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Influence of soil physical properties, chemical contents and rhizobacterial loads on soil quality in maize fields of Southwestern Nigeria

Moses Abiala[1]* and Christopher Blackwood[2]

[1]Department of Biological Sciences, Mountain Top University, Prayer City, Ogun State, Nigeria.
[2]Department of Plant, Soil, and Microbial Sciences and Department of Plant Biology, Michigan State University, East Lansing, MI, United States.

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In Southwestern Nigeria (SWN), the high demand for maize has resulted in increased levels of maize cultivation. However, continuous maize cultivation is directly or indirectly affecting soil nutrient reserves. This study therefore assessed and compared the soil physical conditions, chemical contents, and rhizobacterial loads of soil samples collected in maize fields across the five (Guinea Savannah-GS, Derived Savannah-DS, Lowland Rainforest-LR, Freshwater Swampy Forest-FW, and Mangrove Forest-MF) ecological zones (EZs) of SWN. Three (GS, DS, and FW) of the five EZs were sandy-loam soil. The soil pH, moisture content, and rhizobacterial loads fall within the agronomic standard but were observed to be weakly correlated when compared across the EZs. Available phosphorus, magnesium, manganese, iron, zinc, and copper varied from moderate to high across the five EZs. Soil organic carbon, nitrogen, potassium, calcium, and sodium were generally low in all the EZs. Of interest, the rhizobacterial loads depend on the soil's physical properties and chemical contents across the EZs. The study therefore uncovered that the soil nutrient reserves in maize fields in SWN vary and more favourably in savannah areas than swampy areas. Although some of the soils in SWN are fertile, the rhizobacterial loads of LR, FW, and MF are low. As a result of this, farmer's awareness of best agricultural practices that will help improve soil fertility and nutrient status towards sustainable maize production in SWN should be prioritized.

Key words: Soil nutrient, maize, soil fertility, plant growth promoting rhizobacteria (PGPR), soil properties, soil biomass.

INTRODUCTION

Soil is a dynamic, complex matrix and an essential part of the terrestrial ecosystem. It is a critical resource not only for agricultural production and food security but also for the maintenance of most life processes (Shahane and Shivay, 2021). Most importantly, soils store and supply nutrients to plants for them to reach their maximum growth (Furey and Tilman, 2021). Thus, soil is essential for plant cultivation to produce crops that serve as food for human and animal

*Corresponding author. E-mail: mos4me@gmail.com. or maabiala@mtu.edu.ng.

consumption (Odelade and Babalola, 2019; Silver et al., 2021). Technically, the potential of a soil to support plant growth depends on its nutrient status. Soil nutrients are important in crop production, but they must be optimized for plant growth and maximum yield (Shahane and Shivay, 2021). In addition, soil nutrients play a central role in the transport and reaction of water, solutes, and gases in soils. Their knowledge is very important in understanding soil behavior under applied stresses and transport phenomena in soils, hence for soil conservation and the planning of appropriate agricultural practices (Olorunfemi et al*.,* 2018). However, in many areas of the world, soil nutrients reserves are declining (Borrelli et al., 2020). Apata et al. (2009) reported that the decline of soil nutrients led to poor agricultural outputs, particularly in sub-Saharan Africa. Agboola and Ojeleye (2007) also pointed out that poor crop growth occurs in the tropics due to the soil's inadequate capacity to hold water.

In Africa, the decline in soil nutrients is a major problem facing not only commercial farming but also small-scale farming (Liliane and Charles, 2020). Similarly, in sub-Saharan Africa (SSA), a reduction in soil fertility is gradually becoming a threat to agricultural sustainability in terms of plant development, yield, and health (Odelade and Babalola, 2019). Zingore et al. (2015) reported different soil quality constraints for crop production in SSA, and these problems, according to their significance in terms of area affected, are: aluminium toxicity > low cation exchange capacity > soil erosion > high phosphorus fixation > vertice properties > salinity > sodicity. These constraints are an indication of degraded soil and significantly reduce the productivity of the soil. In Nigeria, there is evidence of soil-based food security crises with respect to maize production due to its utility for sustainable livelihood (FAOSTAT, 2022; Wossen et al., 2023). Briefly, Nigeria cultivates maize on 6.5 million hectares of land spread across various agro-ecological zones, primarily through smallholder farming (Onumah et al., 2021; PWC, 2021; FAOSTAT, 2022; Aramburu-Merlos et al., 2024). It is widely used in Nigerian breweries, flour mills, pharmaceutical, food manufacturing, and animal feed industries, in addition to being used for human use. About 80% of the grain produced from maize is used for human consumption and animal feed, with the remaining 20% going toward the industrial processing of various goods (Onumah et al., 2021), also 10% of the nation's daily caloric intake is estimated to come from maize, with a per capita consumption of roughly 35 kg/person annually. In addition to providing farmers with a substantial source of cash income, the crop has a major impact on the growth of the agro-industrial sector, particularly in the livestock feed sector (Alene et al., 2009; Wossen et al., 2017). The increasing demand and consumption of maize have, however, made attempts to increase its output unsatisfactory because of variations in the soil fertility quality of Nigerian maize fields (Abiala et al., 2013). For example, the yields in Ibadan, representing the forest zone, and Mokwa in the southern guinea savanna were much lower than in the savanna of the northern guinea savanna. This comparison between the forest and savanna zone field trials conducted for four years showed high yield in the savanna and low yield in the forest zone due to poor soil fertility that was much more pronounced in the forest zone than in the savanna ecological zones (IITA, 2009). This is an indication that soil management strategies are critical in a maize field’s prior planting.

