organic acids in the soil solution, liberates K^+ ions into the ecosystem (Zorb *et al*., 2014).

Following release, potassium enters a dynamic equilibrium between soil solution, exchange sites and fixed pools, a flux mediated by soil properties, climate and biological activity. Plant uptake represents a key biological driver, with roots absorbing solution K^+ and potentially stimulating the release of non-exchangeable pools through rhizosphere acidification (Romheld *et al*., 2010). The cycle is completed through the return of potassium in plant litter, which upon mineralization by soil microbes, returns K^+ to the soil solution, making it available for renewed uptake. However, the cycle can be disrupted by agricultural harvesting, which removes potassium from the system, and by leaching, particularly in sandy, low-CEC soils, leading to a gradual depletion of reserves if not managed by fertilization (Zhang *et al*., 2025).

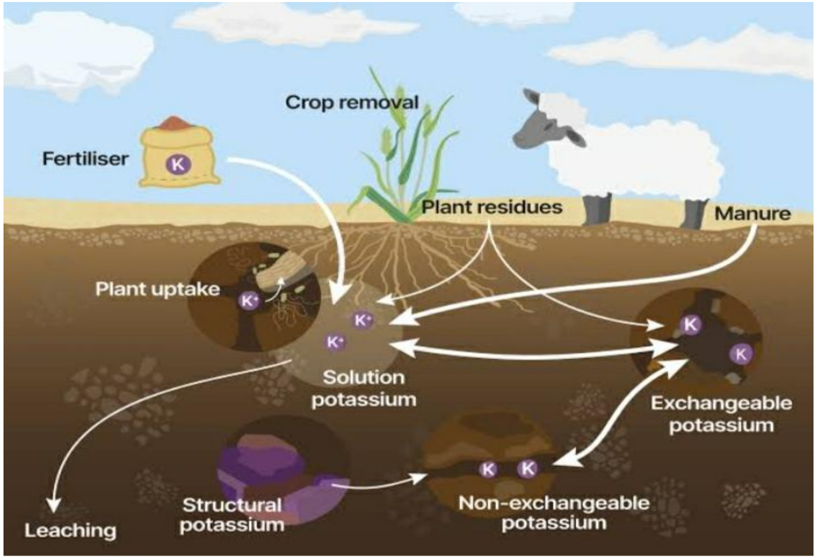

Figure 1: Potassium cycle in farming systems.

Source: Scanlan *et al.* (2023).

2.4 Forms of Potassium in Soils: Bioavailability and Dynamics

Potassium exists in four distinct yet interconnected forms within soils, each governing specific aspects of nutrient availability.

2.4.1 Soluble Potassium (Water soluble K)

Soluble potassium (Water soluble K) comprises freely dissolved K^+ ions in soil water, representing the most immediately plant-accessible form. Concentrations typically range from 1–20 mg/kg but fluctuate dramatically under environmental stresses. For instance, flooding elevates Water-soluble K by 15–30% in clay soils through reductive dissolution of iron/manganese oxides, which displaces adsorbed K^+ ions. Conversely, sandy soils experience rapid leaching during high rainfall events. Plants directly absorb Water-soluble K to regulate stomatal function and enzymatic processes, with tomato cultivation studies confirming its critical role in enhancing fruit sugars and citric acid content. Effective management requires vigilant monitoring since deficiencies below 64 mg/kg trigger leaf scorch in soybeans, while excess accumulation may induce magnesium antagonism (Wu *et al.*, 2023).

2.4.2 Exchangeable Potassium

Exchangeable potassium consists of K^+ ions electrostatically bound to negatively charged sites on clay minerals, organic matter, or oxides. This pool serves as a dynamic reservoir, replenishing soluble K through reversible cation exchange reactions. Concentrations vary significantly by soil texture: clay-rich Vertisols retain 200–450 mg/kg exchangeable potassium, while sandy soils hold merely 35–50 mg/kg. Environmental stressors like drought or high calcium content promote fixation of exchangeable K into non-available forms within clay interlayers. However, amendments such as biochar can increase exchangeable Potassium by 58% by enhancing cation exchange capacity and moderating pH. Strategic banding of fertilizers near root zones optimizes exchangeable K accessibility, boosting soybean yields by 12–18% compared to broadcast applications (Liu *et al.,* 2024).

2.4.3 Non-exchangeable Potassium

Non-exchangeable potassium is trapped within the interlayers of 2:1 clay minerals like illite, releasing ions slowly (0.3–1.2 mg kg^{-1} day^{-1}) through mineral weathering or root-induced chemical changes. Microbial activity, particularly from potassium-solubilizing bacteria, accelerates this process by exuding organic acids that liberate K^+. In the clay-rich soils of Uttar Pradesh, non-exchangeable K supplies 25–40% of maize potassium uptake, reducing dependence on synthetic fertilizers. Acidic conditions enhance non-exchangeable K release, while calcareous soils immobilize it due to calcium dominance. Farmers leverage this pool by integrating crop residues to stimulate microbial activity, allowing fertilizer reductions of 30% in illite-dominated soils (Yadav *et al.,* 2023).

2.4.4 Structural Potassium

Structural potassium, embedded in primary minerals like feldspars and micas, constitutes 90–98% of total soil potassium but remains largely inert on agronomic timescales. Its release depends on geological weathering processes, with minerals like orthoclase feldspar dissolving at rates below 0.1 kg ha^{-1} yr^{-1}. Young soils derived from shale (e.g., Iran’s floodplains) contain up to 35,000 ppm structural K, whereas highly weathered tropical soils retain minimal amounts due to leaching. Though inaccessible for direct plant uptake, preserving structural K through erosion control measures (e.g., contour terracing) sustains long-term soil fertility (Mohammadi *et al.,* 2022).

