Environment, Development and Sustainability
https://doi.org/10.1007/s10668-025-06656-9

Farmers' perceptions and acceptability of Biochar as a soil amendment in the Tolon district of Ghana

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Received: 18 December 2024 / Accepted: 14 July 2025

Abstract

Declining soil fertility undermines the food security in Ghana, and the high cost of inorganic fertilizers highlights the need for affordable alternatives to enhance soil fertility in a smallholder context. While biochar has been widely promoted in the policy arena as a cost-effective and environmentally friendly alternative to chemical fertilizers, research is lacking in terms of its perceived benefits and acceptability at the farm level. The study assessed farmers' perceptions and acceptability of biochar as a soil amendment in the Tolon District of Ghana, surveying 384 subsistence farming households. The perception index (PI) model was used to determine farmers' perceptions and acceptability of biochar as a soil amendment, while the probit regression model was employed to estimate the socio-economic determinants of farmers' willingness to accept biochar as a soil amendment. The findings indicate that majority of farmers were willing to accept biochar as a soil amendment (83.33%) and 16.67% were not willing to accept the technology. The findings from the perception index model further indicate that farmers strongly agreed with all statements regarding the district's perception of biochar as a soil amendment. The most dominant perceptions held by farmers were that biochar application was eco-friendly and increased crop yield. These perceptions ranked 1st and 2nd with mean perception indices (PIs) of 4.08 and 4.04 respectively. The findings from the probit regression model further indicate that the acceptability of biochar as a soil amendment by farmers is strongly influenced by educational level ($p=0.000$) and farming experience ($p=0.000$) of the household head, access to extension services ($p=0.000$), membership in farmer groups ($p=0.000$), access to biochar ($p=0.000$) and access to credit ($p=0.000$). To promote biochar acceptance, the study recommends strengthening extension services and farmers training programs. Additionally, extension services should address negative perceptions among smallholder farmers using practical and hands-on techniques.

Keywords Biochar · Soil amendment · Farmer perceptions · Willingness · Acceptability · Tolon district

Extended author information available on the last page of the article

1 Introduction

The utilization of biochar in arable soils has been proposed as an emerging solution for low-carbon and acidic soils, as well as a means to strengthen agricultural resilience amidst the escalating climate change effects (Rogers et al., 2021). Biochar is a charcoal-like product produced from biomass via the pyrolysis process in the absence of oxygen (Saletnik et al., 2019). This process includes gasification of biomass at temperatures > 800 °C, fast pyrolysis extending from temperatures between 800–500 °C and slow pyrolysis at temperatures < 500 °C. Luo et al. (2023) recommended the slow pyrolysis process as the best strategy for biochar production due to its high aromaticity and storing carbon in the soil for a long time thus enhancing biochar stability. Through the application of biochar, atmospheric carbon is retained in the soil which is restrained in the biochar, leading to its role in climate change mitigation (Kumar & Bhattacharya, 2021). The extent at which carbon can be stored depends on the properties of biochar and soil with the possibility of long-term stability (Bruckman & Pumpanen, 2019). Furthermore, Zhang et al. (2021) stated that biochar addition in the soil improves water retention thus reducing nutrient loss and erosion. Similarly, biochar addition stabilizes soil pH in acidic soils thus creating enabling conditions for microbes and boosting crop yields (Khan et al., 2024).

In the current era, the utilization of biochar as a soil amendment has been the spotlight for research worldwide. But preceding studies have overemphasized on the biophysical characteristics of biochar application (Latawiec et al., 2017). As stipulated by Blanco-Canqui (2017), biochar can reduce soil bulk density by 3 to 31%, increase porosity by 14 to 64%, and enhance wet aggregate stability by 3 to 226%. A more recent study (Acharya et al., 2024) further shows that biochar generally improves porosity and soil-water holding capacity in coarse-textured soils, but its effects on infiltration rates differ depending on the biochar particle size, pyrolysis temperature, soil depth and the type of soil.

