Production and Application of Carbonized Rice Husk and Vermicompost: A Sustainable Approach to Enhancing Soil Fertility and Household Food Security in Nigeria

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Abstract
This study investigated the production process and effectiveness of an organic fertilizer derived from carbonized rice husk and vermicompost. This study adopts a Randomized Complete Block Design (RCBD) to evaluate the effects of different treatments of carbonized rice husk and vermicompost on soil fertility, crop yield, and economic outcomes. The experiment was conducted both in controlled conditions (greenhouse) and in field trials to ensure comprehensive results. The research focused on the step-by-step method of production, its environmental sustainability, and its potential to improve soil health and boost agricultural productivity. The research explored the economic feasibility and its impact on household food security in the production of Maize (Zea mays) in the study area. Households using carbonized rice husk and vermicompost reported increased access to nutritious food, which improved their food security index by an average of 30%. Soil fertility improved most significantly under CRH+VC, indicating synergistic effects. Conclusively, the study recommends that categorized, practical, and prioritized steps in the Production and Application of Carbonized Rice Husk (CRH) and Vermicompost as sustainable inputs to improve soil fertility and household food security in Nigeria.

Keywords: Carbonized Rice Husk, Vermicompost, Fertilizer, Food Security, and Maize Production

1. Introduction

Food security remains a critical challenge in Nigeria, where the agricultural sector faces limitations from soil fertility decline, high costs of conventional fertilizers, and unsustainable farming practices. The increasing need for sustainable, eco-friendly alternatives has brought attention to organic fertilizers, such as carbonized rice husk and Vermicompost. These materials can improve soil quality, reduce input costs, and promote long-term agricultural productivity. The use of carbonized rice husk and Vermicompost offers potential not only for improving crop yield but also for advancing household food security. This concept note aims to explore the economic viability of these alternative fertilizers for Nigerian farmers, especially at the household level, while also assessing their impact on food security indicators.

Agriculture plays a critical role in Nigeria's economy, providing livelihoods for the majority of the rural population. However, the agricultural sector faces significant challenges, particularly in terms of declining soil fertility, high costs of chemical fertilizers, and unsustainable farming practices. These issues contribute to low agricultural productivity,

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which in turn exacerbates food insecurity, especially at the household level in rural areas. Chemical fertilizers, while effective in boosting short-term yields, have several drawbacks. They are expensive, particularly for smallholder farmers, who often struggle to afford sufficient quantities. Additionally, prolonged use of chemical fertilizers depletes soil nutrients, leading to environmental degradation and long-term reduction in soil fertility. This, in turn, affects crop yields and further threatens food security. As the cost of chemical inputs rises, more farmers are at risk of being unable to maintain adequate food production, worsening their financial situation and access to nutritious food. Given these challenges, there is a growing need to explore sustainable alternatives that can improve soil health, reduce the dependence on expensive chemical inputs, and ultimately enhance household food security.

Organic fertilizers such as carbonized rice husk and vermicompost represent a promising solution. However, the economic scale, adoption feasibility, and impact of these alternative fertilizers on rural farmers and household food security in Nigeria have not been fully explored. This gap calls for a systematic study to assess the potential benefits of these organic fertilizers as sustainable agricultural inputs.

The use of chemical fertilizers has led to environmental degradation and soil infertility. Sustainable alternatives like carbonized rice husk and vermicompost offer eco-friendly solutions, but there is limited research on their combined production and application in Nigerian agriculture. This study seeks to address the gap by analyzing the production, economic benefits, and impact on food security.

Research Questions

1. How can carbonized rice husk and vermicompost be efficiently produced?
2. What is the economic feasibility of producing this organic fertilizer for smallholder farmers?
3. What is the impact of using the product on crop yield and household food security?

Hypothesis:

1. H_0: There is no significant difference in soil fertility between plots treated with carbonized rice husk and vermicompost fertilizer and those treated with synthetic fertilizer or left untreated.
2. H_0: There is no significant difference in crop yield between the experimental plots and the control plots.

Aim: Increased sustainable agricultural practices and enhanced household food security in Nigeria

Objectives of the Study

1. To develop a step-by-step process for the production of carbonized rice husk and vermicompost.
2. To assess the economic viability of using this combined product in agricultural practices.
3. To evaluate the impact of this fertilizer on soil fertility, crop yield, and household food security.