The interdependence of these pools dictates potassium availability: soluble K provides immediate nutrition, exchangeable K buffers short-term fluctuations, non-exchangeable K acts as a medium-term reserve, and structural K anchors long-term geogenic reserves. Sustainable management strategies—including pH moderation, organic amendments, residue recycling, and precision placement—optimize equilibria between these pools while addressing soil-specific constraints like leaching in sands or fixation in clays (Zhang *et al.*, 2025)

2.5 Potassium Distribution in Soil Profiles

The vertical distribution of potassium within soil profiles is inherently stratified, shaped by natural pedogenic processes and significantly modified by human management. In undisturbed ecosystems, potassium accumulates predominantly in surface horizons (0–30 cm) due to organic matter cycling and mineral weathering,s while soluble K^+ ions gradually leach to deeper layers in humid regions under the influence of percolating water. Agricultural practices dramatically disrupt this natural stratification, creating distinct distribution patterns based on management systems.

No-till systems concentrate over 75% of exchangeable potassium in the top 0–5 cm layer, as broadcast fertilizers remain near the surface without mechanical incorporation. While this creates a nutrient-dense zone beneficial for seedling establishment, it restricts subsoil accessibility for deep-rooted crops. Conversely, conventional tillage initially homogenizes potassium distribution through plowing but accelerates leaching in sandy soils, depleting root-zone reserves within a single growing season (Robert William *et al.,* 2024).

Root architecture critically regulates vertical potassium accessibility. Deep-rooted crops like alfalfa mine subsoil reserves beyond 1 meter depth, while shallow-rooted cereals such as wheat depend primarily on topsoil potassium. In Brazilian Cerrado soybean systems, 15–25% of total potassium uptake originates below 40 cm depth, demonstrating the significance of subsoil reserves (Oliveira *et al.,* 2021). Vertical availability is further modulated by subsurface geochemical gradients: high-activity clays (e.g., smectite) in subsoil horizons fix potassium ions, reducing bioavailability, while acidic subsoils (pH <5.5) enhance mineral dissolution but increase leaching potential (Zilberman *et al.,* 2024). Hydrological processes impose additional constraints—heavy rainfall leaches soluble potassium to depths exceeding 50 cm in sandy soils, whereas capillary action in arid zones transports K^+ upward, causing surface salinization (Mohammadi *et al.,* 2022).

Strategic management counteracts these distribution challenges. Subsurface banding of fertilizers at 10–20 cm depth in no-till systems improves maize potassium accessibility by 20%, effectively mitigating topsoil stratification limitations. Organic amendments like deep-injected compost enhance subsoil potassium retention by 30% in orchards through the formation of clay-organic complexes that reduce leaching (Yadav *et al.,* 2023). Depth-specific approaches optimize this vertical trade-off: banding starter potassium in the 0–10 cm zone supports seedling establishment where soluble and exchangeable forms dominate; deep-banding (10–40 cm) targets perennial crops accessing non-exchangeable reserves; and below 40 cm, structural potassium reserves are best leveraged through deep-rooted cover crops that prevent erosion while recycling nutrients.

This vertical stratification represents a functional compromise—surface concentration facilitates germination and early growth, while subsoil reserves buffer against seasonal deficits. Sustainable potassium management thus requires diagnostic assessment of depth-specific availability and tailored interventions that align with crop rooting patterns, hydrological regimes, and inherent soil properties.

2.6 Factors Influencing Potassium Availability in Soils

Potassium availability in soils is governed by a complex interplay of inherent soil properties, environmental conditions, and management practices. The geological foundation of potassium reserves originates from parent materials, where primary minerals such as feldspars and micas contain over 90% of soil potassium in structurally inaccessible forms.

2.6.1 Soil Texture and Mineralogy

Soil texture and mineralogy critically determine potassium retention and release mechsanisms. Sandy soils with low clay content (<10%) exhibit minimal cation exchange capacity (CEC), resulting in high susceptibility to leaching losses under precipitation. Conversely, clay-rich soils—particularly those dominated by 2:1 lattice minerals like montmorillonite, illite, or vermiculite—fix potassium within interlayer spaces through a process exacerbated by drying cycles. For example, montmorillonite clays temporarily trap potassium during dry periods but release it upon rewetting, while illite clays exhibit irreversible fixation that permanently reduces availability. Kaolinitic clays, though less retentive, offer limited potassium buffering capacity. The dynamic equilibrium between solution potassium, exchangeable potassium, and fixed potassium governs real-time plant accessibility.

2.6.2 Climate and Hydrological Conditions

Climate and hydrological conditions modulate potassium mobility across landscapes. Regions receiving substantial rainfall (>900 mm annually) accelerate potassium leaching in sandy substrates, depleting root-zone reserves. Arid regions, however, experience upward capillary movement of potassium during evaporation cycles, leading to surface accumulation and potential salinization. Soil moisture fluctuations also influence fixation-release dynamics in expanding-lattice clays, while waterlogged conditions reduce root oxygen supply and impair potassium uptake efficiency. Optimal soil moisture balances potassium diffusion to roots without inducing anaerobic stress (Passel, 2023). Temperature further regulates availability, with potassium uptake peaking between 15°C–27°C as root activity and microbial mineralization intensify. Cold soils (<10°C) suppress these processes, restricting access even when soil reserves are adequate.

2.6.3 Soil chemical properties

Soil chemical properties significantly alter potassium dynamics. Acidic soils (pH <5.5) promote aluminum and manganese toxicity that damages root membranes and impedes potassium absorption, while alkaline conditions (pH >7.5) enhance calcium dominance on exchange sites, competitively suppressing potassium availability. Near-neutral pH optimizes potassium retention-exchange balance. Organic matter serves as a vital potassium reservoir—its decomposition releases soluble potassium, while its colloidal surfaces boost CEC and reduce leaching. Amendments like biochar or manure amplify this effect; biochar application increases exchangeable potassium by up to 58% through surface complexation and CEC enhancement (Liu *et al*., 2023).