While much is known in terms of biophysical or mechanistic benefits, there is a lack of understanding regarding smallholder farmers' perceptions, socio-economic determinants and barriers to the acceptability of biochar. The literature suggests that socio-economic factors (e.g., age, gender, education, income, occupation, traditional beliefs, farm size, and accessibility of feedstocks) could play a crucial role in farmer acceptance of biochar in developing countries (Hounnou et al., 2024; Rogers et al., 2021; Otte & Vik, 2017). Using empirical evidence from Denmark, Bjerregaard and Georg (2011) therefore highlight the importance of a comprehensive analysis that integrates social research into the study of biochar as a new technology. In accordance with Scholz et al. (2014), the main hurdles in the utilization of biochar in agriculture are categorized into socio-cultural and economic aspects. They found that socio-cultural and economic barriers notably the resistance of farmers to new approaches, biochar scarcity, limited knowledge in biochar production and biochar properties as well as farmers doubts regarding biochar. Furthermore, they emphasized the need for further research into the social aspects of biochar systems, particularly concerning farmers' perceptions and adoption decisions.

In Ghana, there exist a significant gap regarding the knowledge of farmers' perceptions and acceptability of biochar as a soil amendment. Recently, the biochar initiatives in Ghana shows that despite the possible advantages that can be derived from biochar in boosting crop yields and supporting farmers' sustainability, its adoption in smallholder context fails to meet expectations (Yeboah et al., 2022). The empirical evidence from this study would contribute in bridging the knowledge gap in the Tolon District in the Northern Region of Ghana. Historically, smallholder farmers have relied on subsistence grain production in the area. However, owing to the rising scarcity of arable land, agricultural systems are struggling to meet the increasing demand for food during the past 20 years in the area (Abdul-Rahman, 2018). Continuous cropping without fallowing or adequate nutrient replenishment is the causative reason for this problem resulting to soil degradation (Bationo et al., 2018).

The semi-arid conditions in the area worsens soil degradation which limits the rate of vegetative recover after man-made modifications thus, inhibiting the organic matter buildup in the soil. As a result, the soil exhibits low organic matter content in the area (Owusu et al., 2020). Over the past 6 decades the use of chemical fertilizers including NPK-based fertilizers in the area has been recommended for the cultivation of field crops (Atakora et al., 2014; Daadi & Latacz-Lohmann, 2022). These recommendations have unfortunately failed to provide the expected benefits, leading to soil acidification in a significant portion of the agricultural land. Therefore, scientists have pointed out the relevance of modifying fertilizer recommendations to specific sites. They also urged smallholder farmers to adopt and use organic fertilizers like biochar as soil conditioners to restore soil nutrients and enhance plant growth (Aremu et al., 2023). In light of this, concerted efforts have been taken to support smallholder farmers through capacity-building programs to use biochar as a soil amendment. These programs promote the use of innovative and implemented strategies through the Ministry of Food and Agriculture (MoFA), research institutes, universities and Non-Governmental Organizations (NGOs). In spite of all these efforts, biochar use in the area has been limited (Yeboah et al., 2022), and the reasons for the limited utilization are not fully understood.

In light of previous mentioned research gap, this study makes a commendable contribution by addressing significant gaps and introducing innovative approaches. Notably, most studies focus on the biophysical aspects of biochar, overlooking its social applicability and acceptability as a soil amendment. In contrast, our study places specific emphasis on the social aspects of biochar, offering a nuanced analysis that is essential given the growing global demand for sustainable food production. Furthermore, this research contributes to literature by introducing a unique methodological approach to assess farmers perceptions and acceptability of biochar. Unlike many studies relying solely on qualitative data, our study employs a mixed-method approach providing a more comprehensive understanding of farmers perspectives on biochar acceptability.

This study assessed farmers' perceptions and willingness to accept biochar as a soil amendment in the Tolon district of Ghana. The study further estimated the influence of socio-economic factors on farmers' willingness to accept biochar. The study has important implications for policy-makers and stakeholders involved in creating policies and strategies to improve sustainable production. It provides valuable insights into the barriers, opportunities and entry points for enhancing biochar acceptance among smallholder farmers. Thus, consistent with the Sustainable Development Goals 2, 12 and 13, this paper could contribute to the promotion of biochar application as a cost-effective and eco-friendly pathway to crop production, particularly in areas characterized by poor soils.

