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Examination of Radiocarbon Levels, Organic Matter, Phosphorus, and Potassium in Acidic Soils under Maize Cultivation in Akwa Ibom State, Nigeria

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Abstract

This study examined the dynamics of radiocarbon (^{14}C), organic matter, phosphorus, and potassium levels in acidic soils across three locations (Ntak Inyang Itam, Nto Ndanga, and Ikot Akpaden) under a maize cropping system in Akwa Ibom State, Nigeria. The control treatment exhibited a negative $\Delta^{14}C$ value (-80‰), whereas compost and manure applications resulted in positive $\Delta^{14}C$ values (50‰ and 30‰, respectively). When combined with NPK fertilizer, $\Delta^{14}C$ values remained positive but slightly lower (40‰ for compost + NPK and 25‰ for manure + NPK). Organic matter content was highest in combined treatments (3.2% for compost + NPK and 3.5% for manure + NPK), followed by manure (3.0%), compost (2.8%), and NPK alone (1.8%), while the control had the lowest (1.5%). Phosphorus availability increased from 5.2 mg/kg in the control to 12.5 mg/kg with compost, 15.3 mg/kg with manure, and 20.4 mg/kg with NPK. The highest values occurred in combined treatments (25.8 mg/kg for compost + NPK and 28.1 mg/kg for manure + NPK). Potassium availability followed a similar trend, peaking at 0.55 cmol/kg (manure + NPK). Maize yields were lowest in the control (1.2 t/ha) and highest in combined treatments (4.2 t/ha for compost + NPK, 4.5 t/ha for manure + NPK). These findings advanced the understanding of carbon sequestration in acidic soils and highlighted the impact of organic and inorganic amendments on ^{14}C dynamics and soil fertility.

Keywords: Acid sands, Radiocarbon, Organic Matter, Phosphorus, Potassium.

INTRODUCTION

Acid soils are widespread globally and are often characterized by low organic matter content, which affects carbon cycling and the distribution of radiocarbon (14C). This study sought to assess the impact of maize cultivation on 14C concentrations in different soil layers of coastal plain sand (CPS), sandstone (SS), and Beach Ridge sand (BRS). It also aimed to examine the potential depletion of 14C due to soil acidity and investigate the relationship between 14C concentration and soil organic matter content (Okon and Bassey, 2020).

Acid sands, also referred to as Ultisols, are common in southeastern Nigeria, including Akwa Ibom State. These soils are known for their acidic nature (low pH), low base saturation, and high aluminum saturation. The region's tropical climate, marked by high rainfall, leads to intense leaching, which depletes vital nutrients like phosphorus (P) and potassium (K), making them less accessible to crops (Eze *et al.,* 2022). In Akwa Ibom State, maize (Zea mays) is an essential staple crop, cultivated predominantly under traditional, low-input farming systems. These practices typically involve minimal fertilizer and organic amendment usage, which progressively depletes soil nutrients. Maintaining soil fertility in acid sands is challenging due to the need to balance crop productivity with sustainable land management practices (Olatunji & Ayolagha, 2021).

Radiocarbon (14C) is a naturally occurring isotope that helps trace the age and turnover of soil organic matter (Trumbore, 2021). By measuring radiocarbon concentrations in soil, researchers gain valuable insights into soil carbon dynamics and the stability of organic matter pools. In tropical soils, where organic matter turnover is rapid, understanding 14C levels is essential for evaluating long-term soil fertility and carbon sequestration potential (Hoffman *et al.,* 2020).

In agricultural systems, organic material incorporation can influence the radiocarbon signature of soil organic matter. Practices that encourage the addition of young, rapidly decomposing organic matter can increase the proportion of modern radiocarbon in soils, signifying faster organic matter turnover. Conversely, the accumulation of older, more stable organic matter may show lower radiocarbon concentrations, indicating longer residence times and potentially more stable soil carbon pools (Trumbore, 2021).

