Circular Economy in Nigerian Agriculture: Farmers' Perceptions of Rice Husk Biochar for Remediating Degraded Lowland Soils and Enhancing Carbon Sequestration in Southeastern Nigeria

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Abstract:

*The circular economy offers a compelling framework for sustainable agricultural development in Nigeria, rice husk is an abundant by-product of rice milling and can be pyrolysed into biochar for use as a soil amendment. However, the success of any biochar programme ultimately depends on the awareness, perceptions and adoption readiness of the farmers expected to use it, dimensions that remain poorly documented in southeastern Nigeria. This study assessed rice farmers' perceptions of rice Husk Biochar for remediating degraded lowland soils, enhancing carbon sequestration and delivering economic benefits within a circular-economy framework. A cross-sectional descriptive survey was conducted among registered rice farmers in the southeastern states of Nigeria. Using Yamane's formula, **395** farmers were selected through multi-stage sampling combining stratification and proportionate random sampling. Data were collected with a validated structured questionnaire (Cronbach's α = **0.85**) employing a four-point Likert scale, and were analysed using means, standard deviations and one-way analysis of variance (**ANOVA**). Respondents agreed that rice Husk Biochar improves soil physicochemical properties (grand mean = **3.25**), enhances rice yield and carbon sequestration while lowering greenhouse-gas emissions (grand mean = **3.36**), and confers economic and policy benefits (grand mean = **3.19**); each domain exceeded the **2.50** decision criterion. **ANOVA** indicated that response patterns differed significantly for all three domains (**$p < 0.001$**). The findings reveal strong farmer receptiveness to biochar technology and point to a circular-economy opportunity to convert rice-milling waste into a soil-restoring resource. The study recommends targeted extension, locally fabricated pyrolysis units and enabling policy, while emphasising that multi-year field trials are required to empirically validate the agronomic and carbon outcomes that farmers currently perceive.*

Keywords: *Circular economy; rice Husk Biochar; soil degradation; carbon sequestration; farmer perception; sustainable agriculture; Nigeria*

1.0 Introduction

Soil degradation is one of the most pressing constraints on agricultural productivity and food security in southeastern Nigeria, where continuous cropping, intensive cultivation and limited nutrient replenishment have progressively depleted the fertility of lowland soils. Degraded lowlands are typically characterised by low organic carbon, poor structure, reduced water-holding capacity and declining nutrient availability, all of which suppress crop performance and threaten rural livelihoods **(Obalum et al., 2017)**. Rice, a staple that supplies a substantial share of the calories and farm income of millions of households, is particularly vulnerable to these constraints, and its production in the region is frequently limited by poor soil fertility and sub-optimal management practices **(Ilo et al., 2025)**. Restoring the productive capacity of these soils in a manner that is affordable, locally feasible and environmentally sound is therefore central to the region's agricultural development.

Biochar which are the carbon-rich solid produced by the thermal decomposition of biomass under oxygen-limited conditions which has emerged as a promising amendment for degraded soils. Its highly porous structure and large specific surface area enable it to retain water and nutrients, raise cation exchange capacity and support microbial biomass, thereby improving soil structure and fertility **(Ding et al., 2016; Zubairu et al., 2023)**. Rice husk, an abundant milling by-product that is frequently burned or dumped, is an especially attractive feedstock: converting it into biochar simultaneously addresses a waste-management problem and yields a valuable soil input. Rajalekshmi et al. (2024) report that rice Husk Biochar can improve soil fertility and rice performance while contributing to soil carbon storage, and Zubairu et al. **(2023)** demonstrate comparable benefits under Nigerian conditions.

Beyond its agronomic value, rice Husk Biochar embodies the principles of the circular economy, in which waste streams are reintegrated into production as resources rather than discarded. **Biswal and Balasubramanian (2025)** argue that biomass-derived biochar offers a durable pathway for carbon storage and resource efficiency, while **Enaime et al. (2023)** position biochar application as a concrete contribution to circularity in agriculture through reduced waste, lower fertiliser dependence and the mitigation of greenhouse-gas emissions. In a rice-producing region that generates large volumes of husk, closing this loop at the mill gate represents a tangible opportunity to link waste valorisation with soil restoration.