The rest of this article is structured as follows: Section two details materials and methods, including description of the study area, research design, sample size determination, sampling procedure, data collection method and instrument, study variables, and statistical analysis. Section three presents and interprets the results, section four presents a discussion of the results and section five summarizes the conclusion and policy recommendations.

2 Materials and methods

This section outlines the methodological framework of the study, encompassing the description of the study area, research design, sampling procedure, data collection methods and instrument, study variables and statistical analysis procedures including the perception index model and the probit regression model.

2.1 Description of the study area

The Tolon District is located in the Northern Region of Ghana (Fig. 1). Encompassing a land area of 1353.66 Km^2, the district shares borders with Kumbungu to the North, Central Gonja to the South, Sagnarigu Districts to the East, and North Gonja to the West. Geographically, it lies between latitudes 9°15' and 10° 02' North and Longitudes 0°53' and 1°25' West.

The district is located in the Guinea Savannah Agroecological Zone. The landscape is therefore characterized by grasslands and scattered guinea savannah woodlands, which host various drought-resistant species such as *Vitellaria paradoxa*, *Pakia biglobosa*, *Adansonia digitata*, *Acacia longifolia*, *Azadirachta indica*, *and Mangifera indica*. In terms of climate, the district experiences unimodal annual rainfall. The rainy season typically commences in late April, gradually intensifying until reaching its peak in July-August, and then abruptly declining and ceasing entirely by October-November. The mean annual rainfall in the dis-

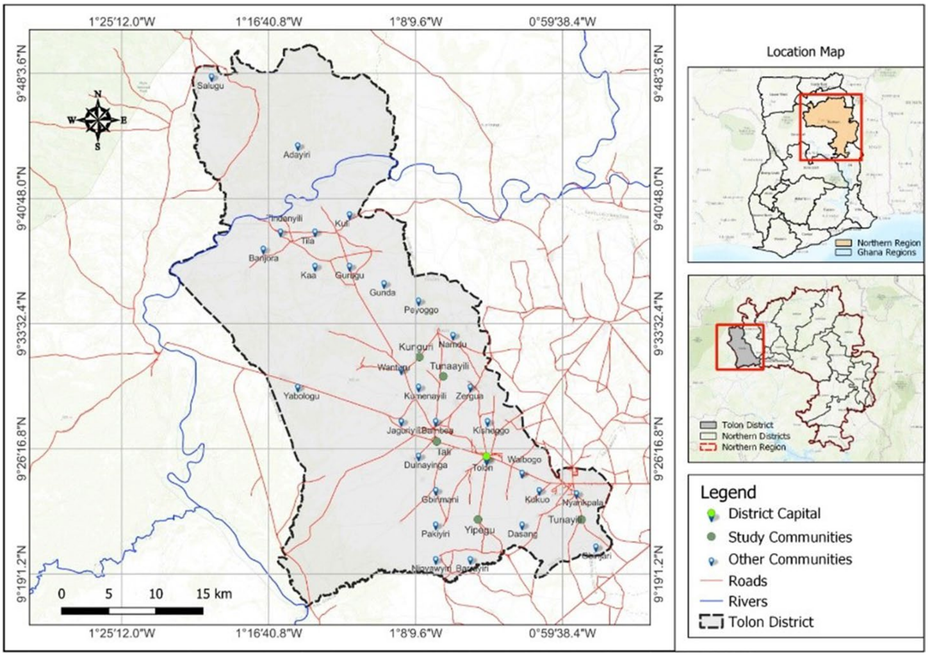

Fig. 1 Geographical location of the study sites

trict ranges from 950 mm to 1200 mm (Larweh & Abukari, 2022). Furthermore, the district witnesses a continuous dry season spanning from November to March. According Larweh and Abukari (2022) temperatures are between 33 °C and 39 °C in the day and ranges from 20 °C to 26 °C in the night. Majority of the people in the district depend on agriculture for their livelihood which is in accordance with the findings of Anang et al. (2022), who stated that 94% of the population in the district are in the agricultural sector.