2.6.4 Agricultural Management

Agricultural management directly reshapes potassium cycling. Tillage systems influence root exploration and potassium distribution; no-till systems concentrate potassium in surface layers (0–5 cm), creating stratified accessibility that limits deep-rooted crop access. Residue removal (e.g., straw export) disrupts nutrient recycling, exporting 45–60 kg K_2O ha^{-1} per harvest and accelerating soil mining. Strategic subsurface banding (10–15 cm depth) of potassium fertilizers like potassium sulfate (K_2SO_4) for chloride-sensitive crops localizes nutrients within root zones, reducing fixation losses by 20% compared to broadcast applications. Organic amendments additionally improve soil structure and water retention, enhancing potassium diffusion to roots under drought stress (Bell *et al.,* 2023).

Diagnostic approaches must evolve beyond conventional exchangeable potassium measurements. The Quantity/Intensity (Q/I) concept evaluates both the intensity (I) of potassium in soil solution and the quantity (Q) of labile potassium, incorporating the soil's buffering capacity. This approach enables customized fertilizer recommendations based on a soil's specific potassium release and fixation characteristics rather than generalized thresholds (Simonsson *et al.,* 2018). Furthermore, near-infrared spectroscopy (NIRS) coupled with machine learning algorithms achieves prediction accuracy (RT=0.882) for soil potassium, reducing error by 19.6% compared to conventional models.

Spatial heterogeneity in potassium availability emerges from the convergence of these factors. Comprehensive soil testing—integrating stratified sampling, exchangeable potassium analysis, and plant tissue monitoring—remains essential for site-specific management. As potassium depletion threatens 20–44% of global agricultural lands, context-sensitive interventions balancing fertilization, residue recycling, and soil health improvement are critical for sustaining crop productivity and resilience.

2.7 Potassium Deficiency in Agricultural Soils and Causes

Potassium deficiency in agricultural soils presents a significant constraint to global crop productivity, manifesting through physiological disruptions and visible symptoms in plants. Initial signs include chlorosis along the margins of older leaves, progressing to necrotic lesions and scorched appearances as deficiency intensifies. These symptoms arise from potassium's mobility within the plant, where it is remobilized to support new growth at the expense of mature tissues. Cereal crops like wheat exhibit weakened stems and lodging due to impaired cellulose synthesis, while fruit crops such as tomatoes develop uneven ripening patterns and reduced brix levels. The physiological basis extends to reduced photosynthetic efficiency and compromised carbohydrate translocation, fundamentally constraining yield potential and crop quality (Wu *et al.* 2023).

2.7.1 Edaphic factors

Edaphic drivers of deficiency are dominated by soil texture and mineralogy. Sandy soils with low clay content (<10%) exhibit minimal cation exchange capacity (CEC), resulting in rapid leaching losses of soluble potassium under high rainfall conditions. This leads to acute deficiency development within 1–2 growth stages, particularly in regions like West Africa. Conversely, clay-rich soils dominated by 2:1 minerals (e.g., montmorillonite, illite) immobilize potassium through fixation in interlayer spaces, creating "hidden hunger" where total soil potassium appears adequate but plant-available fractions remain inaccessible. Calcareous soils further restrict availability through competitive Ca^{2+} saturation of exchange sites (Zilberman *et al*. 2019).

2.7.2 Anthropogenic factors

Anthropogenic factors significantly exacerbate deficiency risks. Imbalanced fertilization regimes emphasizing nitrogen and phosphorus without potassium supplementation actively deplete soil reserves. In Chinese wheat systems, NP-only fertilization reduces exchangeable potassium by 3–5% annually, culminating in yield reductions of 0.55 tonnes per hectare over five years. The removal of crop residues such as rice straw exports 45–60 kg K_2O ha^{-1} of natural recycling potential, accelerating topsoil mining and disrupting nutrient cycles (Zhang *et al.* 2021). Climate interactions intensify these issues, with high rainfall accelerating leaching in sandy soils, while arid conditions promote surface salinization through evaporation-driven potassium concentration (Poozesh *et al.,* 2023).

2.7.3 Diagnostic approaches

Diagnostic approaches must evolve beyond conventional exchangeable potassium measurements. Stratified soil sampling (0–5 cm, 5–20 cm) is critical in no-till systems where >75% of potassium accumulates in surface layers, masking subsoil deficits. The Quantity/Intensity (Q/I) concept provides superior assessment by evaluating both the intensity (I) of potassium in soil solution and the quantity (Q) of labile potassium, incorporating the soil's buffering capacity. This enables customized fertilizer recommendations based on a soil's specific release and fixation characteristics rather than generalized thresholds. Plant tissue analysis remains essential, with critical thresholds such as <1.5% potassium in soybean leaves indicating deficiency (Simonsson *et al.,* 2018).

2.8 Management Strategies

Management strategies require integrated approaches. Biochar application increases exchangeable potassium by up to 58% in acidic soils through cation exchange capacity expansion and intrinsic potassium content. Fertilizer selection must consider crop sensitivity; potassium sulfate (K_2SO_4) is preferred for chloride-sensitive crops (e.g., potatoes, citrus) to avoid salinity stress associated with muriate of potash (KCl). Subsurface banding (10–15 cm depth) localizes potassium within active root zones, reducing fixation losses by approximately 20% compared to surface applications. System-level interventions include residue recycling to close nutrient loops and crop rotations incorporating deep-rooted species that access subsoil reserves. Emerging 4R nutrient stewardship frameworks (right source, rate, time, place) integrate these strategies with digital tools for precision management (Liu *et al.* 2023).

2.9 Consequences of Neglect

Consequences of neglect extend beyond yield reduction. Chronic potassium deficiency diminishes photosynthetic efficiency by 15–40% and compromises plant structural integrity, increasing susceptibility to pathogens like *Helminthosporium* in cereals. Crop quality parameters are significantly impaired; tomatoes exhibit approximately 30% reductions in lycopene content under potassium stress, directly impacting nutritional value and marketability. The economic implications are substantial, with potassium-deficient vineyards producing wines with higher pH, reduced acidity, and compromised phenolic profiles, ultimately diminishing terroir expression (Wu *et al.* 2023).