Among the soil management strategies, monitoring soil nutrients is important to ascertain soil nutrient status prior to the application of any management strategy. The soil's physical properties, chemical contents, and rhizobacteria loads are the main drivers and soil indicators that should be considered for monitoring soil nutrients (Shahane and Shivay, 2021). Up until now, most initiatives to monitor soil quality for maize production in SWN have been based on either soil physical and chemical properties alone (Agboola and Corey, 1976; Adeyemo et al., 2019) or rhizobacteria only (Abiala et al., 2015). There is no study in SWN where the soil physical properties, chemical contents, and rhizobacterial loads have been used together to ascertain soil quality for maize growth in Nigeria. In addition, assessment of soil physical and chemical dynamics as well as the rhizobacteria loads in maize fields of SWN have been limited to either one or two EZs (Agboola and Corey, 1976; Adeoye and Agboola, 1984; Oyedele et al., 2009; Akinde et al., 2020) out of five EZs in SWN, and there is no way this could give proper evidence of the distribution and variation of the soil physical properties, chemical contents, and rhizobacterial loads in maize fields of SWN. On this note, we based our hypothesis on analyzing the relationships among the soil physical properties, chemical contents, and rhizobacterial load across the five EZs in SWN. In this study, we investigated the ecological differences in soil physical properties, chemical contents, and rhizobacterial loads across the EZs because of their importance in determining soil quality for maize production in SWN.

MATERIALS AND METHODS

Field survey, study area, selection of site and collection of soil samples

With the permission of the maize farmers, soil samples were collected in different maize fields across the ecological zones (GS, DS, LR, FW and MF), where maize had been grown for 5 to 10 years by local farmers in SWN. Four study areas of about 20 km were randomly selected and surveyed in each ecological zone. In each study area, five sites about 100 m apart were randomly selected for sampling. In each maize field, rhizosphere soils at a depth of 5 to 15 cm were collected randomly and mixed together to form a composite soil sample for each maize field and subsequently pooled together to form composite soil for each ecological zone (Figure 1). For each EZ, composite soil samples were in four replicates across the five EZs, making a total of 20 samples for this study. In addition, at each ecological zone, a mini-questionnaire was used to gather information

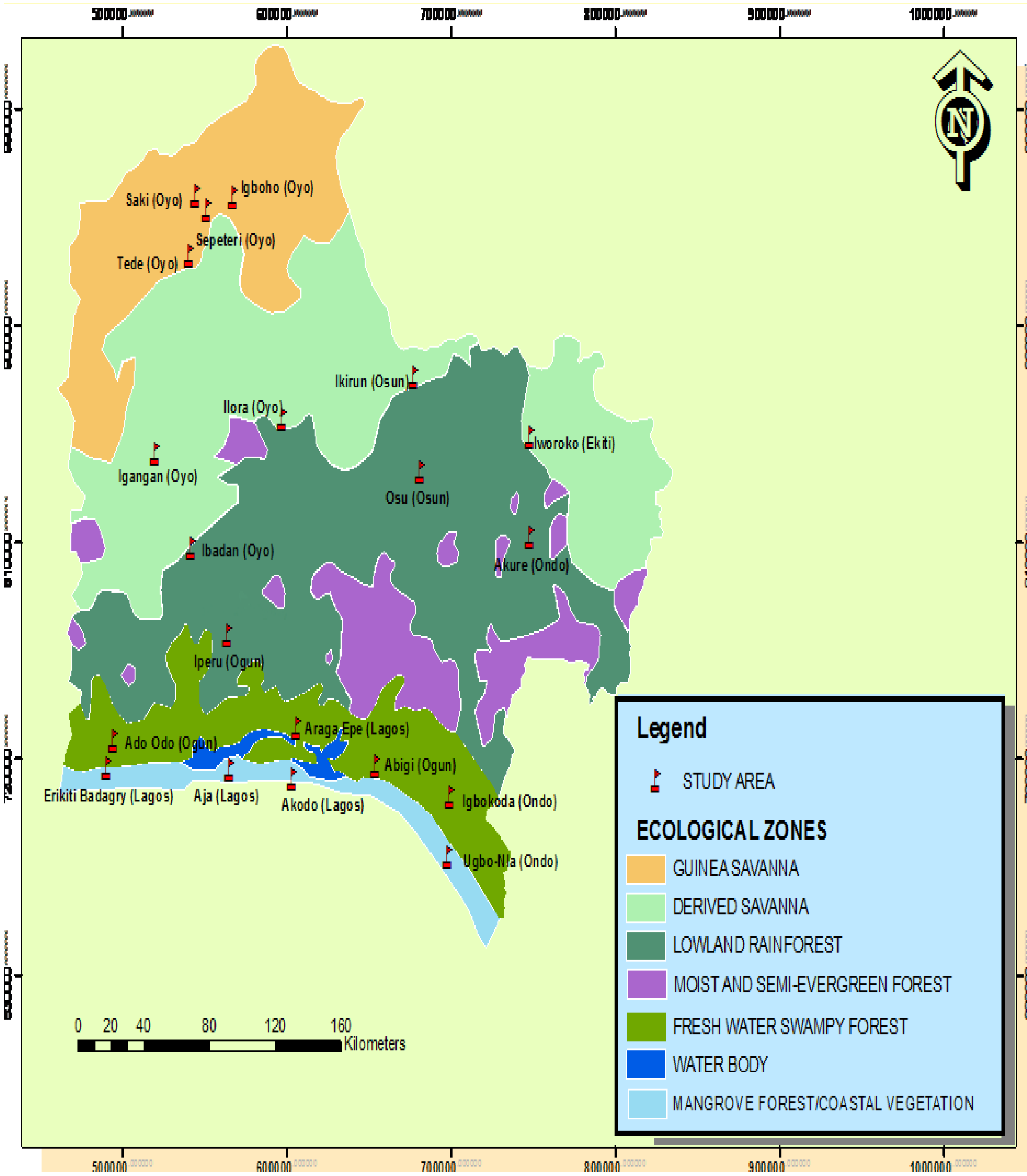

Figure 1. Study areas in ecological zones of Southwestern Nigeria.

on maize cultivation practices by maize farmers, specifically to ascertain the use of chemical fertilizers or organic manures (poultry or animal). For this study, our interest is channeled towards the EZs, not the study areas.