Soil organic matter (SOM) is a vital component of soil health, influencing various physical, chemical, and biological soil properties. It improves soil structure, water retention, and nutrient availability, especially in nutrient-poor soils like acid sands (Hoffman *et al.,* 2020). SOM's role in nutrient cycling and its ability to sequester carbon make it central to sustainable soil management. However, in acid sands, the decomposition of organic matter can be rapid due to the high temperatures and microbial activity in tropical climates, leading to organic carbon loss and decreased soil fertility over time (Trumbore, 2021).

The addition of organic matter through practices like cover cropping, residue management, and applying organic amendments (e.g., compost and manure) has been shown to improve acid sand fertility. These methods enhance soil carbon levels and increase the cation

exchange capacity (CEC), making nutrients such as phosphorus and potassium more available to crops (Nwoke *et al.,* 2020).

Phosphorus is a critical nutrient for plant growth, but its availability in acid sands is often limited due to its strong fixation by iron and aluminum oxides, which is worsened by the soils' acidic conditions (Olusola *et al.,* 2022). This fixation process reduces phosphorus availability to plants, which can severely restrict crop growth and yield, particularly in maize cropping systems. While phosphorus fertilizers are commonly used to address P deficiencies, managing this practice is essential in acid sands to prevent environmental issues like runoff and eutrophication (Udo and Eshiet, 2019). The effectiveness of phosphorus fertilization in these soils can be enhanced by liming to raise soil pH and incorporating organic amendments to help release phosphorus bound to soil particles (Nwokeocha & Akpan, 2021).

Potassium is another crucial nutrient for crop growth, involved in various physiological processes, including enzyme activation, photosynthesis, and osmoregulation. In acid sands, potassium is often deficient due to leaching and the inherently low potassium reserves of these soils (Baiyeri & Uzo, 2019). Effective potassium management is essential for ensuring sustainable crop production, especially for high-demand crops like maize. Studies indicate that regular potassium fertilizer application, combined with practices that reduce leaching (such as mulching and conservation tillage), can help maintain adequate potassium levels in acid sands. Furthermore, recycling crop residues containing significant potassium amounts can be a cost-effective strategy to replenish soil potassium (Ekpo & Udo, 2023).

Objectives of the Study

This study aims to evaluate the radiocarbon concentration in acid sands under maize cropping systems in Akwa Ibom State. The specific objectives are to:

(i) Assess the organic matter content and its influence on soil fertility in the study area;
(ii) Determine the availability and distribution of phosphorus and potassium in acid sands under maize cultivation;
(iii) Analyze the relationship between radiocarbon concentration and soil organic matter dynamics in these soils;
(iv) Provide recommendations for sustainable soil fertility management practices that can enhance maize production in the region.

Statement of the Problem

The agricultural productivity of acid sands in Akwa Ibom State, Nigeria, is significantly hindered by low soil fertility, particularly the deficiencies in vital nutrients like phosphorus (P) and potassium (K), as well as insufficient organic matter content. These soils are highly susceptible to leaching and nutrient fixation, which further limit their agricultural potential. Inadequate soil fertility management practices exacerbate this issue, leading to suboptimal maize yields, a crucial staple crop in the region. Additionally, the dynamics of soil organic matter and nutrient availability in these soils are not well understood, especially regarding radiocarbon (14C) concentration, which could provide valuable insights into soil organic matter turnover and

carbon cycling processes. Understanding these dynamics is critical for developing effective soil management strategies that can enhance soil fertility and support sustainable maize production in the region.

Significance of the Study

This study is significant as it addresses the pressing issue of soil fertility in acid sands, a common soil type in Akwa Ibom State and other southeastern Nigerian regions. By examining the radiocarbon concentration, organic matter, phosphorus, and potassium content in soils under maize cropping systems, the study aims to provide essential insights into nutrient dynamics and carbon cycling in these soils. The findings will help develop sustainable soil fertility management practices that can boost maize yields, improve soil health, and support smallholder farmers' livelihoods in the region. Moreover, this research will contribute to the broader understanding of soil organic matter turnover and nutrient availability in tropical acid sands, which is vital for informed agricultural policy-making.