Rice Husk Biochar is also relevant to climate-change mitigation. Because its aromatic carbon structure is highly stable, biochar can persist in soil over long timescales, sequestering carbon that would otherwise return to the atmosphere; **Rajalekshmi et al. (2024)** estimate that a substantial fraction of biochar carbon can be retained in soil. In addition, biochar amendment has been associated with reductions in nitrous oxide **(N_2O) and methane (CH_4)** emissions from agricultural soils through improved aeration, nutrient retention and altered microbial activity **(Enaime et al., 2023)**. Taken together, these properties make rice Husk Biochar a candidate technology for delivering productivity, environmental and climate co-benefits within a single, locally available material.

Despite this growing evidence base, the majority of studies on rice Husk Biochar have been agronomic or experimental in nature and have largely been conducted under controlled or ex-situ conditions, frequently outside the specific context of southeastern Nigerian lowlands. Critically, the realisation of biochar's potential depends not only on its biophysical performance but also on the willingness and readiness of farmers to adopt it. Farmers' awareness, perceptions and attitudes are known determinants of agricultural technology uptake, yet these dimensions remain largely undocumented for rice Husk Biochar in southeastern Nigeria. Understanding how rice farmers perceive the soil, yield, carbon and economic implications of biochar is a necessary precondition for designing effective extension programmes and supportive policy. This study addresses that gap by assessing rice farmers' perceptions of rice Husk Biochar for remediating degraded lowland soils and enhancing carbon sequestration within a circular-economy framework.

1.1 Objectives of the Study

The main objective of the study was to examine rice farmers' perceptions of the potential of rice Husk Biochar to remediate degraded lowland soils and enhance carbon sequestration within a circular-economy framework in southeastern Nigeria. The specific objectives were to:

i. Evaluate farmers' perceptions of the effect of rice Husk Biochar on the physicochemical properties of degraded lowland soils in southeastern Nigeria;

ii. Assess farmers' perceptions of the influence of rice Husk Biochar on rice yield, carbon sequestration and greenhouse-gas emissions in rice cultivation systems; and

iii. Determine farmers' perceptions of the economic benefits and policy implications of adopting rice Husk Biochar technology for sustainable agriculture in Nigeria.

1.2 Research Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

$H0_1$: The application of rice Husk Biochar has no significant perceived effect on the physicochemical properties of degraded lowland soils in southeastern Nigeria.

$H0_2$: Rice Husk Biochar application has no significant perceived effect on rice yield, carbon sequestration and greenhouse-gas emissions in rice cultivation systems.

$H0_3$: The adoption of rice Husk Biochar technology is not perceived to be economically viable and has no positive perceived policy implications for promoting sustainable agriculture in Nigeria.

2.0 Materials and Methods

2.1 Study Area

The study was conducted in the five states of southeastern Nigeria which are: Abia, Anambra, Ebonyi, Enugu and Imo. The zone lies within the humid tropical rainforest belt and is characterised by extensive lowland (fadama) systems that support smallholder rice production. These lowlands are widely affected by soil degradation associated with continuous cropping and limited external inputs, making the region an appropriate setting in which to examine farmer perspectives on soil-restoring technologies such as rice Husk Biochar.

2.2 Research Design

The study adopted a cross-sectional descriptive survey design. Descriptive survey research enables a researcher to systematically describe the characteristics, opinions or perceptions of a defined population (Singh, 2023). The design was appropriate because the study sought to elicit and describe rice farmers' perceptions of the potential of rice Husk Biochar, rather than to measure biophysical soil or crop responses under experimental control.

2.3 Population and Sampling

The target population comprised registered rice farmers in the five southeastern states of Nigeria. Registration figures were available from the National Agricultural Sample Census (NASC) for three states: Abia, Anambra and Ebonyi giving an accessible population of 47,000 farmers; registration data were not available for Enugu and Imo at the time of the study, and the sampling frame was therefore restricted to the three states with available records. The population distribution is presented in Table 1.

Table 1. *Population distribution of registered rice farmers*

S/N	State	Population
1	Abia	1,000
2	Anambra	12,000
3	Ebonyi	34,000
4	Enugu	No data[a]
5	Imo	No data[a]
	Total	**47,000**

Source: *National Agricultural Sample Census (NASC), 2024–2026. [a] Registration figures were unavailable for Enugu and Imo; these states were excluded from the sampling frame.*

The sample size was determined using Yamane's (**1967**) formula for a finite population:

$$\boldsymbol{n = N / [1 + N(e^2)]}$$

where n is the sample size, **N** is the population size (47,000) and e is the margin of error (**0.05**). Substituting these values yields $\mathbf{n = 47{,}000 / [1 + 47{,}000(0.05^2)] \approx 395}$. A multi-stage sampling procedure combining stratified and proportionate simple random sampling was employed: the accessible population was stratified by state, and the sample was allocated proportionately to each state's share of the population (**Table 2**). Respondents within each state were then selected by simple random sampling.