Profile of soil pH and moisture content

Exactly 25 g (field moist soil) from each EZ were taken into a clean, dry 150 mL beaker, and 50 mL of distilled water was added. The contents were thoroughly mixed using a magnetic base stirring machine (Nuova II, stirrer {thermolyne}). The pH of the suspension was measured with a pH meter (pHo p(R)-pH Tester CE from Hanna Instruments, Italy. For moisture content, 50 g of fresh soil samples were measured separately in clean moisture cans; the weight of the moisture can and the soil were taken together before and after oven drying to a constant weight at 105 ± 3°C for 24 h. The moisture content of the soil was recorded and calculated. Both soil pH and soil moisture content were measured in three replicates.

Determination of particle size of the soil samples

The particle size of the soil samples was carried out with slight modifications using the method described by Beretta et al. (2014). Each composite sample (51 g) was weighed out and transferred to a big container in a high-speed shaker. Then, 25 mL of freshly prepared 5% sodium hexametaphosphate (calgon) and 400 mL of tap water were added to the sample in the sample in the container. The container was shaken for 2 h in a mechanical shaker for particle

Table 1. Field survey information on the farming practices with emphasis on the maize cultivars, NPK fertilizer, plant manure and animal manure across the agro-ecological zones in SWN.

Ecological zones	Maize cultivars	NPK Fertilizer		Plant manure	Animal manure
		Before	Now		
GS	SW 1	-/+	-	+	-
DS	SW 1, TC4	-/+	-	+	+/-
LR	SW 1, TC4	-/+	-	+	-
FW	SW 1, OBA S-2	+	+	+	-
MF	SW 1, OBA S-2	-/+	+	+	+/-

SW1 = Suwan – 1 - Y, TC4 = TZL Composite 4 C2, OBA S-2 = Oba Super 2, + Presence, - Absence, -/+ Irregular. GS = Guinea savannah, DS = derived savannah, LR = lowland rain forest, FW = freshwater swampy forest. MF = Mangrove forest. + Presence, - Absence, -/+ Irregular.

separation. Samples were then transferred into a 1 L measuring cylinder and made to mark by adding tap water before stirring with a paddle for 1 min. The soil hydrometer (Model: ASTM-E100 152H-62, Serial Number: 0252, G.H. ZEAL, UK) was introduced into the cylinder, and the first reading was taken (B) after 4 min and 48 s (silt and clay). The second reading (A) was taken 5 h later for clay. The following formula was used to deduce the sand, silt, and clay percentages. Soil textural determination was made by plotting clay, sand, and silt percentages onto the textural triangle for the soil classification of the USDA (Gee and Or, 2002).

$$\text{Clay (\%)} = [(A\ (gL^{-1}) \times 100) / 50\ g] - 1$$
$$\text{Silt + Clay (\%)} = [(B\ (gL^{-1}) \times 100) / 50\ g] - 1$$

where 1 = calgon correction, Silt (%) = [(Silt + Clay) – Clay]%, and Total sand (%) = [100 – (Silt + Clay)]%.

Chemical contents of collected soil samples

Soil total nitrogen (N) was determined by the macro-Kjedahl method (Bremner and Mulvaney, 1982) and Technicon Autoanalyser (1971), organic carbon by chromic acid digestion (Heanes, 1984). Phosphorus and exchangeable cations (Ca, Mg, K, and Na) measurements were done by Mehlich 3 extraction (Mehlich, 1984), and phosphorus was determined colometrically using the Technicon AAII Auto-Analyzer, while the cations (Zn, Cu, Mn, and Fe) were determined using an atomic absorption spectrophotometer (Model Buck 200A).

Enumeration of bacterial loads based on EZ

A serial-dilution-pour plate technique was used to isolate bacteria (Reynolds, 2005; Abiala et al., 2015) on nutrient agar (NA; Oxoid Chemicals, Loughborough, United Kingdom). Inoculated Petri plates were incubated at 28 ± 2°C for 24 h and counted accordingly. Isolates differing in morphological appearance on NA were selected and streaked onto new plates until pure cultures were obtained. Pure cultures of bacterial isolates were maintained on NA slants and stored at 4°C.

Statistical analyses

Experimental treatments were compared using SAS software version 9.1 (2009); SAS Institute, Cary, NC, USA). For each experiment, three replicated data sets were subjected to the analysis of variance (ANOVA) technique according to the experimental design to find out the significance of the treatments. ANOVA was also used to determine the effect of treatments and errors associated with the experiment. Mean comparison was used and carried out by protected LSD ($P = 0.05$; Students-Newman-Keuls Test), where the error mean square served as the standard error of differences between the means. The principal component analysis (PCA) was run in R (vegan package) using the variable correlation matrix so that they all had equal weights (R Core Team 2015).

RESULTS AND DISCUSSION

Chemical and organic fertilizers on maize field of SWN

The use of plant manure predominated in all the study areas across the EZs, while the use of animal manure was recorded for DS and MF. Apart from a few farmers in FW and MF that were consistent in the use of NPK chemical fertilizer, other farmers across the EZs were not using NPK chemical fertilizer on a regular basis (Table 1). In Nigeria, the high cost of NPK chemical fertilizer, health implications, import restrictions, and, at times, scarcity of NPK chemical fertilizer have discouraged many farmers from using NPK chemical fertilizer (Apeh, 2018; Demi and Sicchia, 2021; Penuelas et al., 2023). As a result of this, all the farmers in the study areas are gradually adapting to the use of plant and animal manures as the cheapest and most readily available source of organic fertilizer, knowing fully well that they are also environmentally friendly and sustainable. According to Bopche et al. (2024), adding organic matter, specifically, manure from poultry, has the ability to enhance soil structure, promote microbial activity, and gradually release nutrients for sustainable crop output.

Soil physical properties in maize fields of SWN

The pH of the soil samples from the study areas ranged from acidic to neutral (Figure 2). The soil of DS had the highest average pH, followed by MF, GS, LR, and FW.

