

Seasonal Soil Nutrients Flux in Managed Ecosystems in FCT, Abuja

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Abstract

The study examined seasonal variations in soil nutrient composition and heavy metal concentrations within the Sarius Palmetum Botanical Garden, a managed recreational ecosystem located in Maitama, Federal Capital Territory, Nigeria. The objectives assessed nutrient dynamics and the influence of seasonal changes on soil properties, evaluated the ecological sustainability of the garden. Soil samples were collected from six sites in both wet and dry seasons using a 50 cm × 50 cm quadrat subdivided into 10 cm × 10 cm cells, with samples taken from intersections and homogenized into composites for laboratory analysis. A total of thirty soil samples were obtained per season making it a total of sixty for both seasons and analyzed for macronutrients such as (N, P, K), soil organic matter (SOM), organic carbon (OC), exchangeable cations, textural fractions, and heavy metals (Fe, Pb, Cu, Zn, Mn) using standard laboratory procedures. Data was analyzed using descriptive and inferential statistics such as means, tables, student's t- test and ANOVA to determine significant variations across seasons. Results revealed distinct seasonal patterns, with higher concentrations of nitrogen, phosphorus, and magnesium recorded during the wet season. N, P, Ca, records 0.40, 29.18, and 4.96 in the wet season and 0.39, 29.02 and 4.94 in the dry season respectively, while soil organic matter and organic carbon showed moderate enrichment. Exchangeable cation varied significantly across the seasons, and textural analysis indicated sandy loam clay dominance in the study area. Heavy metals such as Fe and Cu were detected but fell within permissible limits, with 5.19 (wet), 5.18(dry) and 1.90 (wet), 1.89(dry). indicating minimal contamination. The study concluded that there were seasonal variations in the soil nutrients suitable for sustainable ecological and recreational functions, emphasizing the need for continuous monitoring to preserve soil health and ecosystem stability.

Keywords: Soil nutrients, Heavy metals, Recreational ecosystem

INTRODUCTION

Vegetation and soil maintain a close ecological relationship in which each influences the structure, composition, and functioning of the other (Aweto, 1981a, c, d; Wang et al., 2016). Vegetation cover affects soil physical and chemical properties such as structure, texture, and nutrient composition, while soil characteristics determine vegetation distribution, productivity, and ecological

stability (Aweto, 1981; Brant et al., 2006; Joying et al., 2009). Vegetation contributes to soil fertility through litterfall, root turnover, and organic matter decomposition. During rainfall events, nutrients dissolve and are absorbed by plant roots, while decomposing plant residues release nutrients back into the soil, thereby maintaining a continuous cycle of nutrient renewal (Aweto, 2013; Wang et al., 2016).

Soil acts as a primary reservoir and regulator of both macro- and micronutrients in terrestrial ecosystems. Its mineral and organic components control nutrient storage, transformation, and availability (Brady & Weil, 2016). Clay minerals and soil organic matter govern cation exchange capacity and nutrient retention, while soil pH strongly influences nutrient solubility and bioavailability. In acidic soils, phosphorus (P) tends to be fixed with aluminum (Al) and iron (Fe), whereas under alkaline conditions, micronutrients such as zinc (Zn), copper (Cu), and manganese (Mn) become less soluble (Mengel, 2001). Soil temperature and moisture further influence microbial activity and organic matter mineralization, thereby affecting nutrient cycling and ecosystem productivity (Paul, 2015; Doran & Zeiss, 2000).

Seasonal variation between the wet and dry seasons plays a major role in shaping soil nutrient dynamics in tropical environments. During the wet season, high rainfall and enhanced biological activity promote organic matter decomposition, nutrient mineralization, and plant uptake, whereas the dry season is characterized by reduced microbial activity, slower decomposition, and increased nutrient immobilization (Rossatto et al., 2012; Sposito, 2013). This alternation results in marked differences in the concentrations of macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), as well as micronutrients including iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) (Bustamante et al., 2006; Huang et al., 2021). Seasonal rainfall also influences nutrient leaching, redistribution, and the overall balance of soil fertility (Sagar et al., 2018).

Seasonal variability also extends to heavy metals, as soil moisture and temperature affect their solubility, mobility, and interactions with organic matter. During the wet season, higher soil moisture and lower pH increase the bioavailability of heavy metals such as cadmium (Cd), lead (Pb), and nickel (Ni)

(Bishnu Angon et al., 2024). In contrast, during the dry season, limited microbial activity and reduced organic matter decomposition restrict metal mobility (Li et al., 2018; Xie et al., 2020). Anthropogenic activities such as fertilizer application, irrigation, and waste disposal further contribute to metal accumulation and nutrient imbalance in managed and urban ecosystems (Pouyat et al., 2007; Zhao et al., 2012).

Microbial and enzymatic activities are also seasonally dependent. Enzymes such as β -glucosidase and phosphatase, which facilitate carbon and phosphorus mineralization, are reported to peak during the wet season due to greater substrate availability and favorable soil moisture conditions (Zhao et al., 2021). Similarly, nitrogen mineralization rates are higher during warmer and wetter months compared to the dry season (He et al., 2017). These biological responses reflect the strong coupling between climatic conditions and nutrient cycling processes.

In managed recreational ecosystems such as botanical gardens, soil nutrient dynamics are further influenced by human activities including planting, pruning, mowing, and irrigation (Edmondson et al., 2014). These management practices modify organic matter inputs, soil structure, and microbial communities, thereby affecting the transformation and spatial distribution of nutrients and heavy metals. Unlike natural forests, where nutrient turnover primarily depends on litter decomposition, managed systems rely more heavily on anthropogenic interventions to sustain soil fertility and plant growth.

Having an understanding the seasonal fluctuations of macronutrients, micronutrients, and heavy metals is essential for assessing soil quality, fertility, and environmental health in managed ecosystems. Therefore, this study assessed the seasonal variation of soil nutrients, including macronutrients (N, P, K, Ca, and Mg) and heavy metals (Fe, Zn, Cu, and Mn), between the wet and dry seasons in the Sarius

Palmetum Botanical Garden, Abuja. The findings are expected to provide insights into nutrient cycling processes and contribute to sustainable soil management and ecological conservation strategies in urban recreational landscapes of the Federal Capital Territory.

METHODOLOGY

Study Area

The research was carried out at Sarius Palmetum Botanic Garden, situated within the Ministers' Hill area of the Maitama District, Abuja, Nigeria. Maitama is one of the districts that make up the Abuja Municipal Area Council (AMAC) in the Federal Capital Territory (FCT). Geographically, the Sarius Palmetum Botanical Garden lies at approximately 9°05'47"N and 7°29'25"E. The landscape consists of gently rolling plains interspersed with isolated hills, with elevations ranging between 456m and 757m above sea level, and an average altitude of about 512 m, which is typical of the Maitama region. The soil in the area is predominantly ferruginous tropical, developed under humid tropical conditions and characterized by relatively high concentrations of iron and aluminum oxides. These soils are generally well-drained and slightly acidic, providing suitable conditions for the growth of both indigenous and exotic vegetation, including palms, ornamental trees, and shrubs

(FineLib, 2023). The topsoil contains a considerable amount of organic matter derived from decomposing plant residues, which improves soil texture, enhances nutrient availability, and supports active microbial processes (Sarius Palmetum, 2024). The climatic condition of the study site corresponds with that of the wider Federal Capital Territory, characterized by a hot and humid tropical climate (Balogun, 2001). Temperatures are highest during the dry season, ranging from 30°C to 35°C, and moderate during the rainy season, fluctuating between 25°C and 30°C (Logan, 2001).

The rainy season extends from mid-March to mid-October, lasting for approximately 190 days, with mean annual rainfall between 1,445 mm and 1,631 mm (Hassan, 2008). The vegetation within the garden comprises both natural and cultivated species, forming a continuous canopy cover. A variety of exotic and indigenous plant species coexist within the garden, with over 30 native species cultivated alongside ornamental plants to promote biodiversity and ecological resilience (FineLib, 2023). Apart from numerous palm species, other common trees include *Daniella oliveri*, *Delonix regia*, *Azadirachta indica*, *Terminalia catappa*, and *Polyalthia longifolia*, among others.