2. Literature Review

Soil Fertility and Food Security in Nigeria

Soil fertility plays a pivotal role in determining agricultural productivity and household food security. Nigeria, like many Sub-Saharan African countries, faces challenges of soil degradation, nutrient depletion, and declining crop yields due to continuous cultivation and overdependence on synthetic fertilizers (Bationo et al., 2018). Sustainable soil fertility management is therefore crucial for achieving food security, which is defined by the FAO (2021) as a state where "all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food." Organic inputs such as rice husk and vermicompost are increasingly being considered as affordable and eco-friendly alternatives to synthetic fertilizers (Adesemoye&Kloepper, 2009).

Carbonized Rice Husk (CRH) and Soil Improvement

Rice husk, an abundant agricultural by-product in Nigeria, is often discarded or burnt in open fields, contributing to environmental pollution. However, when carbonized, rice husk becomes a porous, stable soil amendment

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that improves soil aeration, water retention, and cation exchange capacity (Oguntade et al., 2020). Studies have shown that CRH enhances the availability of macronutrients such as phosphorus and potassium, which are essential for crop growth (Matsumura et al., 2019). CRH also reduces soil acidity and increases microbial activity, thereby creating a favourable environment for plant growth (Oni et al., 2022).

Vermicomposting and Its Role in Nutrient Recycling

Vermicomposting is the process of using earthworms to convert organic waste into nutrient-rich compost. The end product, vermicompost, is characterized by high concentrations of nitrogen, phosphorus, potassium, and beneficial microorganisms (Edwards et al., 2011). Unlike raw compost, vermicompost contains plant growth-promoting hormones such as auxins and gibberellins, which stimulate root development and crop yield (Sinha et al., 2010). Research in Nigeria has confirmed that vermicompost improves soil structure, enhances nutrient availability, and reduces dependence on expensive inorganic fertilizers (Yakubu et al., 2021).

Synergistic Effects of CRH and Vermicompost

Recent studies indicate that combining CRH and vermicompost provides synergistic benefits by simultaneously improving soil physical properties (from CRH) and chemical/nutritional properties (from vermicompost). CRH enhances soil porosity and water-holding capacity, while vermicompost enriches the soil with nutrients and beneficial microbes (Kaur et al., 2020). A study in Asia demonstrated that the CRH+VC combination increased maize yield by 35% compared to chemical fertilizers alone (Rahman et al., 2017). This combination has been highlighted as a cost-effective and environmentally sustainable alternative for smallholder farmers.

Organic Fertilizers and Household Food Security

Organic fertilizers such as CRH and VC not only improve soil fertility but also contribute to household food security by reducing input costs and enhancing crop yields. According to Oladipo et al. (2020), farmers who adopted organic fertilizers in northern Nigeria reported a 25–30% increase in yields and improved household nutrition due to better food availability. Additionally, organic fertilizers minimize environmental risks such as groundwater contamination and greenhouse gas emissions associated with chemical fertilizers (Lal, 2015).

Economic and Environmental Implications

The economic feasibility of CRH and vermicompost lies in their availability and affordability. Rice husk is a by-product of rice milling, while vermicompost can be produced using household and farm wastes, thereby reducing disposal problems (Ezeh&Okoro, 2019). The use of these organic inputs aligns with sustainable agricultural practices and supports climate-smart agriculture by enhancing soil carbon sequestration and reducing greenhouse gas emissions (Pretty et al., 2018). Their adoption, therefore, has both economic and ecological significance for Nigeria"s food security strategy.

a. Agricultural Sustainability and Food Security

The increasing demand for sustainable agricultural practices has prompted a shift toward eco-friendly inputs that ensure long-term productivity without damaging the environment (Suleiman, 2020). Food security, defined by the World Food Programme (WFP) as access to sufficient, safe, and nutritious food, remains a critical concern in Nigeria. The use of organic fertilizers, including vermicompost and carbonized rice husk, has been highlighted as a sustainable practice that improves food production systems (Nwosu&Akor, 2022).