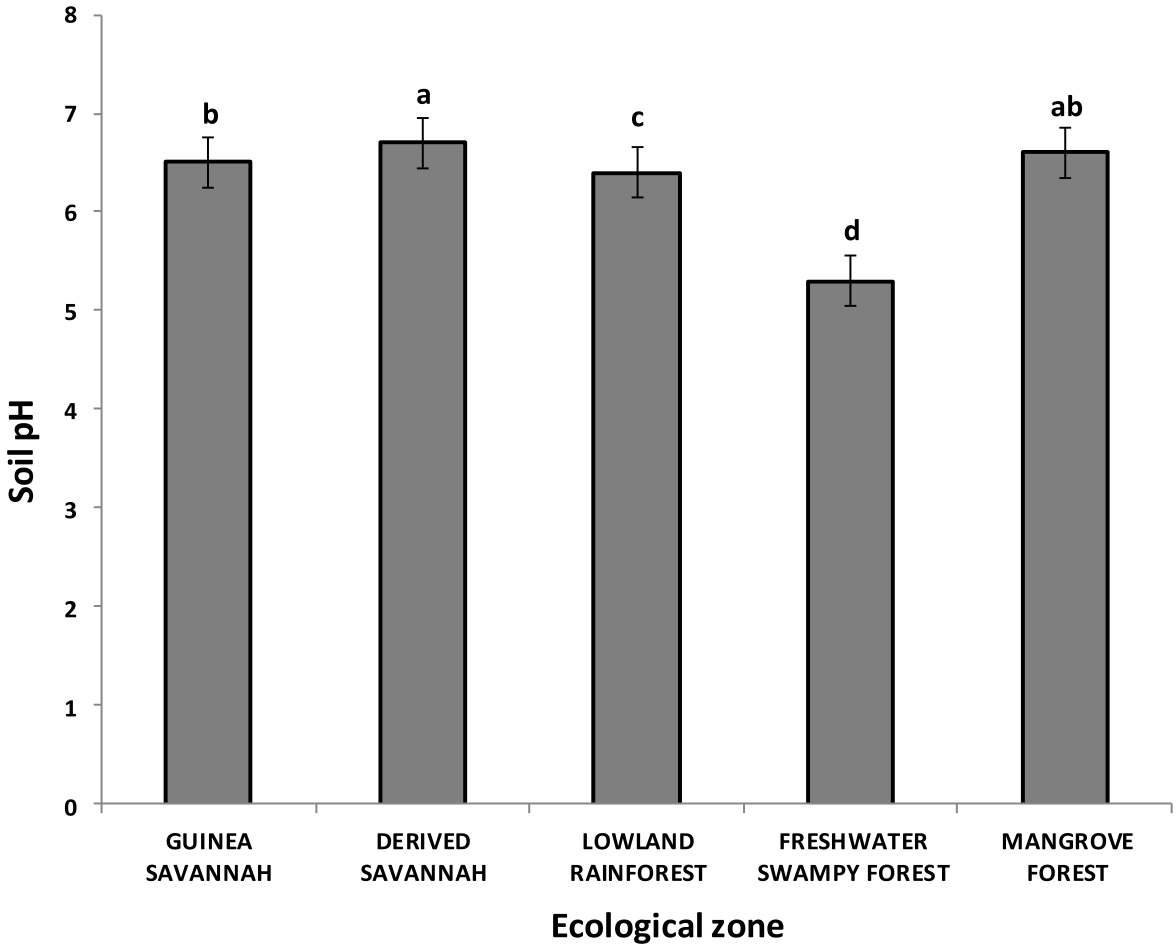

Figure 2. pH of collected soil samples based on ecological zones. Means followed by the same letter (s) are not significantly different ($P \leq 0.05$) according to Student-Newman- Keuls Test. The results shown are means ± standard error (n=5).

This variation in pH may perhaps be attributed to differences in ecozones and litter accumulation from leaf drops. FW soils were uniquely acidic in comparison to other EZs, with an average pH of 5.6 (Ayodele and Omotosho, 2008; Chodak et al., 2015). This suggests that the low soil pH of 5.6 in FW soils could be attributed to the topography affecting the swampy areas and continuous cultivation, thus lowering the soil pH. This is in line with the work of Abdulrashid et al. (2024) on the assessment of soil physical and chemical properties in the parklands of northern Nigeria. Furthermore, we determined the soil moisture content (Figure 3) based on the composite soil for each EZ. Sandy-loam predominates across the EZs (Table 2), which suggests their support for maize growth. MF had the highest moisture content, while FW had the lowest (Adeyemo et al., 2019). According to Zhou et al. (2019), the sandy-like-loamy soil in the MF may have promoted nutrient leakage through the many macropores in this type of soil during the planting season. These results are in line with the findings of Adugna and Abegaz (2016) and Azeez et al. (2020), who reported substantial sand content in their various investigations of forest soils. According to Azeez et al. (2020), the quantity and size of soil particles affect porosity and bulk density, which account for nutrient leaching and retention. This suggests that soil physical qualities have a major impact on soil fertility.

Soil chemical contents varied across the maize fields in the EZs of SWN

Soil samples collected were pooled together for each EZ and chemical contents were determined. DS had the highest organic carbon and nitrogen, followed by FW, whereas MF had the lowest (Table 3). Soil available phosphorus in DS was extremely high compared to other EZs (Table 3). Similarly, DS had the highest exchangeable cations (calcium, magnesium, potassium, sodium and ECEC). Moreso, DS, had the highest extractable zinc and