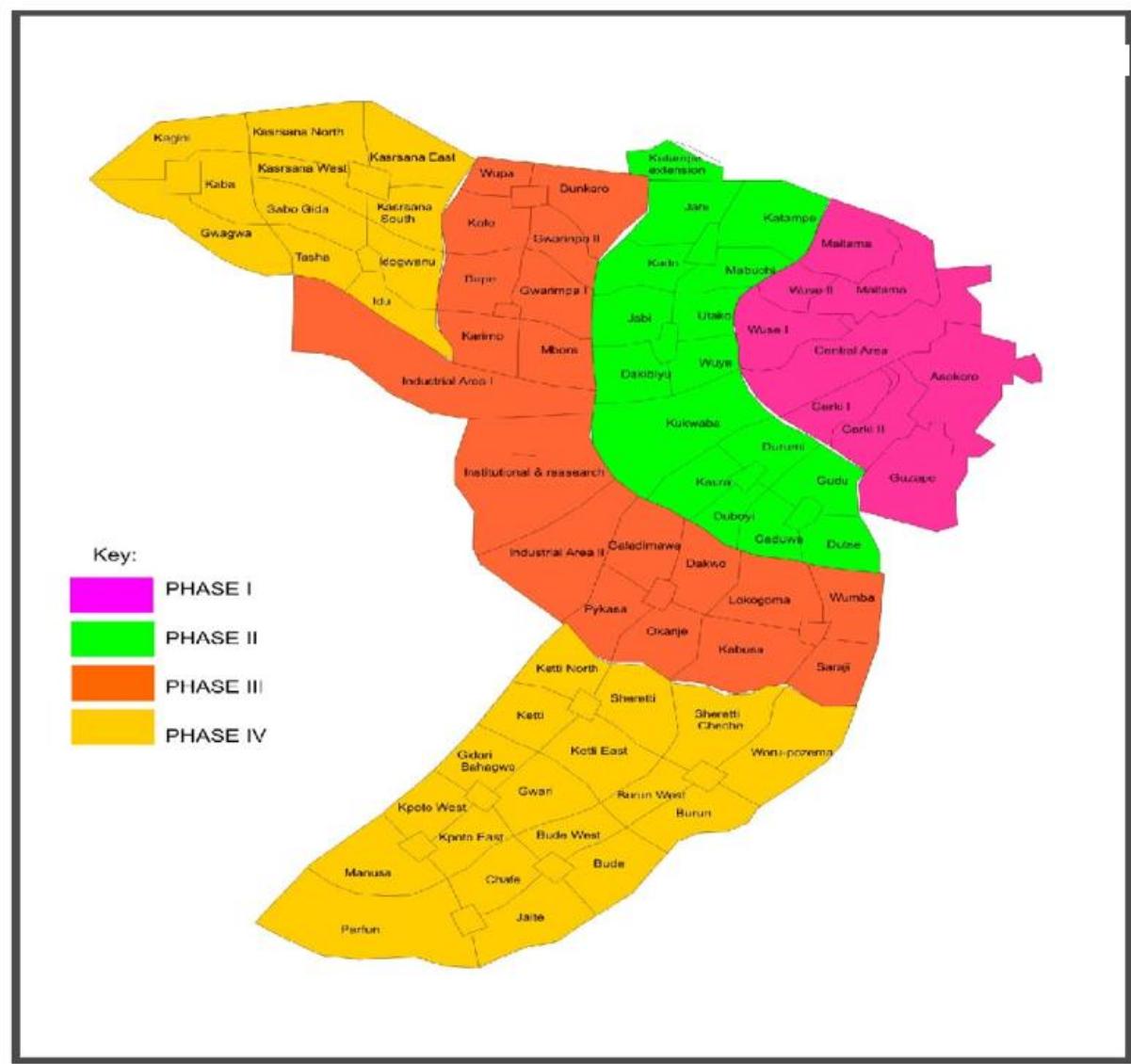


Fig 1: FCC, Showing Districts in Phase I-IV

Source: Abuja Area Guide 2025

Data Management

This study employed an inferential and comparative research design to investigate soil nutrient dynamics within the managed recreational ecosystem of Sarius Palmetum Botanical Garden, Maitama, Abuja. Primary data were used, focusing on soil physical properties (sand, silt, clay, bulk density, and moisture), chemical properties (nitrogen, phosphorus, organic carbon, pH, exchangeable cations Ca^{2+} , Mg^{2+} , K^+ , Na^+ , cation exchange capacity (CEC), and effective cation exchange

capacity (ECEC)), and micronutrients (Zn, Cu, Fe, Mn, and Co).

Based on a reconnaissance survey, three sampling points were purposively selected within relatively undisturbed forested areas of the garden, each spaced approximately 50 meters apart to ensure spatial coverage and ecological uniformity. At each point, a 50 cm \times 50 cm quadrat was established, and soil samples were collected from two depths: 0–15 cm (topsoil) and 16–30 cm (subsoil) using a soil auger. The topsoil at site one was labeled A1TS, while the subsoil at site one was labeled A1SS.

Similarly, samples from site two were labeled A2TS and A2SS for topsoil and subsoil, respectively, while A3TS and A3SS represented topsoil and subsoil samples from site three.

Composite samples were formed by mixing five randomly collected cores within each quadrat to minimize variability and enhance representativeness. In total, thirty soil samples were collected per season (wet and dry), amounting to sixty samples overall. From the thirty samples collected in each season, six homogenized samples were formed per season from all sites. Each soil sample was preserved

separately for verification during laboratory analysis to detect potential outliers.

Soil samples were collected in October 2024 for the wet season and February 2025 for the dry season. All samples were subsequently analyzed at the Soil Science Laboratory, Federal University of Technology, Minna, to determine the physicochemical and nutrient characteristics across seasons and soil depths.

Table 1 shows the abbreviations used to represent the sampling sites throughout the study as well as their coordinates.

Table 1: GPS Coordinates for sample collection

| S/N | Sample Points | Latitude | Longitude |
|-----|---------------|-----------|-----------|
| 1 | A1TS and A1SS | 9°05'47"N | 7°29'25"E |
| 2 | A2TS and A2SS | 9°05'48"N | 7°29'26"E |
| 3 | A3TS and A3SS | 9°05'49"N | 7°29'28"E |

Source: Author's Fieldwork, 2025

The summary of the laboratory analysis is presented on table 2.

Table 2: Method of Laboratory Analysis

| S/N | Parameters | Methods |
|-----|---|--|
| 1 | Particle size distribution | Particle size distribution (PSD) was determined by using the Bouyoucos (Hydrometer) method as described by Udo <i>et al.</i> , (2009). |
| 2 | Bulk density | The soil dry bulk density was determined using the core method. |
| 3 | Soil p ^H | The soil p ^H was determined by electrometric method as described by Mclean, (1982). |
| 4 | Organic Carbon/ soil organic matter | Organic carbon was determined by the modified Walkley – Black method as described by Nelson and Summers (1982), |
| 5 | Total Nitrogen | Total Nitrogen was determined by the macro-Kjeldahl digestion and distillation procedures as described by Bremner (1965). |
| 6 | Available Phosphorus | Sodium bicarbonate {Na (HCO ₃) ₂ } extracting solution was used in this analysis (Olsen and Dean, 1965). |
| 7 | Cation Exchange Capacity (CEC) | This was determined by neutral 1N ammonium acetate method. |
| 8 | Exchangeable Cations and Percentage Base Saturation | This was determined by ammonium acetate extraction method as described by IITA (2015). |
| 9 | Exchangeable Acidity | The exchangeable acidity was determined using barium chloride triethanolamine method as described by Peech (1965). |

Source: Author's Fieldwork, 2025

The data obtained from the field were analyzed using inferential statistics such as student's t-test and Analysis of Variance (ANOVA). The results were statistically determined at 1% and 5% significant level.

RESULTS and DISCUSSION

Physical Properties

Table 3 reveal mean particle size distribution of the topsoil showed higher sand content in the dry season (61.3%) than in the wet season (60.3%), while silt (18.3%) and clay (21.3%) were slightly higher in the wet season compared to the dry season (17.7% silt; 21.0% clay). The soils were classified as sandy, clay loam (SCL). The dominance of sand in both seasons (Table 3) confirms the sandy nature of the soils, consistent with findings by Edicha (2010) in Abuja. Higher dry-season sand content suggests faster drainage and lower water retention, whereas increased silt and clay in the wet season may enhance nutrient-holding capacity. Overall, the soil texture indicates moderate water retention but susceptibility to nutrient

leaching, potentially affecting plant growth and requiring soil management interventions.

Soil p^H was slightly higher in the dry season (6.9) than in the wet season (6.8), indicating moderately acidic conditions (USDA, 2001; USDA, 2008). The slight wet-season decline in p^H is likely due to leaching of basic cations by rainfall. This contrasts with Zhao et al. (2018) and Olatunde et al. (2016), who reported higher wet-season p^H possibly due to site-specific factors such as rainfall intensity, vegetation cover, and parent material. Maintaining p^H within this range supports nutrient availability and microbial activity.

Bulk density remained constant at 1.74 g/cm³ in both seasons, exceeding the USDA threshold (<1.40 g/cm³), indicating compaction that may restrict root penetration, reduce aeration, and limit water infiltration (USDA, 2025). When combined with the sandy clay loam texture, this suggests potential limitations to water and nutrient availability, highlighting the need for organic amendments or mechanical loosening to improve soil structure and productivity.