Research Gaps and Future Directions

While extensive research has been conducted on soil fertility management in acid sands, gaps remain in understanding the long-term effects of various soil management practices on radiocarbon concentration, organic matter dynamics, and nutrient availability in these soils. Further research is needed to explore the interactions between organic matter, phosphorus, and potassium under different management practices and cropping systems. Additionally, studies focusing on the economic and environmental implications of different soil fertility management strategies will provide valuable insights for both policymakers and farmers (Ekpo & Udo, 2023). This study offers a comprehensive examination of radiocarbon concentration, organic matter, phosphorus, and potassium in acid sands under maize cropping systems in Akwa Ibom State, highlighting the challenges and opportunities in managing soil fertility in these soils and setting the stage for further research in this area.

MATERIALS AND METHODS

Area of the Study

This research was conducted in Akwa Ibom State, located in the Niger Delta Region of Nigeria, which includes the states of Akwa Ibom, Bayelsa, Cross River, Edo, Delta, and Rivers. The region is situated between latitudes 04°41’50" and 04°41’48"N, and longitudes 07°41’06"E and 07°41’03"E. The climate of the area typically falls within the range of 26°C to 28°C, with a relative humidity of 75-80%. Akwa Ibom State lies in the southeastern part of Nigeria, within the Niger Delta region, specifically between latitudes 4°32′ and 5°33′ N and longitudes 7°25′ and 8°25′ E. The state experiences a tropical monsoon climate, featuring two main seasons: a prolonged wet season from March to November and a brief dry season from December to February. Annual rainfall varies from 2,000 mm to 3,500 mm, with an average annual temperature of 26-28°C. The predominant soil type in Akwa Ibom is acid sand, primarily categorized as Ultisols, which are highly weathered, acidic, and poor in essential nutrients such as phosphorus and potassium. These soils are susceptible to erosion and leaching, particularly

when subjected to intensive farming. The region's economy is predominantly agricultural, with maize being a key crop. Most farming is on a small scale, relying heavily on rain-fed agriculture and limited use of chemical fertilizers and soil amendments.

Research Design

This study employed an experimental research design, specifically focused on field trials to assess the radiocarbon concentration, organic matter, phosphorus, and potassium content of acid sands under a maize farming system in Akwa Ibom State, Nigeria. The research was organized into several stages, including soil sampling, field experimentation, laboratory analysis, and data interpretation. Both quantitative and qualitative methods were used to provide a comprehensive understanding of the soil properties and their impact on maize productivity.

Soil Sampling Method

Farms from various regions of Akwa Ibom State were selected based on their history of maize cultivation on acid sands. The selection also accounted for differences in soil management practices, topography, and proximity to urban centers. Soil samples were collected using a soil auger at two depth intervals: 0-15 cm for topsoil and 15-30 cm for subsoil. A composite sampling approach was used, combining several subsamples from each site to form a representative sample. The soil samples were then air-dried, sieved through a 2 mm mesh, and stored in labeled polyethylene bags for laboratory analysis.

Field Experimentation

The field trials were designed using a randomized complete block design (RCBD) with three replicates per treatment. The treatments included various soil fertility management practices, such as organic amendments (compost, manure), inorganic fertilizers (phosphorus and potassium fertilizers), and a control (no amendments). Maize was planted according to standard agronomic practices, using a locally grown variety that is relevant to the farming community. All experimental plots underwent the same cultural practices, including weeding, pest control, and irrigation, ensuring that the only variable was the soil treatment.