2.2 Research design

The primary data for this study was collected from both quantitative and qualitative data sources through a household survey, which enabled us to effectively gather primary data from a large population. A descriptive survey design was adopted for this study because it allows for an in-depth explanation of natural phenomena and description of relationships between variables. Furthermore, this design provides complete description of the targeted individuals or groups.

2.3 Sample size determination

The study was conducted using farm households as the target population in the Tolon District of Ghana. The household was chosen as the sampling unit. In this study, a household was defined as a group of people who cohabit, share productive resources, eat from the same pot, and recognize one person as the head to enhance accuracy and reduce sampling bias, the sample size for the study was determined following Cochran's (1977) sample size formula for data large population. A total of 384 farm households were selected for the study based on the estimation derived from Cochran's formula:

$$N_o = t^2xpq/d^2 \tag{1}$$

$N_o = (1.96)^2\ (0.5)\ (0.5)/(0.05)^2 = 384$

where; No is the sample size; t is the t-value for a selected alpha level of 0.05 which is 1.96; p is the estimated proportion of an attribute that represents the population; q is 1-p; (p)(q) are the estimated variance; and d is the acceptable margin of error (5%) for the proportion being estimated.

The determination of the number of households in the four sampled communities took place after establishing the sample size for the study area. To calculate the number of households, the formulae below was employed following Arage (2021):

$$\mathrm{ni} = (\mathrm{n} \times \mathrm{Ni}) \,/\, \left(\sum \mathrm{Ni}\right) \tag{2}$$

Where;

ni= sample size estimated for a given community

n = number of households in a given community.

Ni = the minimum sample size required, which is 384.

∑Ni = total number of households in all the selected communities.

2.4 Sampling procedure

As a mixed method study both purposive and simple random sampling techniques were used for this study. To select the sample households, a two-stage simple random sampling technique was applied factoring variables including proximity, transportation issues, environmental factors and research cost. Firstly, simple random sampling was done by listing all communities in the Tolon district and assigning unique identifiers to each community. A random number generator was used to select four communities Tuuna-yili, Tali, Kunguri and Yepelgu. Within each selected community, a list of all households was complied. Secondly, household heads were selected at random in proportion to the size of households in the communities. This proportional allocation ensured that each community's sample size reflected its population. The rationale for employing simple random sampling is that all the communities are found in the same agro-ecological zone. This approach of sampling procedure allows each community and household head the same chance of being included in the sample. Purposive sampling was used to select key informants in the study area. The selected communities and their respective sample sizes are shown in Table 1.

2.5 Data collection method and instrument

A structured questionnaire was used for this study as the data collection instrument. The questionnaire was designed to collect primary data from household heads who were smallholder farmers. The first section of the questionnaire consisted of closed and open-ended questions on the socio-economic and demographic characteristics of the respondents. Items included are sex, age, educational level, marital status, farm size, household size, farming experience, access to extension service, membership in farmer groups, and access to credit and soil amendment. The second part of the questionnaire focused on farmers' perceptions and willingness to accept biochar as a soil amendment. The perception and knowledge of farmers in this section were measured using a 5-point Likert scale (Likert, 1932): 1(strongly disagree), 2(disagree), 3(neutral), 4(agree) and 5(strongly agree).

A pre-test interview was conducted using 20 respondents at Tali in the Tolon District. This was done to check whether the questions were comprehensible, easy to administer, and met the objectives of the study. Relevant changes were made to the questionnaire based on feedback and lessons learned from the pre-test. Data was collected by four (4) trained research assistants and supervised by the lead Principal Investigator. The research assistants were from the Faculty of Natural Resources and Environment, University for Development Studies. The research assistants were all fluent in the local dialect of the selected communities. Data was collected between April and July 2022.