Table 3: Mean seasonal variation between dry and wet season of soil nutrients in Sarius Palmetum Botanical Garden, in the study area and USDA Standard Range

| S/N | PROPERTIES | TOP SOIL DRY SEASON | TOP SOIL WET SEASON | USDA / Standard Range |
|-----|-----------------------------------|------------------------|------------------------|---|
| 1 | Sand | 61.3 | 60.3 | % |
| 2 | Silt | 17.7 | 18.3 | % |
| 3 | Clay | 21.0 | 21.3 | % |
| 4 | p^H | 6.9 | 6.8 | 6.0 – 7.5 cmol |
| 6 | SOM | 0.84 | 0.82 | 2 – 5 % |
| 7 | OC | 0.28 | 0.27 | 1.2 – 3.0 % |
| 8 | TN | 0.39 | 0.40 | 0.10 – 0.30 % |
| 9 | Available P | 29.2 | 29.18 | 20 – 40 mg/kg |
| 10 | Na^+ | 1.71 | 1.70 | >1.0 cmol |
| 11 | K^+ | 1.67 | 1.66 | \geq 0.2 cmol |
| 12 | Mg^{2+} | 3.98 | 3.98 | 1.0 – 4.0 cmol |
| 13 | Ca^{2+} | 4.94 | 4.96 | 5.0 – 20.0 cmol |
| 14 | (EA) | 0.82 | 0.82 | < 1.0 cmol |
| 15 | ECEC | 12.98 | 12.98 | 7 – 15 cmol |
| 16 | Bulk density (g/cm ³) | 1.74 | 1.74 | 1.10 – 1.60 g/cm ³). (moderate) |

Source: Field work, 2025

Chemical Properties

As shown in table 3, total nitrogen increased marginally from 0.39% in the dry season to 0.40% in the wet season, remaining within the moderate fertility range (0.2–0.5%) for plant growth (USDA NRCS, 2011). Higher wet-season nitrogen was attributed to enhanced mineralization under greater moisture availability (Bergeron et al., 2002; Duke & Ikyaahemba, 2023; Chen et al., 2021). Available phosphorus was slightly higher in the dry season (29.2 mg/kg) than in the wet season (29.18 mg/kg), indicating moderate availability (USDA NRCS, 2008, 2019; Havlin et al., 2014). Lower wet-season phosphorus may result from leaching and reduced organic carbon (Miller & Donahue, 2001; Gupta & Sharma, 2008; Ashraf et al., 2014).

Sodium was marginally higher in the dry season (1.71 cmol/kg) than in the wet season (1.70 cmol/kg), likely due to wet-season leaching (Okoro & Tordue, 2023). Potassium decreased slightly from 1.67 cmol/kg in the dry season to 1.66 cmol/kg in the wet season, consistent with Zhao et al. (2018). Magnesium remained stable at 3.98 cmol/kg across seasons, while calcium increased slightly from 4.94 cmol/kg in the dry season to 4.96 cmol/kg in the wet season, indicating moderate availability and enhanced mineralization under moist conditions (USDA NRCS, 1999; Okoro & Tordue, 2023). These patterns indicate that seasonal rainfall influences nutrient leaching and availability.

Exchangeable acidity remained constant at 0.82 cmol/kg, below 1.0, indicating low acidity (Havlin et al., 2014; USDA NRCS, 1999). Effective cation exchange capacity was stable at 12.98 cmol/kg, reflecting moderate nutrient-holding capacity and minimal seasonal influence on soil fertility (USDA NRCS, 1999; Havlin et al., 2014).

Organic Properties

Data obtain from table 3 shows soil organic matter was slightly higher in the dry season (0.84%) than in the wet season (0.82%), classified as low according to USDA NRCS (2014). This contrasts with Wang et al. (2020), who reported higher wet-season SOM, while Rahman et al. (2021) suggested increased microbial metabolism during wet seasons.

Organic carbon followed a similar pattern, with higher values in the dry season (0.28%) than in the wet season (0.27%), both considered low (USDA NRCS, 2001; USDA NRCS, 2011). The higher dry-season OC aligns with Olatunde et al. (2016), although Duke & Ikyaahemba (2023) and Okhimamhe (2016) reported higher wet-season OC elsewhere. These variations may reflect differences in litter input, decomposition rates, and moisture conditions (Sevgi & Tecimen, 2008). Overall, low SOM and OC suggest reduced nutrient cycling capacity, which may constrain plant growth and ecosystem productivity in the managed area.

Table 4: Mean seasonal variation between subsoil in dry and wet season of soil nutrients in Sarius Palmetum Botanical Garden, in the study area and USDA Standard Range

| S/N | PROPERTIES | SUBSOIL DRY SEASON | SUBSOIL WET SEASON | USDA / Standard Range |
|-----|----------------|-----------------------|-----------------------|--------------------------|
| 1 | Sand | 60.3 | 59.0 | % |
| 2 | Silt | 18.3 | 19.7 | % |
| 3 | Clay | 21.3 | 21.3 | % |
| 4 | P ^H | 6.7 | 6.8 | 6.0 – 7.5cmol |
| 6 | SOM | 0.82 | 0.82 | 2 – 5 % |
| 7 | %OC | 0.27 | 0.27 | 1.2 – 3.0 % |
| 8 | %TN | 0.38 | 0.39 | 0.10 – 0.30 % |
| 9 | Available P | 28.12 | 28.02 | 20 – 40 mg/kg |

| | | | | |
|----|-----------------------------------|-------|-------|--|
| 10 | Na ⁺ | 1.73 | 1.72 | >1.0 cmol |
| 11 | K ⁺ | 1.69 | 1.70 | ≥0.2 cmol |
| 12 | Mg ²⁺ | 3.89 | 3.89 | 1.0 – 4.0 cmol |
| 13 | Ca ²⁺ | 4.68 | 4.69 | 5.0 – 20.0 cmol |
| 14 | (EA) | 0.82 | 0.81 | < 1.0 cmol |
| 15 | ECEC | 12.68 | 12.51 | 7 – 15 cmol |
| 16 | Bulk density (g/cm ³) | 1.80 | 1.80 | 1.10–1.60 g/cm ³). (moderate) |

Source: Field work, 2025

Physical Properties

Table 4 shows sand dominated the subsoil in both seasons, with slightly higher values in the dry season (60.3%) than in the wet season (59.0%), while silt increased in the wet season (19.7%) compared to the dry season (18.3%). Clay remained constant at 21.3% across seasons, indicating stability of the fine fraction. The soils were classified as sandy clay loam (SCL), suggesting moderate water retention but susceptibility to nutrient leaching. Seasonal shifts in sand and silt indicate minor changes in water-holding capacity and infiltration that may influence root growth and nutrient availability. p^H was slightly higher in the wet season (6.8) than in the dry season (6.7), reflecting moderately acidic conditions consistent with Sonko et al. (2016) and Olatunji et al. (2016). This p^H range supports nutrient availability and microbial activity.

Bulk density remained stable at 1.80 g/cm³ in both seasons, exceeding the USDA threshold (<1.40 g/cm³), indicating persistent compaction that may restrict root penetration, reduce aeration, and limit water infiltration. This highlights the need for management practices such as organic amendments or mechanical loosening to improve subsoil structure and plant productivity.

Chemical Properties

As shown in table 4, total nitrogen increased marginally from 0.38% in the dry season to 0.39% in the wet season, consistent with Chen et al. (2021), Ramond et al. (2022), and Okhimamhe (2016), and was attributed to

enhanced microbial activity and nitrogen mineralization under higher moisture (Huang et al., 2021; Bergeron et al., 2002; Singh & Singh, 2006). Seasonal nitrogen pulses during the wet season may enhance plant nutrient uptake and ecosystem productivity (Archer et al., 2017). Available phosphorus declined slightly from 28.12 mg/kg in the dry season to 28.02 mg/kg in the wet season, likely due to leaching and microbial immobilization under high rainfall, while dry-season conservation maintained moderate fertility.

Sodium was marginally higher in the dry season (1.73 cmol/kg) than in the wet season (1.72 cmol/kg), reflecting reduced leaching, whereas potassium increased slightly in the wet season (1.70 cmol/kg) relative to the dry season (1.69 cmol/kg), possibly due to enhanced mineral weathering and organic matter decomposition (Kocak, 2022). Magnesium remained constant at 3.89 cmol/kg, indicating stability across seasons (Okoro & Tordue, 2023), while calcium increased slightly in the wet season (4.69 cmol/kg) compared to the dry season (4.68 cmol/kg), likely due to mineral weathering under higher moisture.