Laboratory Soil Property Analysis

The soil samples were analyzed for radiocarbon (14C) concentration using accelerator mass spectrometry (AMS). This involved isolating the soil organic matter, which was then combusted to convert carbon to CO2. The resulting CO2 was analyzed for its radiocarbon content. The organic matter content was determined using the Walkley-Black method, where organic matter is oxidized by potassium dichromate in an acidic medium. Available phosphorus was assessed using the Bray-1 method, which involves extracting phosphorus using an acidic fluoride solution and measuring its concentration colorimetrically. Exchangeable potassium was extracted using 1M ammonium acetate at pH 7.0, with the concentration measured by flame photometry.

Statistical Analysis of Data

The collected data were analyzed using statistical software such as SPSS or R. Analysis of variance (ANOVA) was used to examine the effects of different treatments on soil properties and maize yield. Pearson correlation analysis was conducted to assess the relationships between radiocarbon concentration, soil organic matter, phosphorus, and potassium content. Additionally, multiple regression analysis was employed to predict maize yield based on the soil properties measured.

Data Interpretation and Reporting

(i) The results were interpreted in terms of how soil fertility management practices influence radiocarbon concentration and nutrient dynamics in acid sands.

(ii) A comparative analysis was performed to identify the most effective soil management practice for improving maize productivity in the region. The findings were compiled into a comprehensive research report, which included discussions on the implications for soil management practices in Akwa Ibom State and offered recommendations for local farmers and policymakers.

Ethical Considerations

Permission was obtained from local farmers and landowners before conducting soil sampling and field trials on their properties. The research was carried out in a way that minimized environmental disruption, ensuring that all experimental plots were restored to their original condition after the study.

RESULTS

The investigation presented in this study is summarized through six tables, each reflecting the findings related to specific objectives of the research titled "Evaluation of Radiocarbon Concentration, Organic Matter, Phosphorus, and Potassium Content of Acid Sands under Maize Cropping System in Akwa Ibom State, Nigeria."

Table 1: Radiocarbon Concentration (Δ14C) in Acid Sands (Bulk from the three locations) under Different Soil Management Practices

This table addresses the objective of assessing the radiocarbon concentration in soil under various treatments. The results reflect the age of carbon inputs, with positive values indicating newer carbon and negative values suggesting older carbon.

Treatments	Radiocarbon Concentration (Δ14C)‰
Control (No Amendment)	-80 ± 0.01
Compost Application	50 ± 0.03
Manure Application	30 ± 0.12

Treatments	Radiocarbon Concentration (Δ14C)‰
NPK Fertilizer	-20 ± 0.01
Compost + NPK Fertilizer	40 ± 0.25
Manure + NPK Fertilizer	25 ± 0.03

Data represents the mean of three replicate determinations ± standard deviation.

The findings demonstrate that radiocarbon concentration varies significantly with different treatments. The positive Δ14C values from organic treatments (compost and manure) suggest that recent carbon inputs are influencing organic matter turnover, indicating a relationship between radiocarbon concentration and soil organic matter dynamics. Specifically, the control treatment had negative radiocarbon concentration, suggesting older carbon pools with minimal recent organic matter input. Organic amendments, both individually and in combination with NPK fertilizers, resulted in positive Δ14C values, reflecting more recent carbon inputs.

Table 2: Soil Organic Matter Content (%) in Acid Sands (Bulk from the three locations) under Different Soil Management Practices

This table presents the soil organic matter content under various treatments, crucial for understanding the soil's nutrient retention capacity.

Treatments	Soil Organic Matter (%)
Control (No Amendment)	1.5 ± 0.01
Compost Application	2.8 ± 0.01
Manure Application	3.0 ± 0.02
NPK Fertilizer	1.8 ± 0.01
Compost + NPK Fertilizer	3.2 ± 0.20
Manure + NPK Fertilizer	3.5 ± 0.02

Data shows the mean of three replicate determinations ± standard deviation.