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b. Alternative Fertilizers: Vermicompost and Carbonized Rice Husk

Research shows that vermicompost improves soil health by enhancing microbial activity, improving moisture retention, and providing essential nutrients (Kale et al., 2018). Carbonized rice husk, a by-product of rice milling, is another promising alternative due to its high silica content, which improves soil structure and nutrient retention (Abu et al., 2021). These fertilizers are cost-effective, abundant in Nigeria, and provide a feasible solution to the high costs associated with chemical fertilizers.

c. Economic Impact on Household Food Security

Studies such as those by Omotayo (2019) emphasize the importance of adopting low-cost organic fertilizers to improve agricultural productivity and household food security. Vermicompost and carbonized rice husk reduce farmers' dependence on expensive chemical inputs, resulting in increased disposable income, improved yields, and enhanced food availability for households. This can contribute to reducing hunger and poverty in rural communities, as observed in various smallholder farming contexts across sub-Saharan Africa.

d. Challenges and Opportunities

The challenges in the widespread adoption of these fertilizers include lack of awareness, limited access to training on organic fertilizer production, and initial capital requirements for setting up vermiculture or carbonization processes. However, there is potential for scaling these solutions through agricultural cooperatives and government policies that promote organic farming practices (Onwubuya&Okoye, 2020).

e. Agricultural Waste Management

Exploring the benefits of recycling agricultural by-products such as rice husks, crop residues, and organic household waste through innovative practices like vermiculture and carbonization to minimize waste and improve soil fertility.

f. Economic and Environmental Impacts

An assessment of the economic and ecological advantages of organic fertilizers compared to synthetic alternatives. This includes a detailed evaluation of the chemical composition, nutritional values, and fertility-enhancing properties of carbonized rice husk and vermicompost, both individually and in combination. The analysis is further supported by practical field trials measuring soil fertility improvement and crop productivity before and after application.

g. Chemical Elements and Nutritional Values of the Fertilizer

i. Carbonized Rice Husk (Biochar). Primary Role: Improves soil structure, enhances water retention, increases cation exchange capacity (CEC), and provides a stable carbon source. Chemical Composition:Carbon (C): 50-70%Function: Enhances soil organic matter and improves soil structure by stabilizing organic compounds.Silicon Dioxide (SiO_2): 15-20%, Function: Enhances plant resistance to pests and diseases by strengthening plant cell walls. Potassium (K): 0.5-2%, Function: Essential for enzyme activation, osmoregulation, and overall plant health. Calcium (Ca): 1-3%, Function: Important for cell wall stability, root development, and pH buffering. Magnesium (Mg): 0.5-1%). Function: A key component of chlorophyll, essential for photosynthesis. Trace Elements: Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Function: Involved in various enzymatic activities crucial for plant metabolism.

ii. Vermicompost-Primary Role: Provides bioavailable nutrients, enhances microbial activity, and improves soil organic matter content. Chemical Composition: Nitrogen (N): 1.5-2.5%, Function: Essential for protein synthesis and vegetative growth. Phosphorus (P_2O_5): 1.0-1.5% Function: Vital for root development, energy transfer (ATP), and flowering. Potassium (K_2O): 1.5-2.5%, Function: Critical for regulating water uptake, stomata function, and plant metabolism. Calcium (Ca): 3-5%, Function: Helps with cell division, membrane function, and root

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development. Magnesium (Mg): 0.5-1.5%, Function: Integral for chlorophyll production and enzyme activation. Organic Carbon (C): 10-15%, Function: Enhances microbial activity and overall soil fertility.Humic and Fulvic Acids: 1-2%. Function: Improve nutrient uptake by chelating essential minerals and stimulating root growth. Beneficial Microorganisms (Bacteria, Fungi): Function: Promote nutrient cycling, improve nitrogen fixation, and decompose organic matter into bioavailable forms.

iii. Combined Fertilizer (Carbonized Rice Husk + Vermicompost) When combined in a 1:2 ratio (biochar), the fertilizer offers a balanced mix of slow-releasing carbon-rich biochar and nutrient-rich vermicompost. The biochar provides long-term structural benefits to the soil, while vermicompost supplies readily available nutrients for plant growth. Nutrient Content (Average): Nitrogen (N): 1-1.7%, Phosphorus (P_2O_5): 1-1.3%, Potassium (K_2O): 1-2%. Calcium (Ca): 2-3%, Magnesium (Mg): 0.5-1.2%, Organic Carbon (C): 25-35%, Trace Elements (Fe, Mn, Zn, Cu): Present in small but essential quantities for plant health.

h. Fertility Benefits to Crops and Soil

i. Improved Nutrient Availability:Vermicompost provides readily available nitrogen, phosphorus, potassium, and other micronutrients necessary for plant growth and development. These nutrients enhance root formation, chlorophyll production, flowering, and fruiting.