Exchangeable acidity was slightly higher in the dry season (0.82 cmol/kg) than in the wet season (0.81 cmol/kg), and effective cation exchange capacity showed a similar trend (12.68 cmol/kg dry; 12.51 cmol/kg wet), indicating moderate nutrient-holding capacity with dry-season concentrations benefiting from reduced leaching. Overall, subsoil chemical properties were moderately stable, with minor

seasonal variations influencing nutrient availability and management needs.

Organic Properties

Table 4 also reveals Soil organic matter and organic carbon remained constant across seasons at 0.82% and 0.27%, respectively. Reflecting limited influence of short-term

surface inputs on the subsoil, consistent with Sonko et al. (2016). The low and stable organic matter content suggests reduced nutrient cycling and microbial activity, which may constrain plant growth and ecosystem productivity. Enhancing SOM through organic amendments could improve nutrient retention and support deeper root systems in this managed ecosystem.

Table 5: Mean soil analysis of heavy metals between the topsoil in DRY and WET seasons in Sarius Palmetum Botanical Garden, Maitama

| S/N | PROPERTIES | TOPSOIL DRY SEASON | TOPSOIL WET SEASON | USDA Range | / Standard |
|-----|------------------|-----------------------|-----------------------|---------------|------------|
| 1 | Zn ²⁺ | 3.35 | 3.36 | 0.5-2 | |
| 2 | Cu ²⁺ | 1.89 | 1.90 | 0.2-1.0 | |
| 3 | Fe ²⁺ | 5.18 | 5.19 | 4.5-10 | |
| 4 | Mn ²⁺ | 0.85 | 0.89 | 1.0-5.0 | |

Source: Fieldwork, 2025

Table 5 shows Zinc (Zn²⁺) was 3.35 mg/kg in the dry season and 3.36 mg/kg in the wet season, showing negligible seasonal variation and remaining below the sufficiency threshold of 5 mg/kg (Lindsay & Norvell, 1978; USDA-NRCS, 2004; Alloway, 2008), indicating consistently low availability for plant uptake, which may constrain enzymatic functions and growth. This aligns with Rahman et al. (2021), who report only marginal seasonal increases in Zn.

Copper (Cu²⁺) measured 1.89 mg/kg in the dry season and 1.90 mg/kg in the wet season, reflecting stable values across seasons (Sparks, 1995; Flynn et al., 1995; CSU, 2023). Similar stability was reported by Wuana and Okieimen (2011), suggesting adequate Cu availability for enzymatic processes and plant metabolism.

Iron (Fe²⁺) was 5.18 mg/kg in the dry season and 5.19 mg/kg in the wet season, exceeding the critical level of 4.5 mg/kg (Lindsay & Norvell, 1978; Havlin et al., 2014), indicating sufficient Fe for plant growth, chlorophyll synthesis, and overall plant health throughout the year.

Manganese (Mn²⁺) increased slightly from 0.85 mg/kg in the dry season to 0.89 mg/kg in the wet season, remaining below the sufficiency threshold of 1.0 mg/kg (Lindsay & Norvell, 1978; Havlin et al., 2014). Mn is therefore marginally limiting for photosynthesis and enzyme activation, with wet-season increases likely due to enhanced solubility from rainfall (Kocak, 2022). Finally, the seasonal variations of the mean value of heavy metals of subsoils were investigated and presented in table.

Table 6: Mean soil analysis of heavy metals between the subsoil in DRY and WET seasons in Sarius Palmetum Botanical Garden, in the study area

| S/N | PROPERTIES | SUBSOIL DRY SEASON | SUBSOIL WET SEASON | USDA Standard Range | / |
|-----|------------------|-----------------------|-----------------------|------------------------|---|
| 1 | Zn ²⁺ | 3.07 | 3.08 | 0.5-2 | |
| 2 | Cu ²⁺ | 1.49 | 1.51 | 0.2-1.0 | |
| 3 | Fe ²⁺ | 5.17 | 5.39 | 4.5-10 | |
| 4 | Mn ²⁺ | 0.82 | 0.87 | 1.0-5.0 | |

Source: Fieldwork, 2025

As shown in table 6 Zinc (Zn^{2+}) was 3.07 mg/kg in the dry season and 3.08 mg/kg in the wet season, showing negligible seasonal variation. This stability aligns with Zhua et al. (2022), indicating marginal Zn availability for plant metabolic and enzymatic functions, potentially limiting growth despite seasonal changes.

Copper (Cu^{2+}) increased slightly from 1.49 mg/kg in the dry season to 1.51 mg/kg in the wet season, remaining above sufficiency thresholds and stable across seasons. Obasi et al. (2022) similarly report minimal seasonal influence on Cu, ensuring consistent availability for essential plant enzymatic activities.

Iron (Fe^{2+}) rose from 5.17 mg/kg in the dry season to 5.39 mg/kg in the wet season,

Differences in soil nutrients parameters

Statistical Analysis was conducted to determine whether the differences observed in the soil nutrients parameters between the wet season

reflecting slightly higher wet-season concentrations, consistent with Wuana & Okieimen (2011) due to enhanced solubility and mobilization. Adequate Fe supports chlorophyll formation and plant productivity, although surface soils may show higher concentrations (Sneha et al., 2020).

Manganese (Mn^{2+}) increased from 0.82 mg/kg in the dry season to 0.87 mg/kg in the wet season, remaining below sufficiency thresholds. Limited Mn availability may constrain enzymatic and photosynthetic functions, with wet-season enrichment likely due to higher soil moisture promoting mobilization (Choudhury et al., 2019).

and dry season and also between the sampling points and depths using ANOVA and student's t-test is statistically significant at 0.05 level. Below are the diagrams

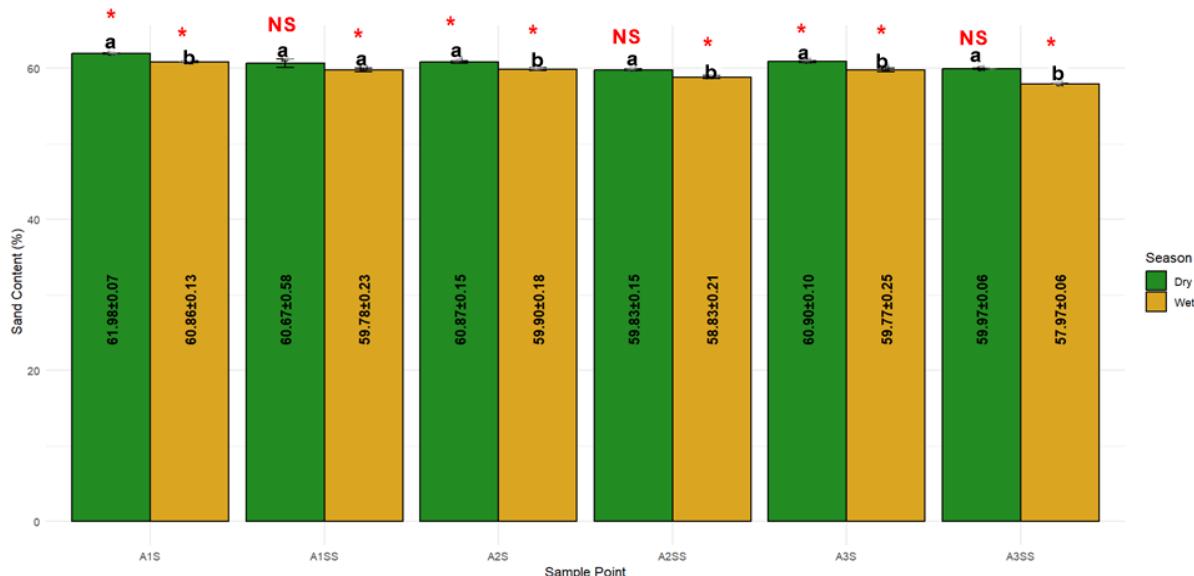


Fig 2: Mean Sand Content (Wet and Dry) Across Sample Points

Sand content showed significant differences at most sampling points (A1S, A2S, A3S, and A3SS; *, $p < 0.05$), while a few sampling points (A1SS and A2SS) showed no significant

variation (NS, $p < 0.05$), as illustrated in Fig. 2. Depth-related variation was also observed between topsoil and subsoil layers.