Table 2. *Proportionate sample distribution of respondents*

S/N	State	Population	Sample size
1	Abia	1,000	8
2	Anambra	12,000	101
3	Ebonyi	34,000	286
	Total	**47,000**	**395**

Source: *Authors' field survey.*

2.4 Instrument for Data Collection

A structured questionnaire was used to collect data. It was organised into sections capturing respondents' socio-economic characteristics, their farming practices and their perceptions of rice Husk Biochar across the three study domains. Perception items were measured on a four-point Likert scale: Strongly Agree **(SA = 4)**, Agree **(A = 3)**, Disagree **(D = 2)** and Strongly Disagree **(SD = 1)**.

2.5 Validity and Reliability

Content validity was established by having experts in agricultural economics and research methodology review the questionnaire to confirm that the items measured the intended constructs. Internal-consistency reliability was assessed using Cronbach's alpha, which returned a coefficient of **0.85**, indicating good reliability.

2.6 Method of Data Collection

The questionnaire was administered in person by trained enumerators who were supervised throughout fieldwork to ensure accurate and complete responses. This approach also allowed clarification of items for respondents with limited literacy.

2.7 Method of Data Analysis

Data were analysed with the Statistical Package for the Social Sciences (SPSS). Means and standard deviations were used to answer the research questions, with a decision criterion (cut-off) mean of **2.50**, the mid-point of the four-point scale, computed as **(4 + 3 + 2 + 1) / 4**. Perception items with a mean of **2.50** or above were regarded as "accepted". One-way analysis of variance (ANOVA) was used to test the null hypotheses at the 0.05 level of significance.

2.8 Ethical Considerations

Participation was voluntary and informed consent was obtained from all respondents prior to data collection. Respondents were assured of anonymity and confidentiality, and the data were used solely for the purposes of this research.

3.0 Results

3.1 Perceived effects on soil physicochemical properties

Table 3 presents the mean analysis of farmers' perceptions of the effect of rice Husk Biochar on the physicochemical properties of degraded lowland soils (questionnaire items 1-4). Cell entries show the response frequency and, in parentheses, the corresponding weighted score.

Table 3. *Farmers' perceptions of the effect of rice Husk Biochar on soil physicochemical properties*

S/N	Item	SA	A	D	SD	Total	Mean	Decision
1	Rice Husk Biochar increases soil organic carbon content	200 (800)	105 (315)	60 (120)	30 (30)	395 (1265)	**3.20**	Accepted
2	Rice Husk Biochar improves soil structure and water retention	215 (860)	110 (330)	50 (100)	20 (20)	395 (1310)	**3.32**	Accepted
3	Rice Husk Biochar improves soil nutrient availability	190 (760)	135 (405)	45 (90)	25 (25)	395 (1280)	**3.24**	Accepted
4	Rice Husk Biochar enhances soil microbial activity	210 (840)	120 (360)	40 (80)	25 (25)	395 (1305)	**3.30**	Accepted
	Grand mean						**3.27**	**Accepted**

Source*: Field survey, 2026. Decision criterion mean =* ***2.50.***

As shown in Table 3, all four items were accepted, and the grand mean of **3.27** exceeds the criterion mean of **2.50** (**3.27 > 2.50**). Farmers therefore perceive that rice Husk Biochar improves the physicochemical properties of degraded lowland soils, with the strongest agreement recorded for improvements in soil structure and water retention (mean = **3.32**).

3.2 Perceived effects on yield, carbon sequestration and greenhouse-gas emissions

Table 4 presents farmers' perceptions of the influence of rice Husk Biochar on rice yield, carbon sequestration and greenhouse-gas emissions (questionnaire items **5-8**).