ii. Increased Crop Yield: The high nutrient content and improved soil structure lead to increased crop productivity, particularly in nutrient-deficient soils.

iii. Enhanced Plant Health:Vermicompost contains humic acids and beneficial microorganisms that improve nutrient uptake and boost the plant's immune system. Balanced Water and Nutrient Uptake: The biochar component helps regulate water availability and nutrient retention, reducing nutrient leaching and ensuring that crops receive nutrients over an extended period.

iv. Improved Soil Structure:Biochar enhances the soil‟s physical structure by increasing porosity, which improves aeration and water retention. This is especially beneficial for sandy or degraded soils.

v. Enhanced Soil Fertility: Both biochar and vermicompost increase soil organic matter, improve nutrient retention, and provide a slow-release nutrient reservoir.

vi. Microbial Activity Boost:Vermicompost introduces beneficial microorganisms that enhance nutrient cycling, decompose organic matter, and fix atmospheric nitrogen.

vii. Soil pH Buffering: The addition of calcium and magnesium from both biochar and vermicompost helps buffer soil pH, making it suitable for a wide range of crops. Long-Term Carbon Sequestration:Biochar sequesters carbon in the soil for decades, contributing to carbon storage and climate mitigation.

3. Materials and Methods

Experimental Design

Design: Randomized Complete Block Design (RCBD) with 4 treatments, replicated 4 times.

Plot Size: 3 m × 3 m (9 m²) with 1 m buffer zone and Crop: Maize (Zea mays).

Treatments

1. T_0 (Control): No fertilizer.
2. T_1 (CRH only): 2 t/ha.
3. T_2 (VC only): 4 t/ha.
4. T_3 (CRH + VC): 2 t/ha CRH + 4 t/ha VC.

Data Collection

Soil fertility parameters: pH, Organic Matter (OM), Nitrogen (N), Phosphorus (P), Potassium (K). Crop parameters: Germination rate (%), Plant height (cm), Biomass (t/ha), Grain yield (t/ha). Economic analysis: Input costs vs. returns.

a). Study Design: A mixed-method approach was used to investigate the production process, economic analysis, and agricultural impact. The research was conducted in three phases:

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laboratory production, field application, and data analysis.

b) Process of Production-Phase 1: Carbonized Rice Husk Production. Equipment: A pyrolysis kiln for carbonization. Variables: Temperature (300–500°C), moisture content of the husk (<15%), and carbonization time. Steps are as follows:

i. Raw Material Collection: Collect rice husks from local rice mills.
ii. Drying Process: Dry the rice husk under the sun or in a drying machine to reduce the moisture content.
iii. Carbonization Process: Perform pyrolysis at 300-500°C for 30-45 minutes to convert the husk into biochar.
iv. Post-Carbonization: Allow cooling and grind the biochar to a fine texture for ease of mixing.

Phase 2: Vermicompost Production a). Equipment: Vermicomposting bin, organic waste, and earthworms (Eiseniafetida). Variables: Feedstock type (plant-based waste, cow dung), moisture content, worm density. Steps: Set-Up Composting Bin: Prepare a bedding of straw and shredded paper. Add Organic Waste: Feed organic waste like vegetable scraps and manure to the earthworms. Composting Process: Allow the worms to break down the waste over 2-3 months. Harvesting: Separate the earthworms and collect the vermicompost. Dry and sieve it for an even texture.

Phase 3: Blending and Final Product. Ratio: Mix the carbonized rice husk and vermicompost in a 1:2 ratio. Variables: Proportion of materials, texture, and moisture content. Process: a). Blending: Uniformly blend the biochar and vermicompost to create a balanced organic fertilizer. Packaging: Store the product in bags and keep it in a cool, dry place for later use.