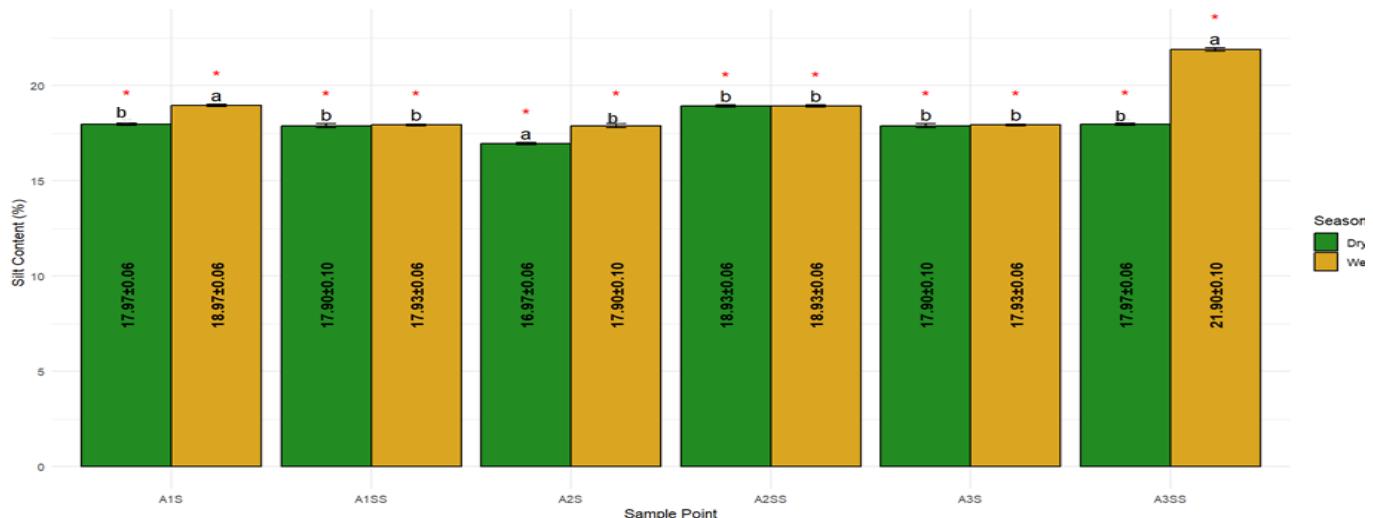


Figure 3: Mean Silt Content (Wet and Dry) Across Sample Points

Significant variation was observed in silt content across all sampling points (*, $p < 0.05$), as shown in Fig. 3. Differences were evident between topsoil and subsoil layers, indicating a

clear depth-related effect. These results suggested a consistent seasonal influence on silt distribution throughout the study area

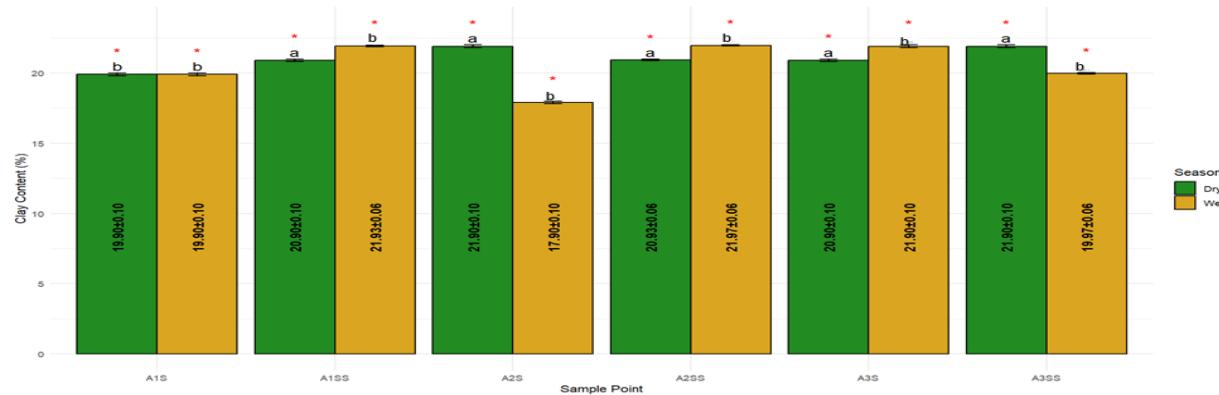


Figure 4: Mean Clay Content (Wet and Dry) Across Sample Points

As shown in Fig. 4, clay content exhibited significant differences across all sampling points (*, $p < 0.05$). Variation was evident between topsoil and subsoil layers, highlighting

depth-related differences. This pattern indicated a consistent distribution of clay throughout the study area.

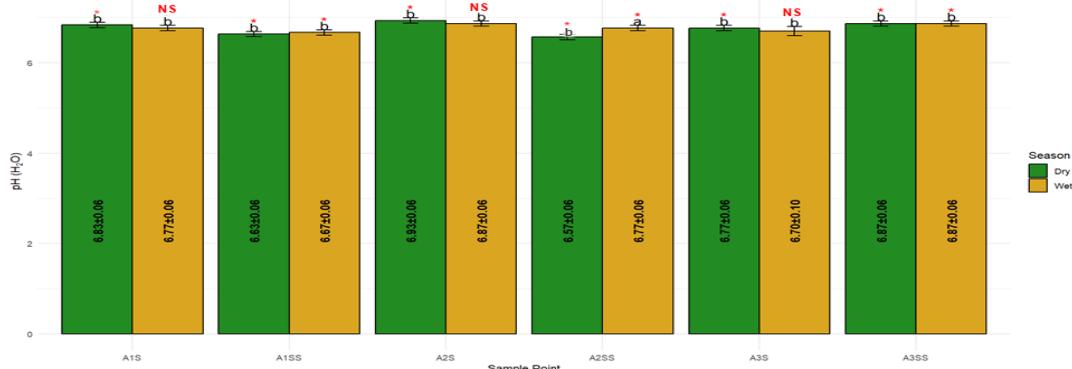


Figure 5: Mean pH (Wet and Dry) Across Sample Points

As illustrated in Fig. 5, soil pH showed no significant differences at A1TS, A2TS, and A3TS during the wet season (NS, $p < 0.05$). All

other sampling points exhibited significant variation (*, $p < 0.05$), indicating that pH response varied across the study area.



Figure 6: Mean Organic Carbon (OC) (Wet and Dry) Across Sample Points

As shown in Fig. 6, organic carbon (OC) displayed significant variation across all sampling points in both wet and dry seasons (*, $p < 0.05$). Noticeable differences occurred between topsoil and subsoil layers, reflecting

depth-related variation. This pattern suggested a consistent influence of environmental and seasonal factors on OC distribution throughout the study area.

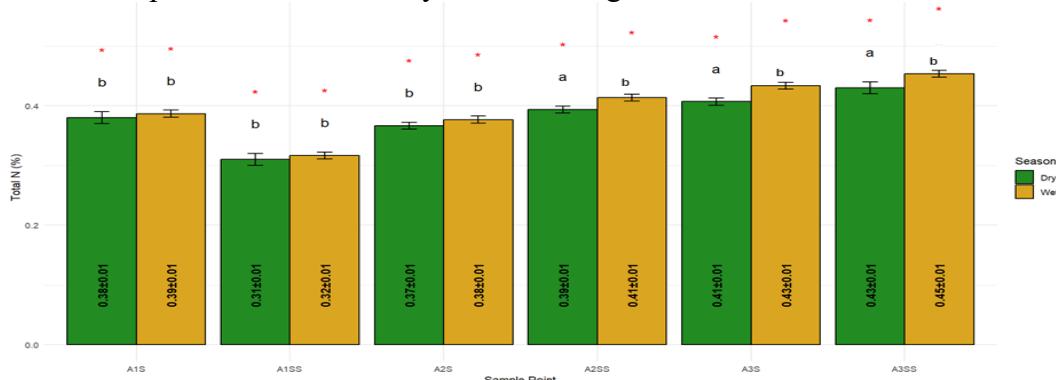


Figure 7: Mean Total Nitrogen (TN) (Wet and Dry) Across Sample Points

As illustrated in Fig. 7, total nitrogen (TN) showed significant differences across all sampling points (*, $p < 0.05$). Both topsoil and subsoil layers contributed to the observed

variation, indicating notable depth-related effects. The results suggested that TN distribution responded consistently to spatial and seasonal influences within the study area.

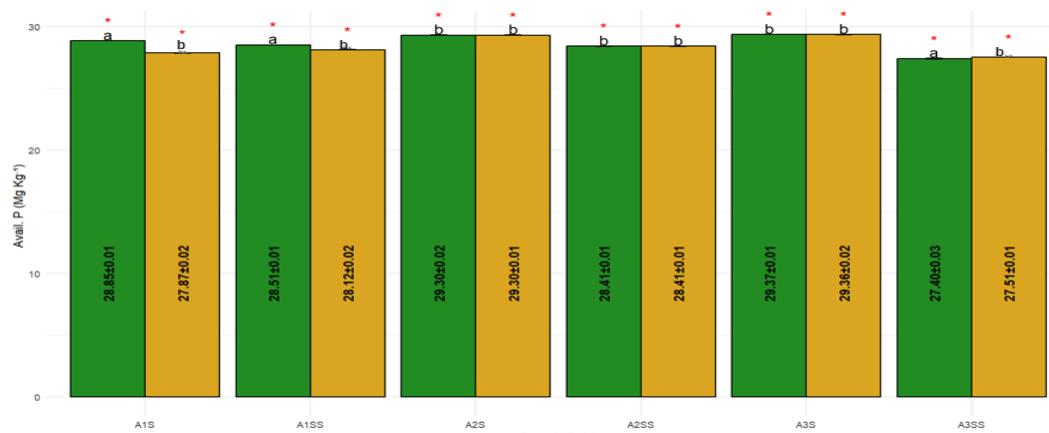


Figure 8: Mean Available Phosphorus (P) (Wet and Dry) Across Sample Points

Figure 8 showed that available phosphorus (P) exhibited significant differences across all sampling points (*, $p < 0.05$). Variation between topsoil and subsoil layers was

apparent, reflecting depth-related influences on nutrient distribution. These findings suggested pronounced spatial and seasonal effects on phosphorus availability within the study area.