2.10 Sustainable resolution

Sustainable resolution necessitates international policy coordination focusing on circular economy principles, including potassium recycling from crop residues and livestock manure, alongside enhanced mining waste management. With approximately 20% of global agricultural soils facing severe potassium deficiency—particularly affecting 44% of soils in South-East Asia and 30% in Sub-Saharan Africa—context-sensitive interventions balancing fertilization, residue recycling, and soil health improvement are critical for sustaining crop productivity and resilience (Römheld *et al*., 2010).

2.11 Methods for Determining Potassium Availability in Agricultural Soils

2.11. 1 Chemical extraction methods

Chemical extraction methods form the cornerstone of potassium assessment, with ammonium acetate extraction (1 M NH_4OAc, pH 7) serving as the benchmark technique. This method quantifies exchangeable potassium by displacing K^+ ions from soil colloids with NH_4^+, followed by flame photometry or atomic absorption spectroscopy quantification. While reliable for short-term availability prediction, it underestimates contributions from non-exchangeable pools in illite-rich soils. For acidic tropical soils, the Mehlich-1 extractant (0.05 M HCl + 0.0125 M H_2SO_4) enables multi-nutrient analysis but overestimates availability in calcareous soils due to mineral dissolution. Comparatively, barium chloride extraction (K{$BaCl_2$}) extracts approximately 12.9% more potassium than ammonium acetate due to differences in extraction chemistry (Madaras *et al.,* 2021).

2.11.2 Resin-based Methods

Resin-based approaches simulate root activity to assess long-term potassium release. The cation exchange membrane burial method involves embedding potassium-selective membranes in soil to adsorb K^+ through diffusion-controlled processes, demonstrating strong correlation ($r^2 = 0.94$) with actual plant uptake. Similarly, the sodium tetraphenylboron method extracts non-exchangeable potassium by precipitating K^+ ions, effectively quantifying reserves in soils dominated by fixed potassium pools. These techniques circumvent limitations of chemical extractants by mimicking natural root-soil interactions (Qian *et al.*, 1996).

2.11.3 Plant-based diagnostics

Plant-based diagnostics provide functional validation of soil potassium status. Leaf tissue analysis establishes critical thresholds such as <1.5% potassium in soybean leaves indicating deficiency.

Stem sap testing using portable ion-selective electrodes enables real-time field assessment, with concentrations <1,500 mg L^{-1} triggering corrective fertilization. These physiological metrics integrate soil supply with plant assimilation, overcoming discrepancies caused by fixation or leaching. Visual symptoms—including marginal chlorosis in older leaves and blotchy fruit ripening—offer supplementary diagnostic cues when exchangeable potassium drops below critical thresholds (Zörb *et al.,* 2014).

2.11.4 Advanced Instrumental Techniques

Advanced instrumental techniques enable rapid, non-destructive analysis. Near-infrared spectroscopy coupled with machine learning algorithms achieves high prediction accuracy (RT = 0.882) through spectral variable selection. Laser-induced breakdown spectroscopy combined with cation exchange membranes quantifies available potassium without chemical extractants, achieving detection limits of 2.2 mg kg^{-1} and relative errors below 2.58% within minutes. Synchrotron radiation Fourier-transform infrared spectroscopy maps potassium distribution at micron resolution, identifying microsites of fixation in clay interlayers critical for diagnosing slow-release zones (Fu *et al.,* 2024).

Integrated frameworks provide comprehensive availability assessment. The Quantity/Intensity concept evaluates potassium through two indices: the intensity factor representing K^+ activity in soil solution, and the quantity factor reflecting labile reserves. This approach incorporates soil buffering capacity to customize fertilization strategies. Geostatistical modeling quantifies spatial heterogeneity, revealing anthropogenic influences on potassium distribution patterns across landscapes. Sequential extraction partitions potassium into water-soluble, exchangeable, non-exchangeable, and mineral-structural pools, clarifying dynamic equilibria between reservoirs (Simonsson *et al.,* 2023).

2.11.5 Field-adaptable methods

Field-adaptable methods facilitate on-site decision making. The sodium chloride extraction with portable ion-selective electrodes offers low-cost (<$0.50/sample) assessment with 80–100% agreement to laboratory standards. Stratified soil sampling addresses nutrient stratification in conservation tillage systems, where >75% of surface-applied potassium accumulates in the top 5 cm, potentially masking subsoil depletion. These approaches enable real-time precision management adjustments (Bell *et al.,* 2023).

2.12 Rooting System of Plantain (*Musa* spp.)

The rooting system of plantain (*Musa* spp.) is composed of an adventitious fibrous network originating from the subterranean corm and rhizome rather than from a taproot. Fine roots proliferate in the upper soil horizons where nutrient and moisture availability are highest, and root growth and biomass are sensitive to soil fertility and structure. Studies in southeastern Nigeria indicate that higher fertilizer rates (including potassium) increase root nutrient uptake and improve both root biomass and root recovery efficiency, while poor fertility reduces root extension and functional root zones (Adetoro and Olaniyi, 2025). Root damage from pathogens such as root-knot nematodes has been confirmed in Nigerian plantain fields; species such as *Meloidogyne enterolobii* and *Meloidogyne arenaria* cause substantial galling and deformation of the root system, which reduces absorptive capacity and overall plant performance (Olajide *et al*., 2023).

2.13 Role of Potassium in Plantain Nutrition

Potassium in plantain serves critical physiological roles including regulation of osmotic potential, enzyme activation, stomatal movements, translocation of photoassimilates to developing bunches, and maintenance of turgor required for cell expansion. Because plantain carries heavy bunches, repeatedly produces new leaves, and sheds old leaves, its demand for potassium is high. Empirical trials in Nigeria show that increasing K_2O application from 150 to 400 kg/ha significantly enhances plant height, pseudostem girth, number of functional leaves, and bunch yield in both plant and ratoon crops (Adetoro and Olaniyi, 2025; Shiyam and Bello, 2021).