Table 1 Number of sampled households in the selected communities

Selected communities	Total households [a]	Sample size
Tuuna-yili	105	75
Tali	209	149
Kunguri	107	76
Yepelgu	119	84
Total	540	384

[a] Ghana Statistical Service (2013), 2010 Population and Housing Census

2.6 Study variables

The dependent variable in this study was a binary variable indicating the acceptability of biochar by farmers (1 if biochar is accepted, 0 otherwise). Acceptance of biochar in this context means the willingness to use biochar. The independent variables (Table 2) were chosen based on previous studies (Abebe & Debebe, 2019; Babasola et al., 2018; Huang & Karimanzira, 2018) and they included socio-demographic factors (e.g., sex, age, marital status, educational level, household size, farming experience, access to extension, access to credit, membership in farmer groups, farm size, and access to biochar.

Table 2 The description of the variables used in the study and their signs

Variable	Description	Definition and unit	Expected sign
Dependent variable	Acceptability of biochar	1 if accepting biochar 0, otherwise	
Independent variables			
Sex	Sex of household head (HH)	1 if HH is male, 0 if otherwise	+/-
Age	Age of HH	computed as a continuous variable (in years)	-
Marital status	Marital status of HH	1 if married, 0 otherwise	+/-
Educational level	The educational level of HH	0 for no education, 1 for primary, 2 for secondary, 3 for tertiary	+/-
Household size	Number of people in the household	Computed as a continuous variable	+/-
Farm size	Size of farmland	Computed as a continuous variable (in acres)	+
Extension service	Access to extension service	1 if HH has access to extension service, 0, otherwise	+
Farming experience	Farming experience	Computed as a continuous variable (in years)	+
Membership in farmer groups	Membership in farmer groups	1 if HH is a member, 0 for otherwise	+
Credit accessibility	Access to credit facilities	1 if HH has access to credit facilities, 0 for otherwise	+
Access to biochar	Household access to biochar	1 if HH has access, 0 for otherwise	+

Source: Field survey, 2022

2.7 Statistical analysis

Microsoft (MS) Excel and the Statistical Package for Social Science (SPSS) were utilized for processing and analyzing the data. Figure 2 illustrates the schematic diagram of the data analysis methods used in the study. The data were used to express the socio-demographic characteristics of farmers, which were analysed descriptively using percentages. Farmers' perceptions of biochar acceptability were assessed using the perception index (PI). Participants were asked to indicate their agreement level with a set of statements using a five-point Likert scale. This scale ranged from Strongly Agree (SA), Agree (A), Neutral (N), Disagree (D) and Strongly Disagree (SD) with corresponding weights of 5, 4, 3, 2, and 1 assigned to positive statements, and vice versa for negative statements. The perception index (PI) for each theme was analyzed by calculating the weighted mean following Roy (2009):

$$Perception\ Index\ (PI):\ [(5 \times SA) + (4 \times A) + (3 \times N) + (2 \times D) + (1 \times SD)] \quad (3)$$

(for positive statements)
or

$$Perception\ Index\ (PI):\ [(1 \times SA) + (2 \times A) + (3 \times N) + (4 \times D) + (5 \times SD)] \quad (4)$$

(for negative statements)