The treatments with organic amendments significantly improved soil organic matter content. Notably, the highest organic matter content was observed in the manure + NPK fertilizer treatment, indicating that organic amendments (compost and manure) significantly increased soil organic matter compared to the control. The combined treatments (compost + NPK fertilizer and manure + NPK fertilizer) led to the highest increases in organic matter.

Table 3: Available Phosphorus (mg/kg) in Acid Sands (Bulk from the three locations) under Different Soil Management Practices

This table focuses on the phosphorus availability in the soil, a crucial nutrient for plant growth.

Treatments	Available Phosphorus (mg/kg)
Control (No Amendment)	5.2 ± 0.02
Compost Application	12.5 ± 0.04

Treatments	Available Phosphorus (mg/kg)
Manure Application	15.3 ± 0.06
NPK Fertilizer	20.4 ± 0.21
Compost + NPK Fertilizer	25.8 ± 0.16
Manure + NPK Fertilizer	28.1 ± 0.23

Data shows the mean of three replicate determinations ± standard deviation.

Phosphorus availability was influenced by the type of soil amendment used. The results indicate that phosphorus levels were lowest in the control treatment. The application of organic amendments, whether compost or manure, enhanced phosphorus availability. The highest phosphorus availability was observed in treatments combining organic amendments with NPK fertilizers, suggesting a synergistic effect.

Table 4: Exchangeable Potassium (cmol/kg) in Acid Sands (Bulk from the three locations) under Different Soil Management Practices

This table provides data on the availability of exchangeable potassium, a key nutrient for crop growth.

Treatments	Exchangeable Potassium (cmol/kg)
Control (No Amendment)	0.12 ± 0.01
Compost Application	0.28 ± 0.12
Manure Application	0.35 ± 0.02
NPK Fertilizer	0.40 ± 0.01
Compost + NPK Fertilizer	0.50 ± 0.01
Manure + NPK Fertilizer	0.55 ± 0.02

Data shows the mean of three replicate determinations ± standard deviation.

The control treatment had the lowest potassium levels (0.12 cmol/kg), while the organic amendments (compost and manure) increased potassium availability. The highest levels of exchangeable potassium were found in treatments combining organic amendments with NPK fertilizer, particularly the manure + NPK fertilizer treatment.

Table 5: Maize Yield (t/ha) in Response to Different Soil Management Practices

This table evaluates the impact of different soil management practices on maize yield.

Treatments	Maize Yield (t/ha)
Control (No Amendment)	1.2 ± 0.01
Compost Application	3.4 ± 0.01
Manure Application	3.8 ± 0.02
NPK Fertilizer	3.6 ± 0.01

Treatments	Maize Yield (t/ha)
Compost + NPK Fertilizer	4.2 ± 0.01
Manure + NPK Fertilizer	4.5 ± 0.02

Data shows the mean of three replicate determinations ± standard deviation.

The maize yield was highest in the manure + NPK fertilizer treatment, followed by the compost + NPK fertilizer treatment. These findings suggest that combining organic amendments with NPK fertilizers enhances soil fertility and crop productivity, significantly improving maize yields compared to the control.

Table 6: Summary Results of Soil Properties and Maize Yield under Different Soil Management Practices

This table provides a comprehensive overview of the soil properties and maize yields under various treatments.

Treatments	Radiocarbon Concentration (Δ14C)‰	Soil Organic Matter (%)	Available Phosphorus (mg/kg)	Exchangeable Potassium (cmol/kg)	Maize Yield (t/ha)
Control (No Amendment)	-80 ± 0.01	1.5 ± 0.01	5.2 ± 0.02	0.12 ± 0.01	1.2 ± 0.01
Compost Application	50 ± 0.03	2.8 ± 0.01	12.5 ± 0.04	0.28 ± 0.12	3.4 ± 0.01
Manure Application	30 ± 0.12	3.0 ± 0.02	15.3 ± 0.06	0.35 ± 0.02	3.8 ± 0.02
NPK Fertilizer	-20 ± 0.01	1.8 ± 0.01	20.4 ± 0.21	0.40 ± 0.01	3.6 ± 0.01
Compost + NPK Fertilizer	40 ± 0.25	3.2 ± 0.20	25.8 ± 0.16	0.50 ± 0.01	4.2 ± 0.01
Manure + NPK Fertilizer	25 ± 0.03	3.5 ± 0.02	28.1 ± 0.23	0.55 ± 0.02	4.5 ± 0.02

Data shows the mean of three replicate determinations ± standard deviation.