2.14 Potassium Deficiency in Plantain: Symptoms and Physiological Consequences

When potassium is deficient, plantain exhibits symptoms first on older leaves owing to potassium's mobility; these leaves show marginal chlorosis, progressing to necrosis along the edges and tips, reduced leaf size and fewer functional leaves, stunted pseudostem growth, poor fruit set, lower bunch weight, and delayed flowering. Root growth is also impaired, which further limits nutrient absorption. Physiologically, deficiency disrupts carbohydrate partitioning, reduces phloem loading, impairs stomatal regulation (with consequent reductions in water use efficiency), and increases susceptibility to drought and disease because tissues are weakened (inferred from nutrient uptake studies in Nigerian plantain and physiological studies in Musa more generally) (Adetoro and Olaniyi, 2025; Shiyam and Bello, 2021).

2.15 Causes of Potassium Deficiency in Plantain

Potassium deficiency arises when supply fails to meet demand, either because inherent soil potassium reserves are low—as is typical in intensely weathered tropical soils with high rainfall and leaching—or because repeated removal of potassium in harvested bunches and fallen leaf biomass is not matched by replacement. Soil acidity reduces availability of exchangeable potassium by increasing competition with hydrogen and aluminium ions and by promoting fixation in clay interlayers. The presence of competing cations such as calcium and magnesium at high levels further suppresses potassium uptake. Root health constraints—such as infection by nematodes which damage fine roots—reduce absorptive surface area. Poor fertilizer management, including low application rates, incorrect timing and lay out of potassium fertilizer, insufficient organic matter to support nutrient retention, and moisture stress which limits ion diffusion to roots, all contribute to deficiency in many plantain production systems in West Africa (Adetoro and Olaniyi, 2025; Olajide et al., 2023; Shiyam and Bello, 2021).

2.16 Prevention and Management of Potassium Deficiency in Plantain

Preventing potassium deficiency requires maintaining soil potassium levels through a combination of regular soil testing to assess available potassium, monitoring leaf tissue potassium to detect early deficiency, and applying potassium fertilizers at rates commensurate with yield potential and removal rates. In several Nigerian trials applying up to 400 kg K_2O/ha yielded highest bunch and ratoon crop yields, indicating that high application rates may be necessary when soils are deficient (Shiyam and Bello, 2021; Adetoro and Olaniyi, 2025). Complementary strategies include correction of soil acidity by liming where necessary to improve potassium availability, incorporation of organic amendments to increase cation exchange capacity and reduce leaching, protecting root systems from pathogen damage, and ensuring adequate soil moisture throughout growth to facilitate potassium diffusion to roots. Genotype selection for root morphology that enhances uptake efficiency under low potassium conditions may also be beneficial.

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted between April-October, 2025, within the University of Benin, Farm Project, located at an elevation of approximately 114 metres above sea level. The site lies within the geographical coordinates of 6°24′15″ to 6°24′20″ N latitude and 5°36′37″ to 5°36′39″ E longitude. Soil samples were collected with an auger at various depths, in the Field, between 10:00 and 11:00 a.m., during which ambient soil temperatures ranged from 28.7 °C to 30.1 °C. The area was primarily a plantation environment, comprising well-drained and seasonal swampy zones, which reflects the site's hydrological variability and heterogeneity in soil moisture conditions.

3.2 Collection of Samples

Soil samples were collected within the plantain farm from 4 (0-30, 30-60, 60-90, 90-120 cm) depth in 3 replicate making a total of 12 soil samples.

3.3 Sample preparation

3.3.1 Soil sample preparation

Soil samples were air-dried, grounded, sieved through 2 mm sieve, and stored in a polythene bag for laboratory analysis, using standard operating procedures of soil science and land management laboratory, university of Benin.

3.4 Laboratory analysis

3.4.1 Particle size distribution

Particle size distribution was determined using the Hydrometer method of Bouyocuos (1951) as modified by Day (1965). 51 g of the soil sample was weighed into a soil shaking bottle. 100 ml of calgon was added and the mixture was stirred using a stirring rod, dispersed using a dispersing machine for 5 minutes and transferred into a 1000 ml measuring cylinder, made up to mark with distilled water and the soil particles were set in motion using a plunger. The first hydrometer (H_1) and temperature (T_1) readings were taken after 40 seconds while the second hydrometer (H_2) and temperature (T_2) readings were taken after 2 hours using the standard soil hydrometer with Bouyoucos scale in g/L and thermometer respectively. The first reading was used to calculate the percentage of clay and silt in the soil while the second reading was used to calculate the percentage of clay in the soil, according to the formula below:

$$\%(\text{Clay+ Silt}) = \frac{H1 \pm 0.3\ (T1 - 20°C) \times 100}{w}$$

$$\%\text{Clay} = \frac{H2 \pm 0.3\ (T2 - 20°C) \times 100}{w}$$

%Sand = 100% - % (Clay + Silt)

Where;

H_1= first hydrometer reading, T_1= first temperature reading, H_2= second hydrometer reading, T_2= second temperature reading, w =weight of soil sample used

3.4.2 Textural Classification

Textural classification was determined using the textural triangle (soil survey staff, 2003).

3.4.3 pH in Water (1:2)

The soil pH (1:2) was determined in 1:2 soil to water suspension ratio using a glass electrode pH meter (Ahmad and Tan, 2001).

3.4.4 pH in Calcium Chloride ($CaCl_2$)

Soil pH (1:2) was determined in 1:2 soil to Calcium Chloride suspension using a glass electrode pH meter (Ahmad and Tan, 2001).