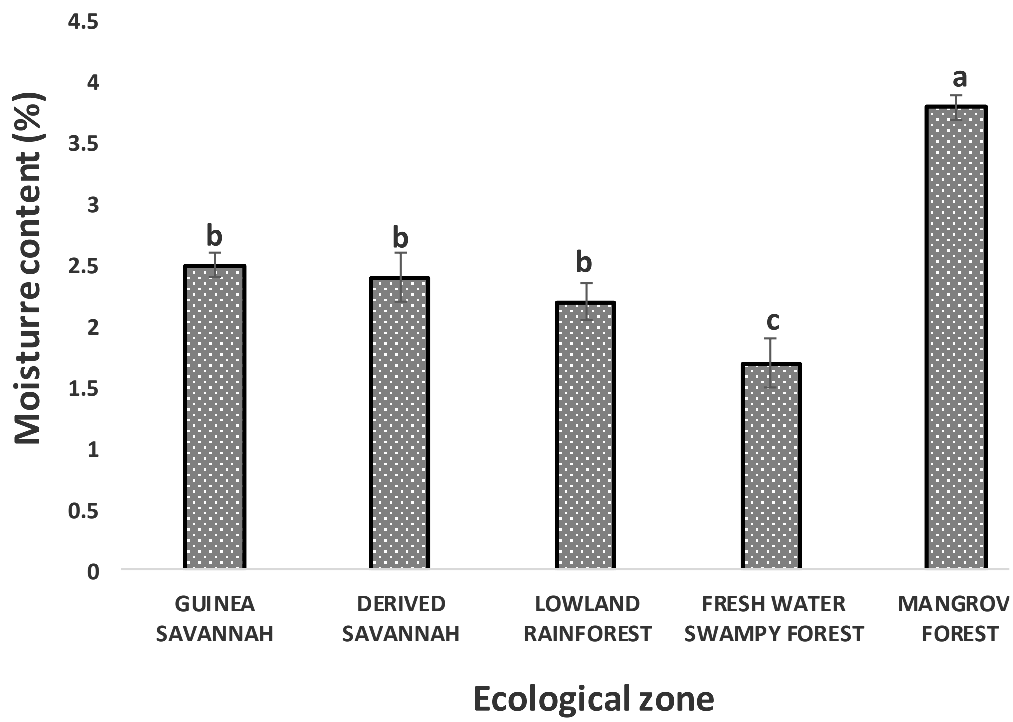

Figure 3. Moisture content (%) of collected soil samples based on ecological zones. Means followed by the same letter (s) are not significantly different (P ≤ 0.05) according to Student-Newman- Keuls Test. The results shown are means ± standard error (n=5).

Table 2. Physical properties of collected soil samples based on study areas.

Ecological zone	Texture	Particle size		
		Clay (%)	**Silt (%)**	**Sand (%)**
GS	Sandy-loam	13 (±0.33)^{c}	14 (±0.67)b	73 (±0.67)^{b}
DS	Sandy-loam	19 (±0.33)^{b}	14 (±0.67)^{b}	67 (±0.87)^{c}
LF	Sandy-clay-loam	21 (±0.57)^{a}	18 (±0.33)^{a}	61 (±0.57)^{c}
FW	Sandy-loam	15 (±0.44)^{c}	14 (±0.67)^{b}	71 (±0.88)^{b}
MF	Sand-Sandy-loam	9 (±0.58)^{d}	6 (±0.33)^{c}	85 (±1.20)^{a}

GS = Guinea savannah, DS = Derived savannah, LR = Lowland rain forest, FW = Freshwater swampy forest. MF = Mangrove forest. Values followed by different letters within a column indicate significant differences according to the Student-Newman-Keuls multiple-range test (α = 0.05).

copper, while manganese and iron were observed to be low (Zhou et al., 2019). LF showed unique high concentration of manganese, followed by GS, FW, and MF (Table 3). Notably, the concentration of iron was generally high in all the EZs with the exception of DS (Table 3). With the exception of available phosphorus, our study revealed that soil nutrients were partly below the established critical level (Table S1) for soil fertility in SWN (FMANR, 1990). Thus, based on chemical nutrients status, soils sampled from maize fields were not really adequate to enhance maize growth in certain EZs such as LF, FW and MF. This could possibly be due to lack of fertilizer availability as possible cause? As well as continuous maize cropping itself exhausting the soil when coupled with low-nutrients parents materials. The organic carbon which is an indicator of the soil organic matter differs among the different EZs in this study. Eludoyin and Wokocha (2011) attest to the fact that the soils in EZs of SWN varied in their chemical properties. Apart from DS, the soil organic carbon in the EZs was low (Zhou et al., 2019). Maize growth would generally perform better in DS compared to other EZs. This is due to the fact that DS had adequate if not enough organic carbon, available P, N, exchangeable cations and extractable micronutrient concentration that

Table 3. Chemical contents of collected soil samples based on the ecological zones.

Chemical contents	Ecological zones				
	GS	DS	LF	FW	MG
% OC	1.14 (±0.05)[b]	1.60 (±0.01)[a]	1.20 (±0.05)[b]	1.46 (±0.01)[b]	0.89 (±0.01)[c]
% N	0.11 (±0.01)[b]	0.16 (±0.01)[a]	0.12 (±0.02)[b]	0.15 (±0.03)[a]	0.09 (±0.01)[c]
Mehlich P (µg/g Soil)	17.27 (±0.08)[c]	177.50 (±7.26)[a]	27.53 (±0.36)[b]	14.22 (±0.30)[c]	37.62 (±0.29)[b]
Exchangeable Cations					
Ca (cmol+/ kg)	8.20 (±0.03)[a]	10.91 (±0.02)[a]	7.17 (0.04)[a]	3.97 (±0.04)[b]	7.29 (±0.19)[a]
Mg (cmol+/ kg)	1.63 (±0.02)[a]	1.64 (±0.01)[a]	1.52 (±0.01)[a]	1.03 (±0.01)[a]	0.68 (±0.01)[b]
K (cmol+/ kg)	0.43 (±0.01)[a]	0.53 (±0.01)[a]	0.40 (±0.02)[a]	0.28 (±0.01)[a]	0.23 (±0.01)[b]
Na (cmol+/ kg)	0.16 (±0.01)[a]	0.17 (±0.01)[a]	0.16 (±0.02)[a]	0.13 (±0.01)[a]	0.16 (±0.02)[a]
ECEC (cmol+/ kg)	10.41 (±0.50)[a]	13.5 (±0.29)[a]	9.25 (±0.25)[a]	5.41 (±1.40)[b]	8.36 (±1.80)[a]
Extractable micronutrients (ppm)					
Zn (ppm)	33.30 (±0.30)[b]	85.87 (0.20)[a]	44.45 (±0.30)[b]	21.72 (±0.90)[c]	37.37 (±1.20)[b]
Cu (ppm)	1.27 (±0.04)[b]	44.45 (±1.03)[a]	1.60 (±0.06)[b]	0.62 (±0.05)[b]	0.60 (±0.03)[b]
Mn (ppm)	181.29 (±1.07)[a]	21.72 (1.27)[b]	188.17 (±1.87)[a]	139.1 (±1.86)[a]	46.96 (±0.58)[b]
Fe (ppm)	144.31 (±0.70)[a]	37.37 (±0.47)[a]	163.14 (±0.53)[a]	147.92 (±0.34)[a]	182.70 (±0.88)