This summary highlights how different soil management practices influence various soil properties and maize yield, emphasizing the significance of combining organic amendments with NPK fertilizers for optimal soil fertility and crop production.

DISCUSSION

The study revealed notable differences in radiocarbon concentrations across various soil management practices. The control treatment had a negative Δ14C value (-80‰), indicating older carbon pools, which is typical for soils with low organic matter input and poor

management (Trumbore, 2021). In contrast, the addition of compost and manure resulted in positive Δ14C values (50‰ and 30‰, respectively), suggesting the incorporation of newer carbon into the soil. This highlights that these organic amendments effectively enhance soil carbon dynamics, crucial for maintaining soil fertility and resilience (Hoffman *et al.,* 2020).

When organic amendments were combined with NPK fertilizer, the Δ14C values remained positive but were slightly lower (40‰ for compost + NPK and 25‰ for manure + NPK) compared to the organic amendments alone. This suggests that while synthetic fertilizers improve nutrient availability, they may not significantly contribute to soil carbon sequestration compared to organic inputs. These findings are consistent with research emphasizing the importance of organic matter in enhancing soil carbon stocks and stability (Lehmann & Kleber, 2015).

Organic matter content is a crucial indicator of soil health, influencing nutrient availability, water retention, and microbial activity. The results showed significantly higher organic matter content in soils treated with compost (2.8%) and manure (3.0%) compared to the control (1.5%). This aligns with findings from Powlson et al. (2011), who emphasized that organic amendments are essential for replenishing soil organic matter, particularly in degraded soils.

The impact of NPK fertilizer alone on organic matter content was modest (1.8%), as inorganic fertilizers do not contribute organic material. However, combined treatments (3.2% for compost + NPK and 3.5% for manure + NPK) led to the highest organic matter content, suggesting a synergistic effect where organic amendments enhance the effectiveness of inorganic fertilizers, promoting nutrient cycling and soil structure (Palm *et al.,* 2014).

Phosphorus availability is vital for plant growth, particularly in acidic soils where phosphorus is often bound and unavailable. The control treatment had the lowest phosphorus availability (5.2 mg/kg), reflecting phosphorus fixation common in acid sands (Obi *et al.,* 2022). The addition of compost and manure increased phosphorus availability to 12.5 mg/kg and 15.3 mg/kg, respectively, by reducing phosphorus fixation and enhancing its availability to plants (Olusola *et al.,* 2022).

NPK fertilizer alone increased phosphorus availability to 20.4 mg/kg, as expected from direct phosphorus supplementation. However, the highest phosphorus levels were recorded with combined treatments of compost + NPK (25.8 mg/kg) and manure + NPK (28.1 mg/kg), supporting the findings of Eze et al. (2022) that organic amendments can enhance phosphorus availability by improving soil structure and microbial activity, which improves fertilizer efficiency.

Potassium, another essential nutrient often deficient in acid sands, was lowest in the control treatment (0.12 cmol/kg). Organic amendments like compost (0.28 cmol/kg) and manure (0.35 cmol/kg) increased potassium availability, likely due to slow potassium release during organic material decomposition and improved soil CEC (Abdul Rahman *et al.,* 2023).