3.4.5 Soil Organic Carbon (OC)

The soil organic carbon (OC) content was determined by the wet oxidation method of Walkley and Black (1934). 1 g of soil was weighed into a conical flask. 10 ml of 0.167 M $K_2Cr_2O_7$ was added and swirled, 20 ml of concentrated H_2SO_4 was added swirled for 1 minute and allowed to cool for 30 minutes, after which 100 ml distilled water was added, swirled and 4 drops ferroin complex indicator was added swirled and titrated against 0.5 N $FeSO_4.7H_2O$ to a brownish red end point (T). Blank determination was carried out using same procedure without soil.

$$\% \text{ OC} = \frac{(B-T)5\times 0.003F}{w} \times 100$$

Where;

B = blank titre value, T = sample titre value, F = correction factor, w = weight of soil

3.4.6 Total Organic Nitrogen

Total organic nitrogen was computed from total organic carbon by dividing values of organic carbon by 20 (Ibitoye *et al.,* 2008).

3.4.7 Available Phosphorus (P)

Available P was extracted with Bray-1 solution according to methods of Bray and Kurtz (1945). The P in the extract was determined colorimetrically using the VIS 720 spectrophotometer and developed using the modified ammonium molybdate blue method (Murphy and Riley, 1962).

3.4.9 Exchangeable Bases

Exchangeable bases (Ca, Mg, Na, K) were extracted with 1 N ammonium acetate (1N NH_4OAc), buffered at pH 7. Na and K were read using the flame photometer while Ca and Mg were determined using EDTA Titration method.

3.4.10 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) was determined by summation methods. CEC was calculated by summation of values of Ca, Mg, K and Na. (Udo *et al.,* 2009).

3.4.11 Exchangeable acidity (EA)

Exchangeable acidity was determined by extracting soils with 1 M KCl as reported by Juo (1979). 5 g of soil was weighed into a soil shaking bottle, 100 ml 1 M KCl was added, shaken for 1 hour and filtered using whatman No. 42 filter paper. 10 ml of the filtrate was measured into a conical flask, 5 drops of phenolphthalein was added and made up to 50 ml mark. The extractant was titrated against 0.01 M NaOH to a pink endpoint and the EA was calculated using the formula below;

$$EA = \frac{T \times M \times V1}{V2} \times \frac{100}{w}$$

Where:

EA = Exchangeable Acidity, T = titre value, M = molarity of acid used (0.01 M), V_1 = volume of extractant (100 ml), V_2 = final volume of extract used for titration (10 ml), W = weight of soil

3.4.12 Effective Cation Exchange Capacity (ECEC)

Effective Cation Exchange Capacity (ECEC) was calculated by summation of Exchangeable bases (CEC) and Exchangeable acidity (EA).

3.5 Determination of Forms of potassium (K)

Five forms (water soluble, exchangeable, difficultly exchangeable and fixed) of K was determined at different soil depths using standard procedure (Udo *et al.,* 2009). The different forms, were determined as follows:

3.5.1 Water-soluble potassium

1 g soil was weighed into a plastic shaking bottle, 10 ml distilled water was added and left overnight. The content was swirled and filtered through Whatman No. 42 filter paper into a 25 ml volumetric flask, the soil in the filter paper was leached with distilled water to a total volume of 25 ml and K in the extract was determined using flame photometer.

3.5.2 Exchangeable and soluble potassium

1 g soil was weighed into a conical flask; 10 ml 1 Molar ammonium acetate (I M NH_4Cl) solution was added and left overnight. The content was swirled and filtered through Whatman

No. 42 filter paper into a 25 ml volumetric flask and the soil in the filter paper was leached with 1 M NH_4Cl to a total volume of 25 ml and K in the extract was determined using flame photometer.

3.5.3 Difficulty extractable potassium

1 g soil was weighed into a 25 ml conical flask, 10 ml conc. HNO_3 was added and allowed to stand overnight. The content was boiled for 10 minutes, cooled and filtered through Whatman No. 42 filter paper into a 25 ml volumetric flask. The soil in the filter paper was further leached with cold 1 M HNO_3 to a total volume of 25 ml and K in the extract was determined using flame photometer. The difficultly exchangeable K was calculated by subtracting values obtained for exchangeable and soluble K from values of difficultly exchangeable K.

3.5.4 Fixed potassium

Fixed forms of K were extracted by weighing 1 g soil into a 25 ml conical flask, 10 ml concentration was added, the content was boiled gently for24 minutes and the content was filtered through Whatman No. 42 filter paper into a 25 ml and the soils in the flter paper was further leached with cold 0.01 M HCl to a total volume of 25 ml and K in the extract was determined using flame photometer. Fixed potassium was calculated by subtracting exchangeable and soluble K values from values obtained from hydrochloric acid soluble potassium determination.

3.5.5 Total potassium

Total potassium was calculated by addition of values obtained from water soluble, exchangeable, difficultly exchangeable and fixed potassium determination.

3.7 Determination of Relationship between some Soil Properties and Forms of k

The relationship between some soils properties and forms of K was determined by simple linear correlation.

3.8 Statistical Analysis

Data obtained from soil analysis were statistically analyzed using the Genstat statistical package (12th edition). Duncan multiple range test was used to separate means at 5% level of probability.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Some Physical properties of Soils Planted to Plantain

Results of some physical and chemical properties of the soils studied are shown in Table 1.

The result showed that sand was the dominant soil fraction and decrease significantly with increased soil depth. The Sand content range between 68.11 and 81.77%, with a mean value of 73.71%, across the 4 soil depths. The silt had same value of 5.00% at 0-30 and 30-60 cm soil depths and decreased significantly to 3.33% and 3.67% at 60-90, 90-120 cm soil depths respectively. The Clay increased significantly with increased soil depth possibly due to clay illuviation in line with the report of Sauzet *et al*. (2023). The high sand content observed could be due to the parent material from which the soils are derived from, in line with findings of Orhue and Emomu (2022), who reported decrease in sand content with increased soil depth.