$$MPI = PI/n \quad (5)$$

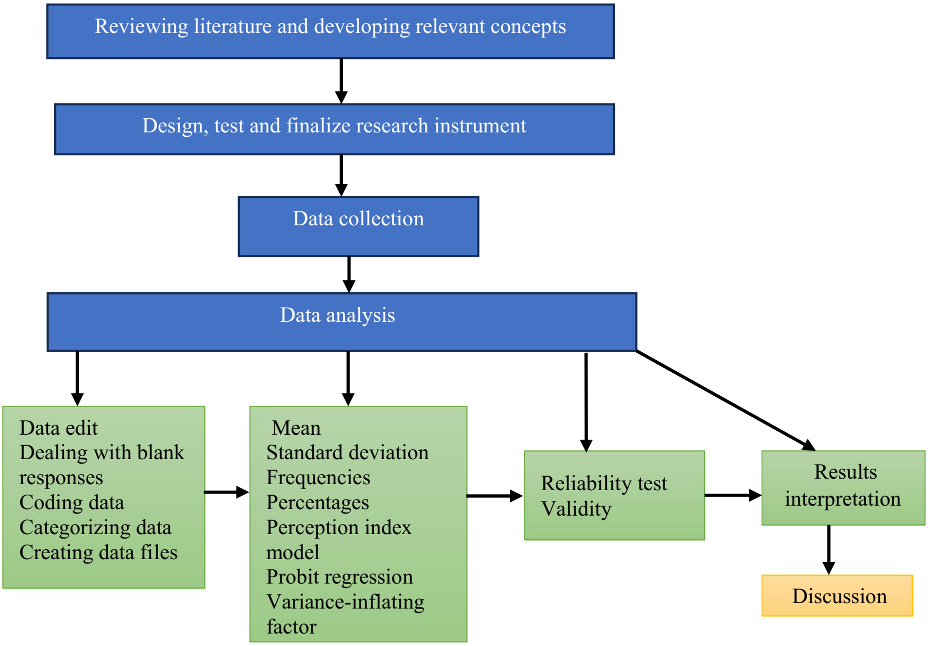

Fig. 2 A schematic diagram of data analysis

where n = total number of the respondents

MPI = Mean Perception Index.

The probit regression model was used to estimate the influence of socio-economic factors on farmers' willingness to accept biochar as a soil amendment. The variance inflating factor was employed to test for multicollinearity between the explanatory variables in the model (Gujarati, 2004). No multicollinearity was detected. A *p*-value < 0.05 was used to determine statistical significance. A combination of the explanatory variables was modelled using a log-linear function for the categorical dependent variables in the probit model (Noreen, 1988).

The probit function is given as:

$$Pr\left(Yi = 1\left|xi\right.\right) = F\left(\beta' xi\right) = \phi\left(\beta' xi\right) \tag{6}$$

where Pr denotes the probability that an individual uses biochar or not, Y_i is the binary choice variable representing use and ϕ is the cumulative distribution function of the standard normal distribution. β is a vector of unknown parameters. It is assumed that the latent variable Y_i^* can be specified as follows:

$$Y_i{*} = \Sigma\left(n = 1\right)^n \beta nxni + ui \tag{7}$$

And that:

$Y_i = 1$ if $Y^* > 0$.

$Y_i = 0$ otherwise.

where x_i represents a vector of explanatory variables, u_i is a random disturbance term, N is the total sample size, and β is a vector of unknown parameters to be estimated by the method of maximum likelihood.

Model specification:

$$Y_i = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4 + \beta 5X5 + \beta 6X6 + \beta 7X7 + \beta 8X8 + \beta 9X9 + \beta 10X10 + \beta 11X11 + ui \tag{8}$$

Where Y_i = is the probability of biochar acceptability (1 if the farmer has accepted biochar, 0 otherwise); X1 is the sex of HH (1 if a male, 0 if a female); X2 represents the age of HH (expressed as a continuous variable in years); X3 is the marital status (1 if married, 0 otherwise); X4 means educational level of HH; X5 is HH size; X6 represents farm size (expressed as a continuous variable in acres); X7 indicates access to extension services; X8 is the farming experience (expressed as a continuous variable in years); X9 means membership in farmer groups; X10 is access to credit; X11 represents access to biochar; β0 is the regression coefficient and ui is a random error term. The marginal effect of an increase in the explanatory variable is the expected value of the dependent variable (Anang, 2016). The coefficients derived from this model provide valuable information that can be utilized in policy decision-making processes. The estimation of marginal effects involves differentiating Eq. (6) concerning x_i, as outlined by Greene (2001):

$$dy/dx = \phi\left(\beta x_i\right)\beta \tag{9}$$

where ϕ is the probability density function of the standard normal distribution.

3 Results

This section presents a comprehensive overview of the study's findings commencing with the socio-demographic characteristics of selected farming households, followed by farmers willingness to accept biochar as a soil amendment, small-scale farmers perception of the merits and drawbacks of biochar production and application and finally on the socio-economic factors influencing farmers acceptability of biochar as a soil amendment.