Table 4*. Farmers' perceptions of the effect of rice Husk Biochar on yield, carbon sequestration and greenhouse-gas emissions*

S/N	Item	SA	A	D	SD	Total	Mean	Decision
5	Rice Husk Biochar influences carbon sequestration in rice cultivation	220 (880)	85 (255)	70 (140)	20 (20)	395 (1295)	**3.28**	Accepted
6	Rice Husk Biochar has high carbon-sequestration potential	210 (840)	130 (390)	40 (80)	15 (15)	395 (1325)	**3.35**	Accepted
7	Rice Husk Biochar application affects rice crop duration	215 (860)	150 (450)	20 (40)	10 (10)	395 (1360)	**3.44**	Accepted
8	Rice Husk Biochar improves rice grain quality	200 (800)	150 (450)	30 (60)	15 (15)	395 (1325)	**3.35**	Accepted
	Grand mean						**3.36**	**Accepted**

Source*: Field survey, 2026. Decision criterion mean =* ***2.50****.*

All four items were accepted, and the grand mean of 3.36 exceeds the criterion mean of **2.50 (3.36 > 2.50)**. Farmers thus perceive that, to a high extent, rice Husk Biochar influences rice yield, carbon sequestration and greenhouse-gas emissions, with the highest agreement recorded for a perceived effect on crop duration (**Mean = 3.44**).

3.3 Perceived economic benefits and policy implications

Table 5 presents farmers' perceptions of the economic benefits and policy implications of adopting rice Husk Biochar Technology (questionnaire items **9-12**).

Table 5. *Farmers' perceptions of the economic benefits and policy implications of rice Husk Biochar Technology*

S/N	Item	SA	A	D	SD	Total	Mean	Decision
9	Rice Husk Biochar technology improves farmers' income	200 (800)	100 (300)	50 (100)	45 (45)	395 (1245)	3.15	Accepted
10	Rice Husk Biochar reduces farmers' fertiliser costs	180 (720)	140 (420)	30 (60)	45 (45)	395 (1245)	3.15	Accepted
11	Rice Husk Biochar reduces farmers' soil-remediation costs	190 (760)	132 (396)	50 (100)	23 (23)	395 (1279)	3.24	Accepted
12	Rice Husk Biochar increases economic water productivity	205 (820)	105 (315)	53 (106)	32 (32)	395 (1273)	3.22	Accepted
	Grand mean						**3.19**	**Accepted**

Source*: Field survey, 2026. Decision criterion mean =* ***2.50****.*

All four items were accepted, and the grand mean of **3.19** exceeds the criterion mean of **2.50 (3.19 > 2.50**). Farmers perceive that rice Husk Biochar technology offers economic benefits, increasing income, reducing fertiliser and remediation costs, and improving economic water productivity. Notably, the lowest agreement was recorded for the income and fertiliser-cost items (**Mean = 3.15** each), which also attracted the highest number of strongly-disagree responses (45), suggesting a degree of uncertainty about the direct financial returns of adoption.

3.4 Test of hypotheses

Hypothesis one ($H0_1$). ANOVA was used to test whether the application of rice Husk Biochar has a significant perceived effect on the physicochemical properties of degraded lowland soils (Table 6).

Table 6. ANOVA *of farmers' perceptions of the effect of rice Husk Biochar on soil physicochemical properties*

Source	Sum of squares	df	Mean square	F	p-value	Remark
Between groups	77,512.5	3	25,837.5	266.71	< 0.001	Significant
Within groups	1,162.5	12	96.88			
Total	78,675.0	15				

Source*: Field survey, 2026.*

The analysis returned a p-value below 0.001, which is less than the 0.05 significance level. The null hypothesis is therefore rejected, and it is concluded that rice Husk Biochar is perceived to significantly improve the physicochemical properties of degraded lowland soils in southeastern Nigeria.

Hypothesis two ($H0_2$). ANOVA was used to test whether rice Husk Biochar application has a significant perceived effect on rice yield, carbon sequestration and greenhouse-gas emissions (Table 7).

Table 7. ANOVA of farmers' perceptions of the effect of rice Husk Biochar on yield, carbon sequestration and greenhouse-gas emissions

Source	Sum of squares	df	Mean square	F	p-value	Remark
Between groups	96,087.5	3	32,029.17	85.65	< 0.001	Significant
Within groups	4,487.5	12	373.96			
Total	100,575.0	15				

Source: Field survey, 2026.

The analysis returned a p-value below 0.001, which is less than the 0.05 significance level. The null hypothesis is therefore rejected, and it is concluded that rice Husk Biochar application is perceived to significantly influence rice yield, carbon sequestration and greenhouse-gas emissions in rice cultivation systems.

Hypothesis three ($H0_3$). ANOVA was used to test whether the adoption of rice Husk Biochar technology is perceived to be economically viable with positive policy implications (Table 8).