4.2 Chemical properties of Soils Planted to Plantain

The pH (H_2O) of the soils was slightly acidic while pH ($CaCl_2$) showed moderate acidity. pH (H_2O) and pH ($CaCl_2$) ranged between 5.00 to 5.15 and 4.04 to 4.22 with mean value of 5.06 and 4.12 respectively. Acidic pH (H_2O) values obtained in this study have been reported for soils of the study area (Okonofua *et al.,* 2023). Soil organic carbon content decrease significantly with increased soil depth and ranged between 158% (0-30 cm) and 0.44 % (90-120 cm) soil depth with mean value of 0.82 %. The higher organic carbon content observed at the top soil could be due to litters fall from surrounding vegetation as reported by Heger *et al.* (2021), while total

Table 1: Some Chemical properties of the soils

Depth	Ph	pH	OC	TON	Av. P	Ca+Mg	EA
Cm	(H_2O)	$(CaCl_2)$	← g/kg	→	mg/kg	← cmol/kg	→
0-30	5.15a	4.22a	15.80a	0.80a	5.76a	0.04a	0.37a
30-60	5.00a	4.04b	7.80b	0.40b	7.84a	0.01b	0.43a
60-90	5.03a	4.07ab	4.90bc	0.30bc	8.89a	0.01ab	0.37a
90-120	5.05a	4.11ab	4.40c	0.20c	9.82a	0.01ab	0.53a
Mean	5.06	4.12	8.20	0.40	8.08	0.02	0.43
SEM	0.08	0.05	0.90	0.10	1.63	0.01	0.06
Cv	2.80	2.00	199.00	199.00	35.0	78.60	26.00

OC= Organic Carbon, TON= Total Organic Nitrogen, Av-P= Available Phosphorus, Ca+Mg= Calcium and Magnesium, EA= Exchangeable acidity. Means with same alphabet within row are not significantly different, using Duncan multiple range test at 5% level of probability.

Table 2: Some physical properties of the soils

Depth cm	Sand ←	Silt g/kg	Clay →	Textural Class
0-30	817.70a	50.00a	132.30d	SL
30-60	744.40b	50.00a	205.60c	SCL
60-90	705.30c	33.30b	261.30b	SCL
90-120	681.10d	36.70ab	282.30a	SCL
Gmean	737.10	42.50	220.40	—
SEM	5.60	4.30	4.30	—
Cv	13.00	175.00	34.00	—

SL = Sandy Loam, SCL = Sandy Clay Loam, Gmean = Grand mean, Means with same alphabet within row are not significantly different, using Duncan multiple range test at 5% level of probability.

organic Nitrogen content follows same trend as organic carbon, organic carbon have been reported to significantly influence total soil nitrogen (Huang *et al.,* 2021).

4.3 Forms and Distribution of K in the Soil

The result of different forms of K and their distribution in Table 2.The result showed that different forms of K varied significantly across the various soil depths, except difficultly exchangeable K which did not show significant difference across the various soil depths. The water soluble K and exchangeable K ranged between 0.01 to 0.03 cmol/kg and 0.01 to 0.05 cmol/kg, respectively. Higher values of K was obtained for DEK and fixed K forms. The DEK values were inconsistent with incremental soil depth but had highest value of 0.10 cmol/kg and lowest value of 0.03cmol/kg at 30-60 and 60-90 cm soils depth, respectively. Fixed K increased with increased soil depth from 0.04 cmol/kg (0-30cm soil depth) to 0.07 cmol/kg (at 60-90 cm soils depth). While total K was observed to be highest amongst the different forms of K,it however ranged between 0.2 cmol/kg (0-30 cm soil depth) to 0.18 cmol/kg (30-60 cm soils depth) and were ;not significantly different among the different soil depth. Very low water soluble and exchangeable K obtained could be due to high K mobility, leaching and adsorption (Delgado *et al.,* 2024; Awgchew *et al.,* 2024).

The higher values of difficultly exchangeable K when compared with water soluble and exchangeable K obtained in this study could be an indication of K buffering fixation by soil inorganic particles in line with the findings of Fajarini *et al.* (2025), who reported soil inorganic particle K buffering to be influenced by soil inorganic particles.

Table 3: Forms and distribution of K in the soil

Depth	WsK	ExK	DEK	FK	TK
Cm	←		cmol/kg		→
0 -30	0.03a	0.05a	0.08a	0.04ab	0.20a
30 – 60	0.02ab	0.01b	0.10a	0.06b	0.18a
60 – 90	0.01b	0.01b	0.03a	0.07a	0.12a
90 – 120	0.02ab	0.05a	0.04a	0.02b	0.12a
Gmean	0.02	0.03	0.06	0.08	0.15
%cv	43.30	43.30	72.50	49.80	28.1
SEM	0.00	0.01	0.03	0.01	0.03
LSD	0.01	0.04	0.09	0.05	0.09

Ws-K = Water soluble K, Ex-K = Exchangeable K, DEK = Difficultly Extractable K, TK = Total K, Gmean = Grand mean, cv = Coefficient of variations, SEM = Standard errors of Means. Means with same alphabet within row are not significantly different, using Duncan multiple range test at 5% level of probability

4.4 Relationship between some Properties (Physical and Chemical) and Forms of K

The relationship between some soil properties and forms of K at different (0 – 30, 30 – 60, 60 - 90 and 90 – 120 cm) depths is shown in Table 3a and 3b. The correlation matrices showed both positively and negatively significant relationships between some soil properties and forms of K at 0 – 30 cm depth correlated with % total organic nitrogen (r = 0.029*)

Water soluble K positively correlated with sand (r = 0.998*). pH in water significantly negatively correlated with difficultly exchangeable K (r = 0.999*) while Ca + Mg negatively correlated significantly with total K (r = 0.997*). Clay positivrly significantly correlated with total K (r = 0.999*).