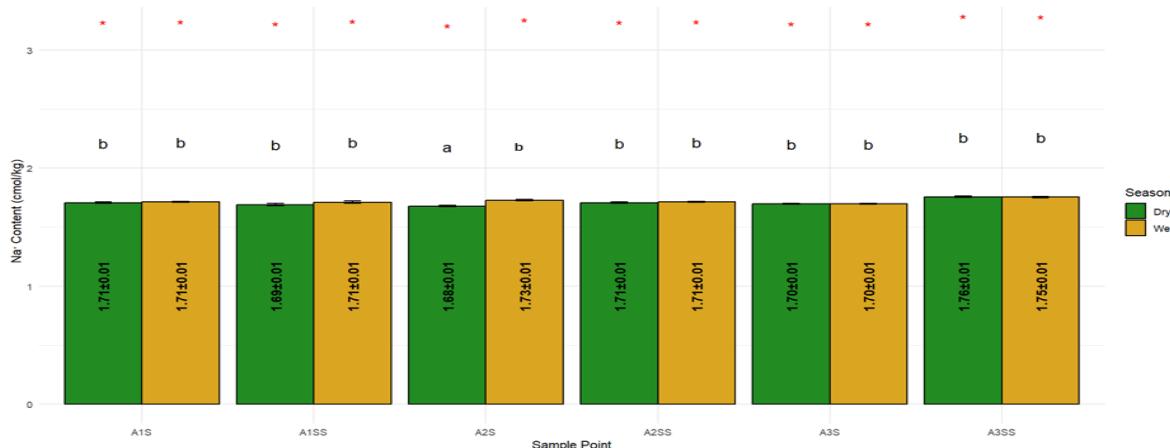


Figure 9: Mean Sodium (Na) (Wet and Dry) Across Sample Points

Analysis of Fig. 9 indicated that sodium (Na) exhibited significant differences across all sampling points (*, $p < 0.05$). Both topsoil and subsoil layers showed noticeable variation,

reflecting depth-related effects. These findings suggested that spatial and seasonal factors consistently influenced sodium distribution throughout the study area.

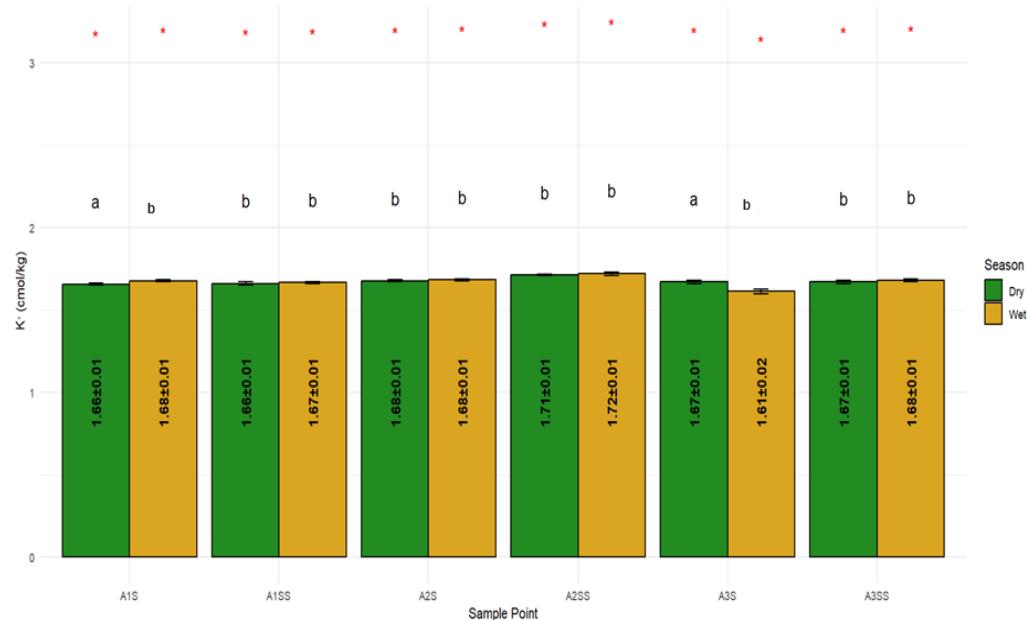


Figure 10: Mean Potassium (K⁺) (Wet and Dry) Across Sample Points

As depicted in Fig. 10, potassium (K⁺) showed significant differences across all sampling points (*, $p < 0.05$). Variation between topsoil and subsoil layers was apparent, highlighting depth-related influences on potassium

distribution. These results indicated that potassium availability was consistently affected by both spatial and seasonal factors within the study area.

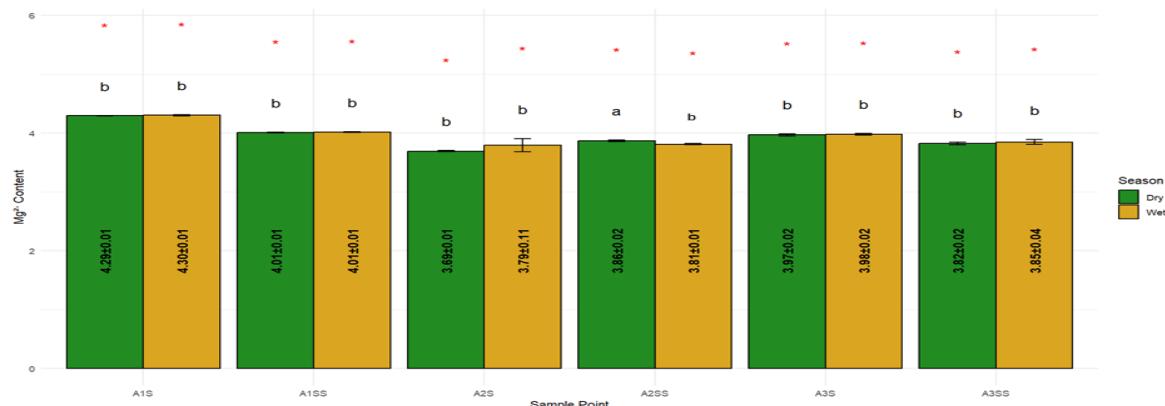


Figure 11: Mean Magnesium (Mg²⁺) (Wet and Dry) Across Sample Points

Examination of Fig. 11 revealed that magnesium (Mg²⁺) exhibited significant differences across all sampling points (*, p <

0.05). Distinct variation between topsoil and subsoil layers was observed, indicating depth-related influences on magnesium distribution.



Figure 12: Mean Calcium (Ca²⁺) (Wet and Dry) Across Sample Points

As shown in Fig. 12, calcium (Ca²⁺) exhibited no significant variation at A1TS, A2TS, and A3TS during the dry season (NS, p < 0.05). All other sampling points in both wet and dry seasons showed significant differences (*, p <

0.05). Depth-related variation between topsoil and subsoil layers was also evident, highlighting spatial heterogeneity in calcium distribution across the study area.

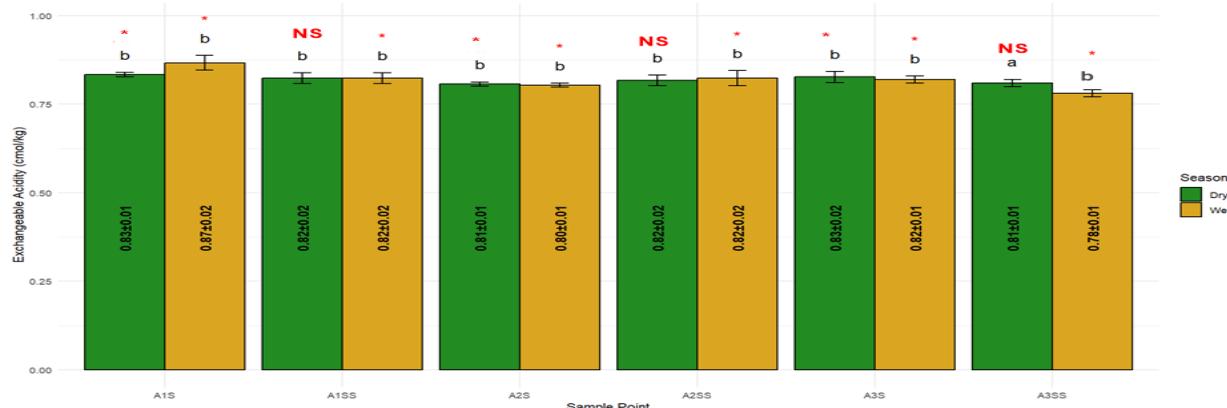


Figure 13: Mean Exchangeable Aluminium (EA) (Wet and Dry) Across Sample Points

As illustrated in Fig. 13, exchangeable aluminium (EA) showed no significant differences at A1SS, A2SS, and A3SS during the dry season (NS, $p < 0.05$). The remaining sampling points in both wet and dry seasons

exhibited significant variation (*, $p < 0.05$). Depth-related differences were also apparent, indicating that EA distribution varied with both soil layer and season across the study area.