% C = Percentage of organic carbon, % N = percentage of nitrogen, P = Phosphorus, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, Zn = Zinc, Cu = Copper, Mn = Manganese, Fe = Iron. GS = Guinea savannah, DS = Derived savannah, LR = Lowland rain forest, FW = Freshwater swampy forest. MF = Mangrove forest. Ppm = part per million. Values followed by different letters within a row indicate significant differences according to the Student-Newman-Keuls multiple-range test (α = 0.05).

can support maize growth. This therefore suggests that the low organic carbon have the potentials to influence exchangeable cations (K, Ca and Mg), CEC, total nitrogen, P and clay content suggesting the dependence of soil nutrient lands on organic matter in tropical soils. Soils of the savannah region are physically fragile because the topsoil contains a large proportion of sand, causing weak aggregation and low levels of organic matter (Salako et al. 2002). Soils of the LF, FW and MF EZs were also observed to be low in organic carbon, perhaps due to continuous rainfall that may leach organic matter and macro and micronutrients. In addition, this could be as a result of soil exposure to continuous cropping and lack of protection of soil against changes in climatic factors. In Nigeria, growing food crops is hampered by low soil fertility, which results in decreased yields in variable lands in the tropics that are noticeable even after one or two years of cultivation (Wawire et al., 2021).

This suggests that if adequate care is not taken, soil for arable crop in SWN will continue to be degraded and this will directly have ecological effects on mankind. So, directly or indirectly, the low fertility status of the studied soils will continue to hinder maize production as maize has a strong exhausting effect on the soil. Woodruff (1949) stated that whenever virgin soils are brought under cultivation and cropping, organic carbon content generally declines because the amount of organic materials returned to the soil decreases sharply and erosion and leaching increases. Similarly, extensive use of chemical fertilizers and pesticides in the absence of organic matter amendments can deplete soil organic matter and soil biodiversity, also resulting to nutrient depletion. This suggests that the availability of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna may be responsible for the variation in this study. Remarkably, relatively high organic carbon was observed in the soil of DS (1.6%) (Jibril and Yahaya, 2010), which is in-line with the soil nutrient critical level for SWN (FMANR, 1990). Over 50% of the EZs were deficient in nitrogen content (Table 3 and Table S1) compared with the established 0.15% critical level of soil fertility in SWN (FMANR, 1990). Although, in Nigeria, maize is a high nitrogen demanding crop, however, the nitrogen deficiency in soil always show up when soil contain less than 1% of organic matter (Sobulo and Osiname, 1985). This can be attributed to the removal of aboveground biomass due to grazing, logging, firewood collection, and deterioration of soil physical parameters. On a similar note, during the annual dry season, the usual slash-and-burn land clearing practices could have caused the complete oxidation of the litter and humified organic materials, with loss of nitrogen as oxides into atmosphere (Jones and Wild, 1975; FMANR, 1990).

The high available phosphorus within and across the EZs (Table 3) were similar to the report of Eghball and Power (1999). All the maize farmers in the EZs, as observed from the field information obtained in this study, had engaged in the use of plant and partly animal manure, which may have contributed to the increase in available phosphorus (Liang et al., 2020). Interestingly, DS

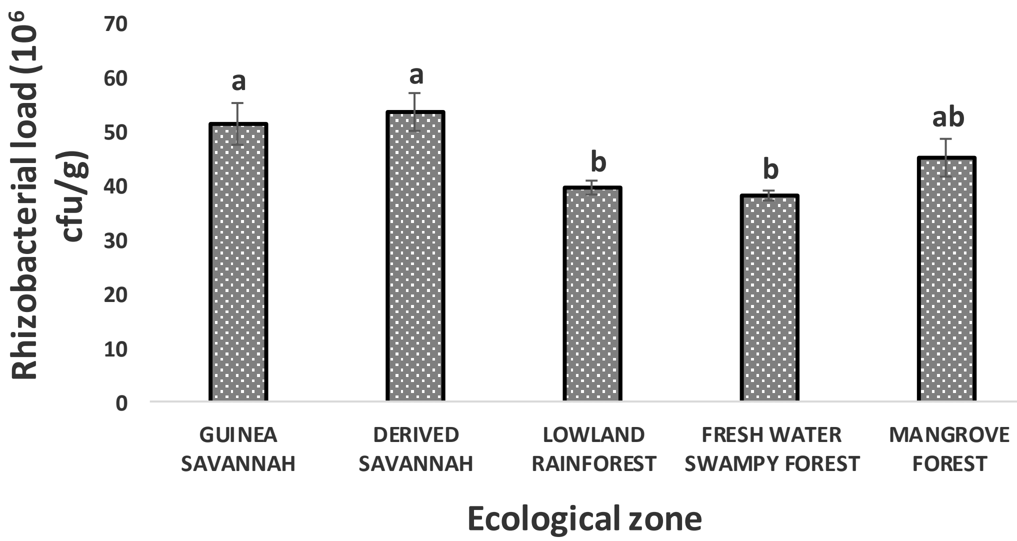

Figure 4. Rhizobacteria load based on source of collection (Rhizosphere / Soil) at 10^{-6} CFU/g soil. Means followed by the same letter (s) are not significantly different (P ≤ 0.05) according to Student-Newman-Keuls Test. The results shown are means ± standard error (n=5).