NPK fertilizer increased potassium availability to 0.40 cmol/kg, but the highest potassium levels were seen in the combined treatments (0.50 cmol/kg for compost + NPK and 0.55 cmol/kg for manure + NPK), reinforcing findings by Ogunlade and Akinbode (2021) that integrated nutrient management enhances potassium availability by improving both immediate and long-term soil fertility.

The maize yield data clearly highlighted the advantages of improved soil management. The control treatment produced the lowest yield (1.2 t/ha), reflecting the poor fertility of untreated acid sands. Organic amendments significantly boosted yields (3.4 t/ha for compost and 3.8 t/ha for manure), aligning with multiple studies showing that organic matter positively affects crop yields (Nwoke *et al.,* 2020).

NPK fertilizer also increased yields (3.6 t/ha), but the highest yields were achieved with combined treatments (4.2 t/ha for compost + NPK and 4.5 t/ha for manure + NPK). These results emphasize the effectiveness of integrated soil fertility management, combining the benefits of both organic and inorganic inputs to maximize crop productivity (Ekpo & Udo, 2023). This approach is especially beneficial in areas with poor soils, as it ensures a balanced nutrient supply, improves soil health, and enhances crop resilience (Palm *et al.,* 2014).

Value Added to Knowledge

(i) By examining phosphorus and potassium levels, this study provides insights into optimizing fertilizer use in maize cropping systems on acid sands, promoting efficient nutrient application and potentially reducing costs and environmental impacts.
(ii) Investigating radiocarbon concentration enhances understanding of carbon cycling in tropical soils, contributing to strategies for carbon sequestration and climate mitigation in agriculture.
(iii) The study clarifies how organic matter can improve soil quality in acid sands, impacting nutrient availability, soil structure, and moisture retention.
(iv) The results offer practical recommendations for soil management, improving maize yields for farmers in Akwa Ibom and similar regions.
(v) This research promotes sustainable practices in managing acid sands, supporting long-term soil health and productivity amidst challenges like soil acidity and nutrient limitations.

Recommendations

Based on the findings of the study it was recommended that:

(i) Farmers should be encouraged to adopt integrated soil fertility management practices, combining organic amendments (like compost and manure) with inorganic fertilizers to maximize nutrient availability, enhance soil organic matter, and improve crop yields.
(ii) Organic amendments should be promoted, especially in regions with acid sands, as they not only improve soil fertility but also enhance radiocarbon concentration, indicating improved carbon dynamics in the soil.

(iii) Fertilizer application should be tailored to the specific soil conditions, recommending combined organic amendments and phosphorus fertilizers for soils with high phosphorus fixation capacity to enhance phosphorus availability.
(iv) Sustainable soil management practices, including crop rotation, cover cropping, and reduced tillage, should be integrated with soil fertility management to preserve soil health and prevent degradation.
(v) Extension services should be strengthened to educate farmers about the benefits of integrated soil fertility management and provide guidance on best practices for specific soil conditions. Training programs and demonstration farms can help farmers adopt these practices effectively.
(vi) Governments and agricultural institutions should consider offering subsidies or support for organic inputs like compost and manure to encourage their use among smallholder farmers, particularly in areas with degraded soils.

Conclusion

Based on the findings of the study the following conclusions were made:

(i) The study highlights the importance of integrating organic amendments with inorganic fertilizers to enhance soil fertility and crop productivity in acid sands.
(ii) It emphasizes that combining organic and inorganic amendments improves soil fertility and crop yields in nutrient-poor acid sands of Akwa Ibom State.
(iii) The findings demonstrate that such integrated approaches enhance nutrient availability, improve soil health by increasing organic matter, and promote better carbon dynamics.
(iv) These strategies are essential for sustainable agriculture, particularly in regions with degraded soils like Akwa Ibom State.
(v) The results provide valuable insights for policymakers and agricultural extension services to support sustainable agriculture strategies in the region.
(vi) By implementing these recommendations, farmers can improve soil health, increase agricultural productivity, and contribute to the long-term sustainability of their farming systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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