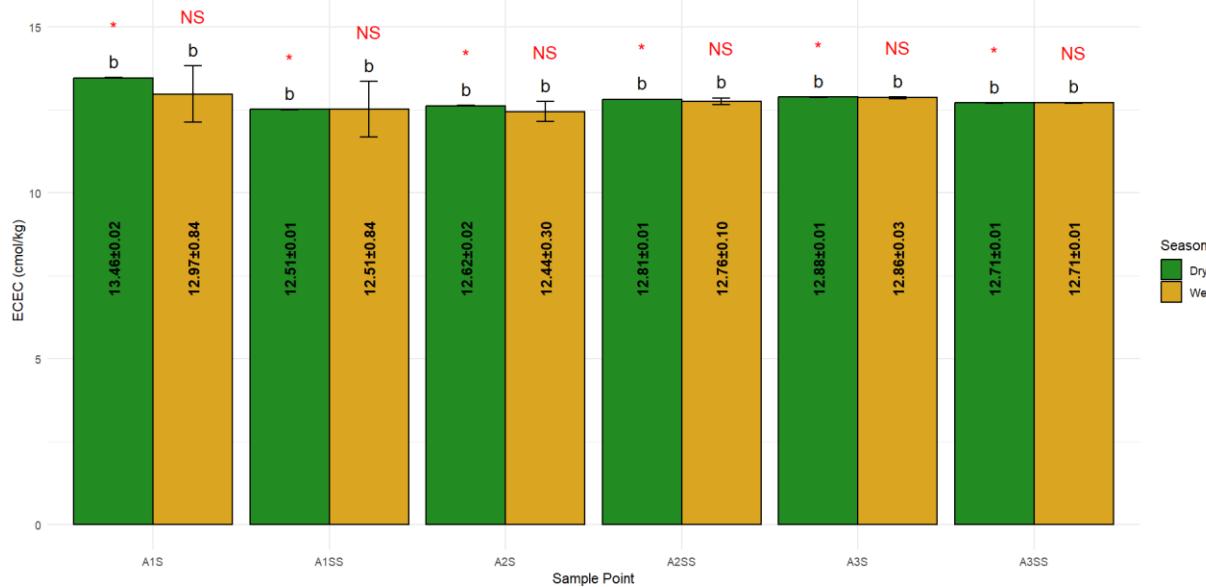


Figure 14: Mean Effective Cation Exchange Capacity (ECEC) (Wet and Dry) Across Sample Points

Examination of Fig. 14 indicated that ECEC exhibited no significant differences across all sampling points during the wet season (NS, $p < 0.05$). In contrast, all sampling points in the dry season showed significant variation (*, $p <$

0.05). This pattern highlighted a clear seasonal influence on cation exchange capacity throughout the study area, with notable consistency across soil depths.

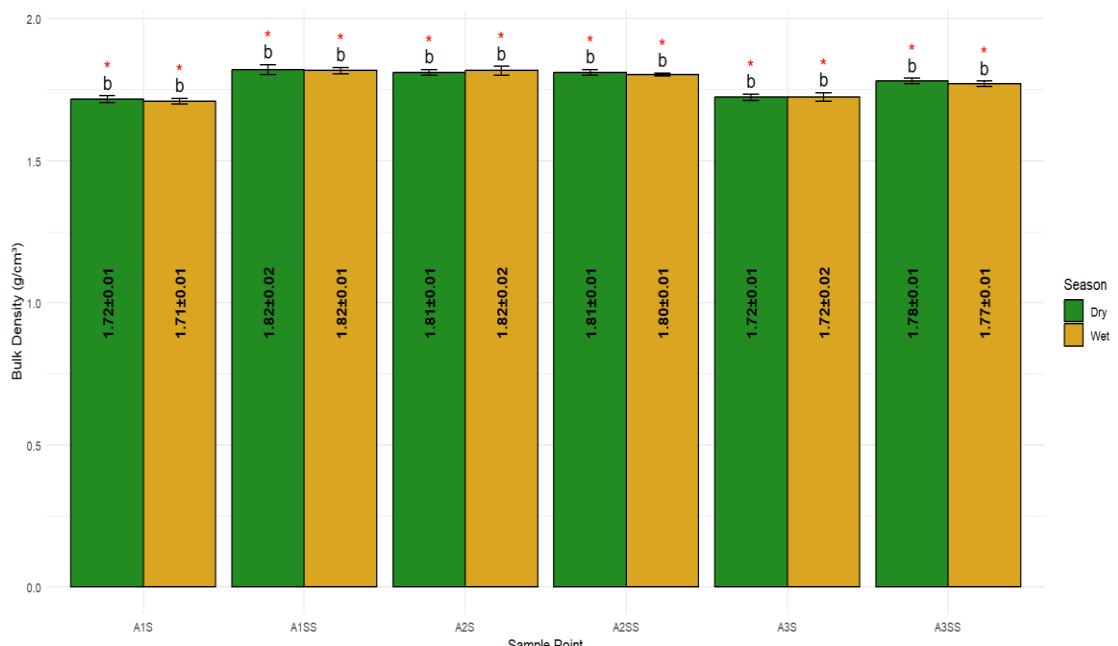


Figure 15: Mean Bulk Density (g/cm³) (Wet and Dry) Across Sample Points

As illustrated in Fig. 15, bulk density showed significant differences across all sampling points in both wet and dry seasons (*, $p < 0.05$). Variation between topsoil and subsoil layers was evident, reflecting depth-related effects on

soil compaction. These results suggested that bulk density was consistently influenced by both seasonal and spatial factors throughout the study area.

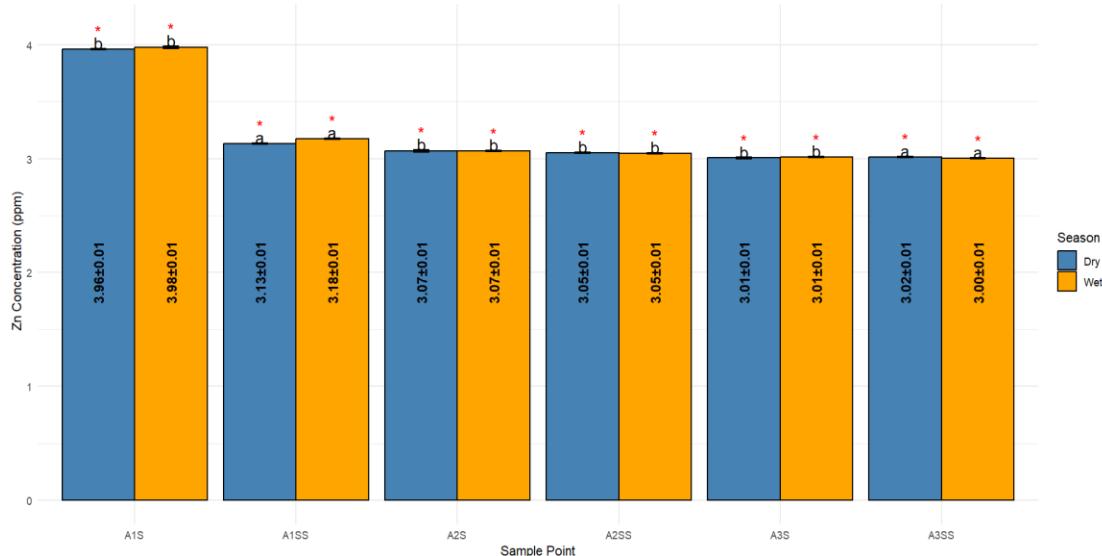


Figure 16: Mean Zinc (Zn) Concentration (Wet and Dry) Across Sample Points

Analysis of Fig. 16 revealed that zinc (Zn) exhibited significant differences across all sampling points in both wet and dry seasons (*, $p < 0.05$). Both topsoil and subsoil layers contributed to the observed variability,

highlighting depth-related effects on zinc distribution. These findings indicated that spatial and seasonal factors consistently influenced zinc availability within the study area.