Table 1. Method for Required Resources and Measurements

Material	Required Amount	Scientific Discipline Involved	Measurement/Variables	Process
Rice Husk	100 kg	Chemistry, Physics	Moisture content: <15%, Particle size	Drying, Carbonization (Pyrolysis)
Pyrolysis Kiln	1 unit	Physics	Temperature: 300–500°C, Time: 30–45 minutes	Carbonizing rice husk to biochar
Organic Waste (e.g., Cow Dung, Vegetable Scraps)	150 kg	Biology, Chemistry	Ratio: 25–30:1	Vermicomposting
Earthworms (Eiseniafetida)	1000 worms	Biology	Worm density: 1 kg/m²	Breakdown of organic waste
Water	As needed	Physics, Biology	Moisture content in compost: 40–60%	Maintains optimal decomposition conditions
Biochar (Carbonized Rice Husk)	Produced from 100 kg rice husk	Chemistry, Physics	Carbon content, pH	Added to compost or used as soil amendment
Vermicompost	Produced from organic waste	Biology, Chemistry	Nutrient content (N, P, K)	Mixed with biochar or used directly

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Sieving Machine	1 unit	Physics	Particle size: <2 mm	Sieving compost for uniformity
Blending Equipment	1 unit	Integrated Science	Ratio: 1 (biochar): 2 (vermicompost)	Uniform blending of the final fertilizer

Source: Field study (2025)

Practical Size of Farm Plot for Testing Before and After Application

Plot Size for Experimental Trials: To ensure robust and statistically valid results, a randomized complete block design (RCBD) will be used. The experiment will include different treatments with and without the fertilizer, and measurements will be made before and after the fertilizer application. Plot Size: Each plot will measure 3 m x 3 m (9 m²). Number of Plots: Four replications per treatment for statistical significance. Control: No fertilizer (untreated soil). Treatment 1 (Biochar only): Application of 2 tons per hectare of carbonized rice husk. Treatment 2 (Vermicompost only): Application of 4 tons per hectare of vermicompost. Treatment 3 (Combined Fertilizer): Application of 2 tons per hectare of carbonized rice husk + 4 tons per hectare of vermicompost. Buffer Zone: A buffer zone of 1 meter was left between plots to avoid cross-contamination.

Pre-Application Soil Test: Soil Sampling: Collected soil samples from each plot before applying the fertilizer. Parameters: pH, organic matter content, nutrient content (N, P, K), and moisture retention capacity. Analysis: Analyze soil samples in a laboratory to establish baseline fertility levels.

Post-Application Soil and Crop Test: Soil Testing After Fertilizer Application: Re-assess soil parameters (pH, organic matter, N, P, K, moisture retention) two weeks after applying the fertilizer and at the end of the cropping cycle. Crop Growth Monitoring:Germination Rate: Number of seeds that successfully germinate in each plot. Plant Height: Measure weekly to monitor growth trends. Leaf Area Index (LAI): Used to assess the amount of leaf cover and plant development. Biomass: Harvest aboveground biomass and calculate total productivity. Crop Yield: At harvest, measure grain or fruit yield (in tons per hectare) and compare across treatments.

Data Collection and Analysis

Data for this study were collected through a combination of surveys, interviews, and field observations involving 10 smallholder farmers across different localities in the study area.. Quantitative data include yield rates, production costs, and household income before and after using alternative fertilizers. Qualitative data were gathered from interviews with agricultural experts, cooperative members, and local government agricultural officers.

a) Economic Cost-Benefit Analysis

The economic scale was measured by comparing the costs associated with producing and applying carbonized rice husk and vermicompost against conventional chemical fertilizers. Preliminary results suggest that farmers who adopted alternative fertilizers experienced an average 25% reduction in input costs while maintaining comparable or improved crop yields.

b) Household Food Security Index

The Household Food Security Index (HFSI) was used to evaluate the impact of these fertilizers on food availability and affordability. Households using carbonized rice husk and vermicompost reported increased access to nutritious food, which improved their food security index by an average of 30%.

c) Comparative Yield Analysis

A yield analysis comparing farmers using alternative fertilizers with those using chemical fertilizers revealed that carbonized rice husk and vermicompost performed equally well or better in terms of crop output, especially for maize, rice, and cassava. The organic alternatives also demonstrated improved long-term soil fertility, suggesting

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sustainable benefits beyond immediate yield outcomes.

d) Environmental Impact

The environmental impact assessment showed that the use of organic fertilizers resulted in reduced soil degradation and lower greenhouse gas emissions compared to chemical fertilizers, aligning with global goals for sustainable agriculture. Phase 4: Field Testing- Study Area: Agricultural fields in Akwanga, Nasarawa State.Participants: Smallholder farmers and agricultural cooperatives. Variables: Soil fertility (pH, organic matter), crop yield (tons/hectare), cost savings, and household food security indicators.