had extremely high available P that was 6-fold higher than other EZs. The extremely high available phosphorus observed in DS soil sample could be a result of consistent use of poultry manure. Our study, therefore, supports the reports of Adeleye and Ayeni (2009) and Ayeni (2011) that poultry manure may have enhanced the soil phosphorus. Ayeni (2010) have also demonstrated that the use of animal manures and agricultural wastes improves soil fertility maintenance. Regarding potassium content (Table 3), DS had the highest (0.53 cmol+/kg) while FW and MF were lowest. The calcium contents were within the expected standard (>1.6) across the EZs (Table 3) but GS, FW and MF had low calcium contents compared to others. Potassium and calcium were moderately high (Eludoyin and Wokocha, 2011), whereas magnesium and sodium were adequate and significantly ($P < 0.05$) varied from low to medium quantity across the EZs (Table 3) based on the soil nutrient critical level for SWN (Agboola and Ayodele, 1985; FMANR, 1990). Even though potassium and calcium were observed to be dominant among the exchangeable cations, their effect may not be significant in comparison to the low content of magnesium and sodium that can limit maize growth (Kang, 1981). Apart from copper, which was generally low in MF in comparison to other EZs (Table 3), more than 80% of the soils in the EZs showed high zinc, manganese and iron and were considered adequate (Agboola and Ayodele, 1985; FMANR, 1990) for maize growth far beyond the observation reported by Ayodele and Omotosho (2008).

Maize is a staple and popular food for the populace of Nigeria, and mostly intercropped with crops like cassava, vegetables and yam in subsistence farming due to the decrease in virgin land (Aweto et al., 1992). Therefore, nutrient depletion observed in soils of maize fields in SWN may be associated with the history of continuous intercropping of cassava and maize in most of the EZs. This finding reaffirms the report of Aweto et al. (1992) that continuous intercropping of cassava and maize appeared to have a greater degrading effect on soil in terms of soil organic matter, total nitrogen, and available phosphorus. Similarly, extensive use of chemicals as fertilizer to improve plant health and productivity and for control of pathogens has disturbed the ecological balance of soil and has led to the depletion of nutrients (Molina-Santiago and Matilla, 2020). Further physical and chemical degradation of soil in maize fields of SWN will not only increase food insecurity, but it will also degrade soil biodiversity beyond restoration.

Variation in rhizobacterial loads in maize fields across the EZs in SWN

Despite the acknowledged importance of rhizobacteria in SWN for plant growth (Abiala et al., 2015), little is known about their ecological variation especially in maize fields of SWN. Based on the composite soil from each ecological zone, GS and DS had the highest rhizobacterial loads (Figure 4). We attribute the high rhizobacterial loads in GS and DS to the high level of soil nutrients found in that EZ (Akinde et al., 2020; Trivedi et al., 2020). Rhizobacterial loads in the EZs compared favourably with most agricultural soils (Orole and Adejumo, 2011). Studies have shown that microbial load changes with host specificity, geographical distribution, plant age, and tissue type (Kobayashi and Palumbo, 2000). Several factors may be responsible for the variation of the rhizobacteria loads. For example, nutritional status of the maize cultivars, soil

Table 4. Correlation coefficient between selected physico-chemical properties and rhizobacteria load.

Correlation	pH	MC	RB	OC	N
pH	1.00				
MC	- 0.36	1.00			
RB	0.40	- 0.30	1.00		
OC	0.14	0.10	0.05	1.00	
N	0.05	0.23	0.06	0.96	1.00

pH, MC = Moisture Content, RB = Rhizobacteria, OC = Organic Carbon, N = Nitrogen.

structure, micronutrient status of the soil, and root morphology, physiology, age, or emergence (Akinde et al., 2020) may have directly or indirectly influenced the variation observed in bacterial load in this study.

Relationship between soil physical and chemical factors and rhizobacterial population

The soil pH, moisture content, organic carbon and nitrogen were selected to ascertain their relationship with rhizobacteria across the EZs (Table 4) because they are essential factors in crop production (Zhou et al., 2019). The soil pH and moisture content negatively correlated (r = -0.36); this negative correlation is a common observation due to climate and hydrological differences (Minasny et al., 2017). On the other hand, the soil pH was positively correlated with rhizobacteria (r = 0.4). Sangakkara et al. (1993) stated that larger bacterial population in maize rhizosphere are due to optimum soil pH (Higa and Wididana, 1989), which also influences uptake of nutrients into the maize tissues (Oyekanmi et al., 2008). This implies that EZs with appropriate soil pH and adequate rhizobacteria population should experience good soil quality (Abiala et al., 2015), further supporting the increased soil fertility of DS among the EZs. The soil moisture content was negatively correlated with the rhizobacteria (r = -0.30). This suggests that the low bacterial population experienced by GS and FW could be as a result of shortage of water, probably due to irregularity in rainfall during the collection of the soil samples. Also, excess soil water due to flooding may have affected the bacterial population in the rhizosphere of the maize field in LR, FW and MF. In contrast, the correlation between organic carbon and rhizobacteria was not as strong as expected (r = 0.05), this suggests that organic carbon had no influence. Nitrogen was also only weakly correlated with rhizobacteria. Previous studies have shown that both nitrogen and organic carbon are important in sustaining soil quality, crop production, and environmental protection (Akinde et al., 2020). However, we found that over 60% of the studied soils in the EZs of SWN had adequate nitrogen, while low organic carbon was exhibited across the board. The variation observed may be associated with plant and animal manure/residue inputs (Han et al., 2015; Wakelin et al., 2016; Zhou et al., 2019) across the EZs because this would also affect the rhizobacteria (Trivedi et al., 2016).