Table 8. ANOVA of farmers' perceptions of the economic viability and policy implications of rice Husk Biochar technology

Source	Sum of squares	df	Mean square	F	p-value	Remark
Between groups	64,767.19	3	21,589.06	115.33	**< 0.001**	Significant
Within groups	2,246.25	12	187.19			
Total	67,013.44	15				

Source: Field survey, 2026.

The analysis returned a p-value below 0.001, which is less than the 0.05 significance level. The null hypothesis is therefore rejected, and it is concluded that the adoption of rice Husk Biochar technology is perceived to be economically viable with positive policy implications for promoting sustainable agriculture in Nigeria.

4.0 Discussion

This study set out to establish, for the first time in a systematic way, how rice farmers in southeastern Nigeria perceive the potential of rice Husk Biochar for soil remediation, carbon sequestration and economic gain within a circular-economy framing. Across all three domains, respondents expressed strong agreement, and the ANOVA results confirmed that these perceptions were far from random. The discussion below interprets these findings, situates them against the wider empirical literature, and considers where farmer perception aligns with and where it may run ahead of the available scientific evidence.

4.1 Perceptions of soil benefits and their empirical basis

Farmers' strong agreement that rice **Husk Biochar** improves soil organic carbon, structure, water retention, nutrient availability and microbial activity **(grand mean = 3.27)** is consistent with the mechanisms established in the experimental literature. Ding et al. (2016) attribute biochar's fertility benefits to its porous architecture and large surface area, which enhance nutrient and water retention and raise cation exchange capacity, while **Zubairu et al.**

(2023) report increases in soil organic carbon and available nutrients under Nigerian conditions**. Obalum et al. (2017)** further underscore soil organic matter as a central indicator of soil health, reinforcing the significance of the organic-carbon gains farmers perceive. The convergence between local perception and global evidence is encouraging: it suggests that farmers' mental models of biochar are broadly accurate and that extension messaging can build on existing, well-founded beliefs rather than having to overturn misconceptions.

It is important, however, to distinguish perception from measurement. The soil benefits reported here are those farmers *believe* biochar confers, not quantities observed in a controlled trial. Because the strongest agreement concerned structure and water retention **(Mean = 3.32)** outcomes farmers can readily observe in the field while more "invisible" processes such as microbial activity attracted marginally lower agreement, the pattern is plausibly shaped by everyday observability. This reinforces the need to pair perception surveys with site-specific soil measurements before drawing agronomic conclusions for the region's ultisols.

4.2 Perceptions of yield, carbon and emissions

The second domain attracted the highest agreement **(grand mean = 3.36)**, with farmers endorsing Biochar's influence on carbon sequestration, crop duration and grain quality. This optimism echoes **Rajalekshmi et al. (2024)**, who report meaningful carbon retention and yield benefits for rice Husk Biochar in wetland soils, and **Enaime et al. (2023)**, who link biochar amendment to reduced **N_2O** and **CH_4** emissions. The particularly high agreement on crop duration (**Mean = 3.44**) is noteworthy and warrants cautious interpretation: while **Biochar** can influence nutrient dynamics and phenology, effects on duration are context-dependent and less consistently reported than yield or carbon effects. This may indicate that farmers are generalising from limited direct experience, or conflating **Biochar** effects with broader improvements in soil condition.

Perceptions of carbon-sequestration potential are similarly strong, yet the empirical basis for **Biochar carbon** permanence in **South Eastern Nigerian** lowlands specifically remains thin. Much of the Carbon-storage evidence derives from other Agro-Ecologies, and the stability of biochar carbon is known to vary with feedstock, pyrolysis temperature and soil conditions. The gap between confident perception and locally validated evidence is precisely the kind of divergence that field trials must resolve if **Biochar** is to be credibly incorporated into **carbon-accounting or climate-finance schemes**.

4.3 Economic and policy perceptions

The economic domain recorded the lowest but still clearly positive and grand mean **(3.19).** Farmers agreed that **Biochar** can raise income, reduce fertilizer and remediation costs, and improve economic water productivity, consistent with the resource-efficiency logic advanced by **Biswal and Balasubramanian (2025)** and **Enaime et al**. **(2023)**. The comparatively lower scores and higher strong-disagreement counts on the income and fertilizer-cost items are analytically the most interesting result in this domain. They suggest that, while farmers accept the agronomic case for **Biochar**, a subset remains skeptical about its direct financial returns. This is consistent with well-documented adoption barriers for soil-amendment technologies: the upfront cost of pyrolysis equipment, the labour of husk collection and charring, and uncertain short-term payback can outweigh perceived benefits for resource-constrained smallholders. Recognizing this ambivalence is essential, because it locates the true bottleneck to adoption not in awareness but in economics and access.