Data Collection Methods:

i). Soil Tests: Measure improvements in soil structure and nutrient content.
ii). Yield Data: Monitor crop yields before and after the application of the fertilizer.
iii). Economic Surveys: Survey farmers on cost savings, fertilizer usage, and perceptions of food security.
iv). Household Surveys: Evaluate changes in food production and household dietary intake.

4. Results and Discussion

Table 2. Soil Fertility Before and After Fertilizer Application

Treatment	**Soil pH**	**OM (%)**	**N (%)**	**P (mg/kg)**	**K (cmol/kg)**
T_0 (Control)	5.2 → 5.3	1.1 → 1.2	0.08 → 0.09	5.3 → 5.4	0.14 → 0.15
T_1 (CRH)	5.2 → 6.0	1.1 → 1.8	0.08 → 0.12	5.3 → 6.2	0.14 → 0.23
T_2 (VC)	5.2 → 6.3	1.1 → 2.4	0.08 → 0.18	5.3 → 7.1	0.14 → 0.31
T_3 (CRH+VC)	5.2 → 6.5	1.1 → 3.0	0.08 → 0.22	5.3 → 8.4	0.14 → 0.38

Source: Field study (2025)

Interpretation**:** Soil fertility improved most significantly under CRH+VC, indicating synergistic effects.

Table 3. Crop Yield Performance

Treatment	**Germination Rate (%)**	**Mean Plant Height (cm)**	**Biomass (t/ha)**	**Grain Yield (t/ha)**	**Yield Increase vs. Control (%)**
T_0 (Control)	78	122	4.2	2.5	-
T_1 (CRH)	84	135	5.6	3.1	+24%
T_2 (VC)	88	142	6.1	3.4	+36%
T_3 (CRH+VC)	92	150	6.8	3.7	+48%

Source: Field study (2025)

Interpretation**:** CRH+VC gave the highest maize yield (3.7 t/ha), outperforming single applications of CRH and VC.

Table 4. Economic Cost-Benefit Analysis

Fertilizer Type	**Input Cost (₦/ha)**	**Yield (t/ha)**	**Gross Revenue (₦/ha)***	**Net Return (₦/ha)**	**Cost Reduction vs. Chemical Fertilizer (%)**
Chemical Fertilizer (NPK)	180,000	3.5	700,000	520,000	-

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CRH only	80,000	3.1	620,000	540,000	56%
VC only	120,000	3.4	680,000	560,000	33%
CRH+VC	150,000	3.7	740,000	590,000	17%

Source: Field study (2025)

Interpretation: CRH+VC provided the highest net return (₦590,000/ha), showing strong economic viability.

CRH improved soil structure and water retention, while VC provided nutrients and microbial activity. Combined CRH+VC treatments had synergistic effects, boosting yield by 48% compared to the control. Economically, CRH+VC offered higher returns with reduced dependence on chemical fertilizers. Household food security improved through increased yields and reduced input costs.

5. Conclusion

This study highlights the potential of using carbonized rice husk and vermicompost as a sustainable and economically viable fertilizer. The process not only contributes to better soil health and increased crop yields but also supports household food security in smallholder farming communities. The integration of carbonized rice husk and vermicompost as organic fertilizers significantly improved soil fertility, increased maize yields, and enhanced economic returns for smallholder farmers in Nasarawa State. Their adoption can reduce reliance on synthetic fertilizers and strengthen household food security sustainably. Further research on large-scale production and regional adaptation is recommended. The experimental design research to evaluate the production and application of carbonized rice husk and vermicompost as a sustainable fertilizer, the research aimed to assess the effects of the fertilizer on soil fertility and crop yield under controlled and field conditions.

6. Recommendations

Categorized, practical, and prioritized tailored steps to Production and Application of Carbonized Rice Husk (CRH) and Vermicompost as sustainable inputs to improve soil fertility and household food security in Nigeria.

i. Co-locate processing encourages rice mills to host small carbonization units and vermicomposting hubs so feedstock (rice husk, crop residues) is locally available and transport costs fall.

ii. Appropriate technology promotes low-cost, low-smoke carbonization kilns (retort or improved "top-lit up-draft" designs) and simple vermicomposting units suitable for smallholder communities.

iii. Quality control at source implements simple on-farm checks (moisture, odour, absence of plastic/metal) and community-level testing to ensure consistent product quality.

iv. Aggregation & packaging support cooperatives to bag and brand products in standard sizes to improve marketability and storage.

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