Next, we further considered the relationship among physicochemical factors and rhizobacteria using PCA (Figure 5). The PC1 and PC2 accounted for 51 and 27% of the variance, respectively. The rhizobacteria loads positively correlated with soil pH as well as the available phosphorus and zinc (Lagos et al., 2015). On the same PCA, rhizobacterial loads negatively correlated with soil moisture content (Trivedi et al., 2016). The PCA also indicates that both MF and DS have higher rhizobacterial loads, soil pH, available phosphorus, and zinc than the other three zones on PC2, but MF and DS differ in contents of sand, organic carbon, nitrogen, iron, calcium, manganese and magnesium on PC1. More so, among the EZs, the soil physicochemical properties and rhizobacteria loads negatively drifted away from FW. Thus, this suggests that the soil physicochemical properties and rhizobacteria loads have the potentials to vary based on each EZ.

Conclusions

Generally, the study revealed variation in soil nutrient reserves across the ecological zones in southwestern Nigeria according to Federal Ministry of Agriculture and Natural Resources Agronomic Guidelines. In comparison to the Federal Ministry of Agriculture and Natural Resources Agronomic Guidelines, 70% of the collected soil samples have declined in their chemical nutrients which may have directly affect the rhizobacterial loads. Moreso, the rhizobacterial loads trend with the soil physical properties and chemical contents across the ecological zones. Based on the ecological zones, only the soil of DS maintained adequate soil physical properties, chemical contents and rhizobacterial loads. Thus, to the best of our knowledge, this is the first report that revealed differences in soil physical properties, chemical contents and rhizobacterial loads across the five EZs because of their importance in determining soil quality for maize

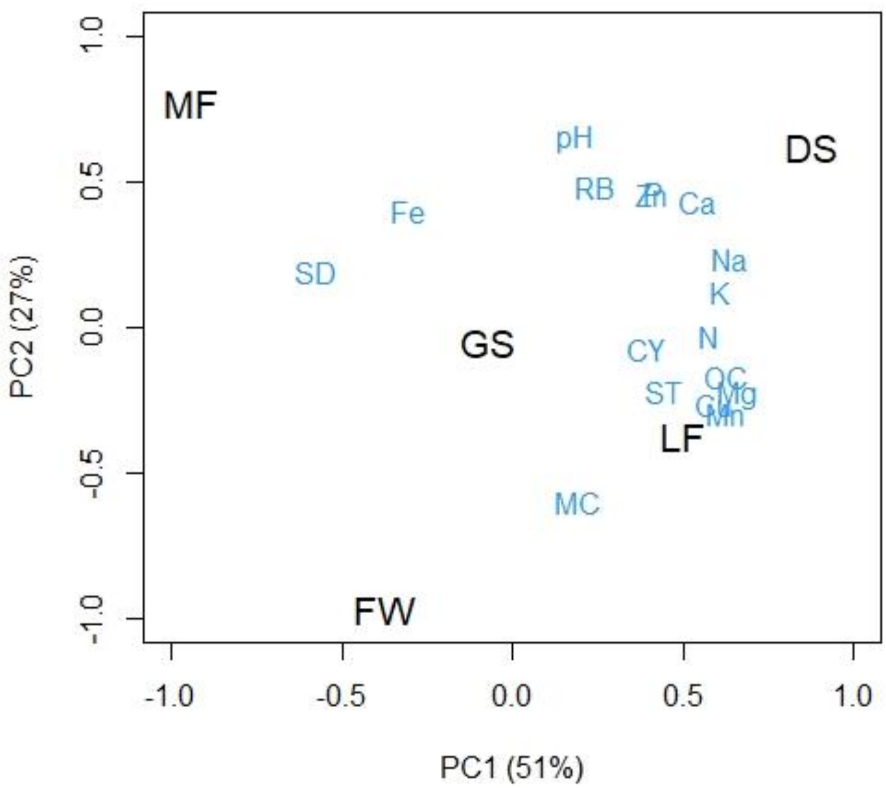

Figure 5. Principal component analysis (PC1 and PC2) showing relationship effect between soil physico-chemical properties and rhizobacteria loads across the EZs. MC = Moisture Content, N = Nitrogen, K = Potassium, OC = Organic Carbon, P = Potassium, RB = Rhizobacteria, CY = Clay, ST = Silt, SD = Sand, Na = Sodium, Ca = Calcium, Mn = Manganese, Zn = Zinc, Mg = Magnessium, Fe = Iron, GS = Guinea savannah, DS = Derived savannah, LR = Lowland rain forest, FW = Freshwater swampy forest, MF = Mangrove forest.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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SUPPLEMENTARY DATA

Table S1: Criteria for soil test interpretation and soil fertility classes in Southwestern Nigeria.

		Fertility class		
Soil properties	Criteria level	Low	Medium	High
Acidity (pH)	-	6.0-6.9	5.0-5.9	<5.0
Organic matter (%)	2.00	0-2.0	2.0-3.0	>3.0
Total N (%)	0.15	0-0.15	0.15-0.20	>0.20
Available P (mg kg^{-1})	8.50	0-8.5	8.5-12.5	>12.5
Exchangeable K (cmol kg^{-1})	0.16	0-0.16	0.16-0.31	>0.31
Mg (cmol kg^{-1})	0.28	-	-	-
Ca (cmol kg^{-1})	1.50	0-1.5	1.6-4.0	>4.0
Available S (mg kg^{-1})	5.00	0-5.0	5.0-7.0	>7.0
Zn (mg kg^{-1})	1.00	0-1.0	1.0-1.5	>1.5
Cu (mg kg^{-1})	0.50	0-0.5	0.5-0.7	>0.7
B (mg kg^{-1})	0.50	0-0.5	0.5-0.6	>0.6
Fe (mg kg^{-1})	3.50	-	-	-
Mn (mg kg^{-1})	3.00	-	-	-

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Source: Agboola and Ayodele (1985).