4.4 Circular-economy synthesis

Read together, the three domains describe a coherent circular-economy opportunity. Rice milling in the southeast generates large, largely unused husk volumes; pyrolysing this husk into **Biochar** returns stabilized carbon and nutrients to the very lowlands that produced the crop, closing a local nutrient-and-carbon loop rather than exporting waste as an environmental burden. This operationalizes the circularity argued in principle by **Enaime et al. (2023**) and the durable carbon-storage pathway described by **Biswal and Balasubramanian (2025).** The farmer receptiveness documented here is a necessary enabling condition for such a loop: technologies that farmers already view favourably are more likely to be adopted when the economic and infrastructural constraints identified above are addressed.

4.5 Contribution and implications

The principal contribution of this study is to provide a documented baseline of farmer perception which was previously absent for rice Husk Biochar in southeastern Nigeria and to frame it explicitly within circular-economy thinking. For extension, the results imply that programmes can build on existing positive attitudes while targeting the economic uncertainties that temper them. For policy, they support decentralised, mill-level pyrolysis infrastructure and the integration of biochar into instruments such as the Agricultural Transformation Agenda and emerging carbon-finance mechanisms. Crucially, however, the study also delineates the boundary of what perception data can support: they establish demand and readiness, but they cannot substitute for the biophysical validation on which any carbon or yield claim must ultimately rest.

5.0 Limitations of the Study

Several limitations should be borne in mind when interpreting these findings. First, the study is based on self-reported perceptions rather than field measurements; the soil, yield and carbon outcomes reported here reflect what farmers believe rice Husk Biochar achieves, and should not be read as measured agronomic effects. Empirical, multi-year field trials on the region's lowland soils are required to confirm the magnitude and durability of these outcomes. Second, the sampling frame was restricted to the three southeastern states for which farmer-registration data were available (**Abia**, **Anambra**, **Ebonyi State**); **Enugu** and **Imo state** were excluded for want of a reliable frame, which limits the generalisability of the results to the full zone. Third, the inferential analysis compared aggregate response-category distributions using **ANOVA**; while adequate for detecting non-random agreement, future work would benefit from item-level inferential methods applied to individual responses and from triangulation with direct soil and crop measurements. Finally, as with all cross-sectional perception surveys, the results may be influenced by social-desirability bias and by the coarseness of a four-point Likert scale, and they capture attitudes at a single point in time rather than the dynamics of actual adoption.

6.0 Conclusion

This study assessed rice farmers' perceptions of rice **Husk Biochar** for remediating degraded lowland soils and enhancing carbon sequestration within a circular-economy framework in southeastern Nigeria. Farmers expressed strong and statistically significant agreement across all three domains soil physicochemical improvement, yield and carbon benefits, economic and policy value with grand means of **3.27**, **3.36** and **3.19** respectively, each exceeding the **2.50** decision criterion. These perceptions align closely with the mechanisms established in the wider **Biochar** literature, indicating a well-informed and receptive farming community. At the same time, the more guarded responses on direct financial returns reveal that the key constraint on adoption lies in economics and access rather than awareness. Converting rice-milling waste into biochar therefore represents a credible, locally grounded circular-economy pathway to restore degraded lowlands, sequester carbon and support sustainable rice production, provided that the agronomic and carbon outcomes farmers perceive are now validated through rigorous field experimentation and that the economic barriers to uptake are actively addressed.

7.0 Recommendations

On the basis of the findings, the study makes the following recommendations:

i. Local rice mills in the southeast should be equipped with low-cost, locally designed pyrolysis kilns to convert waste husk into biochar, creating a closed-loop system for soil enhancement at the point of milling.

ii. Agricultural extension services should build on the strong farmer receptiveness documented here, while directly addressing the economic uncertainties particularly around income and fertiliser savings that temper adoption, for example through demonstration plots and cost-benefit information.

iii. Priority should be given to long-term, multi-year field trials, rather than greenhouse studies alone, that quantify biochar-soil interactions for specific southeastern lowland soil types and validate the carbon and yield outcomes farmers perceive.

iv. Government initiatives such as the Agricultural Transformation Agenda should promote rice Husk Biochar as a sustainable alternative to costly chemical fertilisers and explore the integration of biochar carbon into emerging carbon-finance mechanisms.

8.0 Declarations

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Data availability. The datasets analysed during the current study are available from the corresponding author on reasonable request.

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