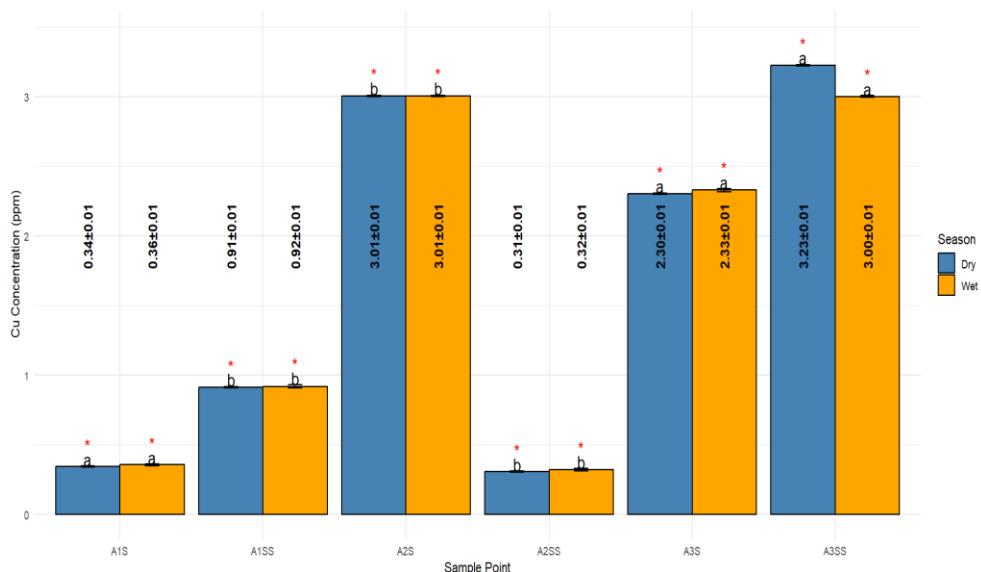


Figure 17: Mean Copper (Cu) Concentration (Wet and Dry) Across Sample Points

As shown in Fig. 17, copper (Cu) displayed significant variation across all sampling points in both wet and dry seasons (*, $p < 0.05$). Differences between soil layers were apparent,

reflecting depth-dependent patterns in copper distribution. This consistent variability suggested a strong influence of environmental and seasonal conditions on copper levels.

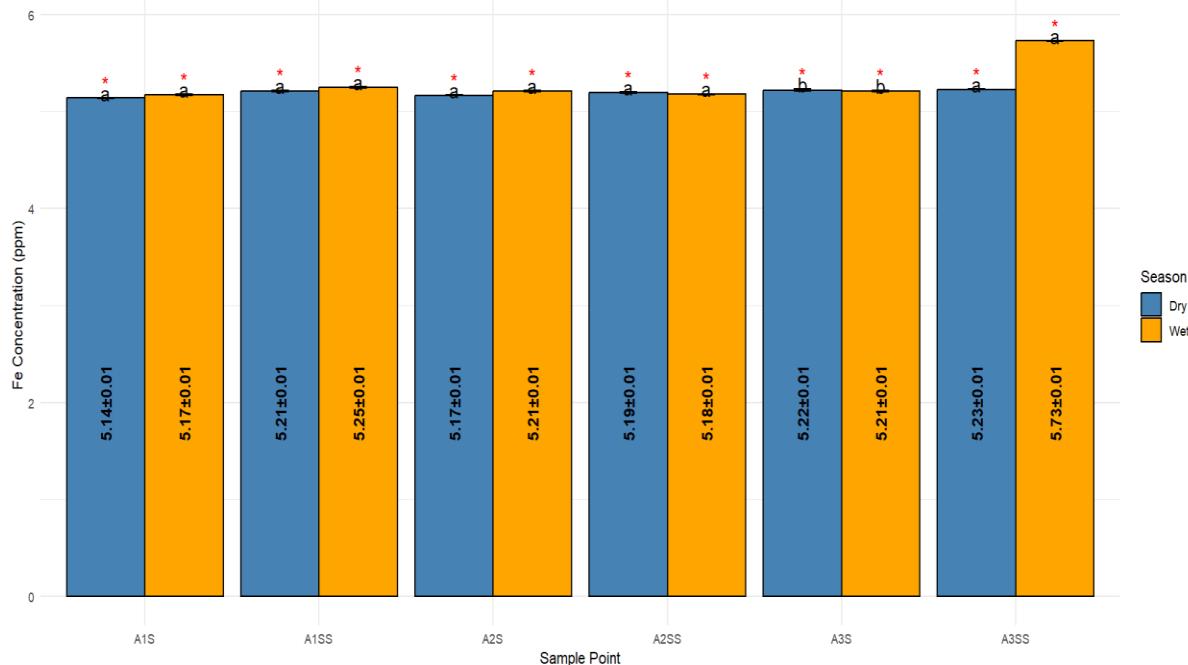


Figure 18: Mean Iron (Fe) Concentration (Wet and Dry) Across Sample Points

Examination of Fig. 18 indicated that iron (Fe) exhibited significant differences across all sampling points in both seasons (*, $p < 0.05$). The observed depth-related variation between

topsoil and subsoil underscored the heterogeneous distribution of iron. These results highlighted the combined effects of spatial and seasonal factors on iron availability.

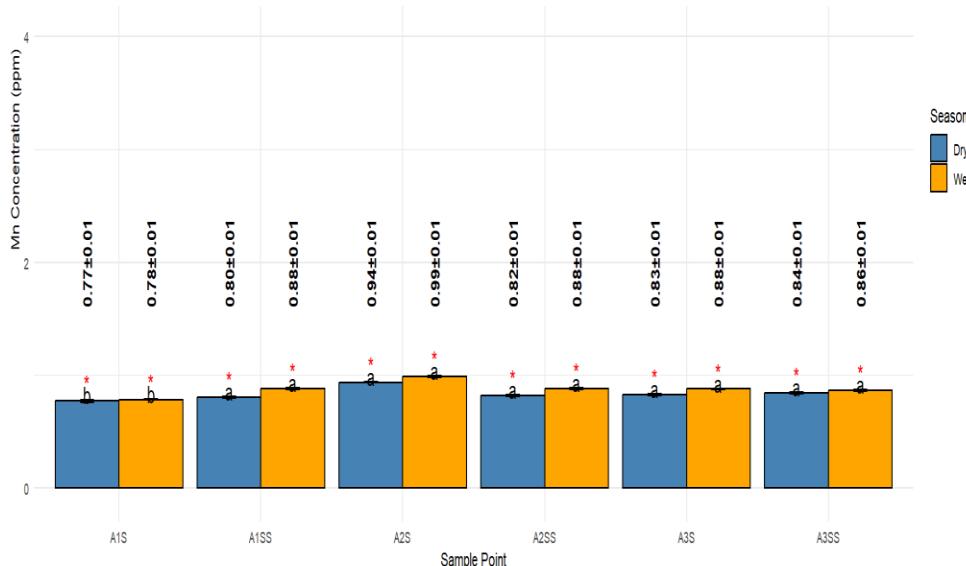


Figure 19: Mean Manganese (Mn) Concentration (Wet and Dry) Across Sample Points

As illustrated in Fig. 19, manganese (Mn) showed significant differences across all sampling points in both wet and dry seasons (*, $p < 0.05$). Both soil layers contributed to the observed variation, emphasizing depth-related influences. This pattern indicated a consistent impact of seasonal and spatial factors on manganese distribution throughout the study area.

Statistical analysis showed that most soil properties exhibited significant differences across the study area, although a few properties showed no significant variation at certain sampling points or during specific seasons. Depth-related variation between topsoil and subsoil layers was evident for most properties. Overall, the results indicated that soil characteristics were largely influenced by spatial and seasonal factors, with significant variation representing the dominant pattern across the study area.

CONCLUSION

The study revealed distinct seasonal variations in soil nutrient composition within the managed ecosystem of Sarius Palmetum Botanical Garden, Maitama, Abuja. The wet season was characterized by higher concentrations of macronutrients such as nitrogen, phosphorus, and potassium, as well as elevated levels of heavy metals including zinc, copper, and iron. These increases were attributed to enhanced mineralization, organic matter decomposition, and increased microbial activity under higher soil moisture conditions. Conversely, the dry season exhibited relatively lower nutrient concentrations due to reduced biological activity, limited organic matter breakdown, and leaching losses from previous rainfall events. However, some exchangeable cations such as calcium and magnesium remained relatively stable across seasons, reflecting inherent soil fertility and buffering capacity. The findings demonstrated that soil nutrient dynamics within the garden were strongly influenced by seasonal rainfall patterns and moisture availability,

which regulated nutrient mobilization and bioavailability.

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