At 30 – 60 cm soil depth (Table 3b), positive and negative statistical relationship between forms of K both positive and negative relationships were observed but were not statistically significant. At 60 - 90 cm (Table 4a) soils depth, highly significant negative correlation coefficient was obtained between Ca + Mg and exchangeable K (r = 1.000***), while pH (H_2O) has significant positive relationship with total K (r =0.999*).

At 90 - 120 cm (Table 4b) soil depth, pH (H_2O) significantly correlated with water soluble K, showing positive correlation coefficient of r = 0.999** and significant negative correlation of r = -0.999** was obtained for the relationship between Ca+Mg & fixed K, and silt & fixed K, respectively, while negatively significant perfect correlation was obtained between sand and total K (r = 1.00**). The result of significant relationship between pH and forms of K obtained in this study is in line with the study of Ferrarezi *et al.* (2022). The relationships between sand, Ca + Mg and silt in this study have earlier been reported (Simonsson *et al.,* 2009; Atta *et al.,* 2020).

Table 4a: Relationship between some soil properties and forms of K at 0-30 cm soil depth

	Ws-K	Ex-K	DEK	FK	TK
pH(H_2O)	-0.98	-0.68	0.99*	-058	0.73
pHCaCl_2	-0.57	-0.03	-0.69	0.74	-0.99**
% OC	-0.03	0.57	0.19	-0.99	0.82
%TON	-0.03	0.57	0.19	-0.99	0.82
Ca+Mg	0.66	0.08	-0.76	0.66	-0.99*
EA	-0.96	-0.61	0.99	-0.15	0.79
Sand	0.99*	0.84	-0.97	-0.20	-0.53
Silt	-0.50	-0.92	0.36	0.93	-0.40
Clay	-0.63	-0.05	0.75	-0.69	0.99*

Ws-K = Water soluble K, Ex-K = Exchangeable K, DEK = Difficultly extractable K, TK = Total K, OC = Organic carbon, TON = Total organic nitrogen, EA = Exchangeable acidity.

Table 4b: Relationship between some soil properties and forms of K at 3-60 cm soil depth

	Ws-K	Ex-K	DEK	FK	TK
pH(H_2O)	0.00	-0.23	0.41	-0.46	0.356
pH$CaCl_2$	0.00	0.92	-0.83	-0.95	-0.86
% OC	0.00	-0.50	0.66	-0.19	0.61
%TON	0.00	-0.50	0.66	-0.19	0.61
Ca + Mg	0.00	0.00	0.00	0.00	0.00
EA	0.00	-0.95	0.99	-0.50	0.98
Sand	0.00	0.50	-0.66	0.19	-0.61
Silt	0.00	0.00	0.00	0.00	0.00
Clay	0.00	-0.50	0.66	-0.19	0.61

Ws-K = Water soluble K, Ex-K = Exchangeable K, DEK = Difficultly extractable K, TK = Total K, OC = Organic carbon, TON = Total organic nitrogen, EA = Exchangeable acidity.

Table 5a: Relationship between some soil properties and forms of K at 60-90 cm soil depth

	Ws-K	Ex-K	DEK	FK	TK
pH(H_2O)	0.00	0.25	0.83	0.98	0.99*
pH$CaCl_2$	0.00	0.10	-0.97	-0.86	-0.92
% OC	0.00	0.08	0.92	0.93	0.97
%TON	0.00	0.08	0.92	0.93	0.97
Ca + Mg	0.00	-1.00***	0.33	-0.43	-0.29
EA	0.00	-0.50	0.98	0.56	0.68
Sand	0.00	0.23	-0.99	-0.78	-0.87
Silt	0.00	-0.50	0.98	0.56	0.68
Clay	0.00	0.07	0.92	0.93	0.98

Ws-K = Water soluble K, Ex-K = Exchangeable K, DEK = Difficultly extractable K, TK = Total K, OC = Organic carbon, TON = Total organic nitrogen, EA = Exchangeable acidity.

Table 5b: Relationship between some soil properties and forms of K at 90-120 cm soil depth

	WsK	ExK	DEK	FK	TK
pH(H_2O)	0.99*	-0.54	0.90	0.85	0.98
pH($CaCl_2$)	-0.38	0.97	-0,72	-0.78	-0.15
% OC	0.93	-0.23	0.69	0.62	0.99
%TON	0.93	-0.23	0.69	0.62	0.68
Ca + Mg	0.87	-0.91	0.99	0.99**	0.72
EA	0.00	0.81	-0.40	-0.49	0.24
Sand	-0.97	0.36	-0.79	-0.72	-1.00**
Silt	-0.87	0.91	-0.99	-0.99**	-0.72
Clay	0.97	-0.70	0.97	0.94	0.92

Ws-K = Water soluble K, Ex-K = Exchangeable K, DEK = Difficultly extractable K, TK = Total K, OC = Organic carbon, TON = Total organic nitrogen, EA = Exchangeable acidity.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study shows that the soils were predominantly sandy, and physical and chemical properties of the soils are within normal levels suitable to support plant growth. It showed that different forms of K are distributed across the various soils depth, with very low available K and slightly higher difficultly exchangeable and fixed K, while soil properties could be said to significantly influence availability by the correlation coefficient values obtained in the study. This, indicating the crucial rule of some physical and chemical properties of K forms, distribution and availability.

5. 2 Recommendations

The following recommendations could be made based on the findings of this study:

1. Further studies to examine several other physical and chemical properties not covered in this study are recommended.

2. Total form of K should be examined using total elemental methods and compared with the forms of K to ascertain the actual contribution of each forms to the total K pool.

3. Other essential nutrients such as N and P should be evaluated in the soil and related to the forms of K, to ascertain their influence on one another.

4. The relationship between other soil chemical and physical properties and other forms of K, not covered by the study should be examined to ascertain their influence on K in the soil.

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