3.1 Socio-demographic characteristics of the selected farming households in the Tolon district

The socio-demographic characteristics of farming households selected for the study are shown in Table 3. The mean age of the household heads interviewed was 56.13 ± 11.4. Most of the respondents were males (77.34%), and only 22.66% were females., The majority (73.95%) of respondents had access to soil amendments. Thus, only 26.05% had no access

Table 3 Socio-demographic characteristics of the selected households in the Tolon district (*n* = 384)

Categorical variables	Number of respondents	Percent (%)
Sex of household head (HH)		
Male	297	77.34
Female	87	22.66
Marital status		
Single	73	19.01
Married	286	74.47
Widowed	15	3.90
Divorced/separated	10	2.60
Educational level of HH		
Tertiary	6	1.56
Secondary	30	7.81
Primary	69	17.96
No formal education	279	72.65
Access to extension services		
Yes	297	77.34
No	87	22.66
Membership in farmer groups		
Yes	301	78.38
No	83	21.62
Access to credit		
Yes	70	18.23
No	314	81.77
Access to biochar		
Yes	284	73.95
No	100	26.05
Continuous variables		Mean ± SD
Age of HH (years)		56.13 ± 11.4
Household size		8.47 ± 4.42
Farm size (acres)		2.53 ± 1.43
Farming experience of HH (years)		27.72 ± 12.33

SD (Standard deviation)

Source: Field survey, 2022

to soil amendments. The data further shows that more than half (72.65%) of the respondents had no formal education. Only 17.96%, 7.81% and 1.56% had completed primary, secondary and tertiary education respectively. The majority (77.34%) of respondents had access to extension services, and only a small proportion (22.66%) had no access to extension services. Most of the respondents (78.38%) were members of farmer groups while only 21.62% were not members of any farmer groups. Furthermore, the majority (81.77%) of respondents had no access to credit but 18.23% had access to credit facilities. The mean age, household size, and farm size of the selected households have also been presented in Table 3.

3.2 Farmers' willingness to accept and reasons for not accepting Biochar as a soil amendment

Farmers' willingness to accept and reasons for not accepting biochar as a soil amendment in the Tolon District of Ghana are presented in Table 4. The majority of farmers (83.33%) confirmed that they were willing to accept biochar as a soil amendment and only 16.67% of the farmers were not willing to accept biochar as a technology for soil amendment in the district.

The survey also revealed reasons regarding farmers not willing to accept biochar as a soil amendment. 18.75% of the farmers expressed that they did not know about biochar, 42.19% of them stated that they do not know how biochar is produced and 39.06% of the farmers also expressed that biochar production is labour-intensive.

A farmer stated, *'I am willing to accept and apply biochar in my farm if it can help improve my crop yields and nutrient status.'* This quote demonstrates that farmers' acceptance of a technology depends on the benefits they drive from it.

3.3 Small-scale farmers' perception of the merits and drawbacks of biochar production and application in the Tolon District

The perceptions held by farmers on the production and application of biochar (including their mean PIs and ranks) have been presented in Table 5. The most dominant perceptions held by farmers were that biochar application was eco-friendly and increased crop yield. These perceptions ranked 1 st and 2nd with mean perception indices (PIs) of 4.08 and 4.04

Table 4 Farmers' responses to the willingness to accept and reasons for not accepting Biochar as a soil amendment

Statement	Description	No. of Respondents	Percent (%)
Are you willing to accept biochar as a soil amendment	Yes	320	83.33
	No	64	16.67
Reasons for not accepting biochar as a soil amendment	I do not know about it	12	18.75
	I do not know how it is produced	27	42.19
	Biochar cannot address soil fertility problems labour-intensive	25	39.06

Source: Field survey, 2022

Table 5 Small-scale farmers' perceptions of the merits and drawbacks of Biochar in the Tolon district

Perception statement	The frequency of perception levels					Total score (PI)	Mean (PI/n)	SD	Rank
	1	2	3	4	5				
Biochar production									
Biochar use is labour-intensive	30	68	40	66	180	1450	3.77	0.65	6th
Biochar can be produced from various feedstocks	40	60	52	89	143	1387	3.61	0.43	8th
Biochar production requires technical skill	35	29	50	120	147	1458	3.79	0.51	5th
Biochar utilization									
Biochar application does not require any special skills	78	22	85	99	100	1273	3.31	0.68	12th
Application of biochar is eco-friendly	25	30	31	100	198	1568	4.08	0.57	1st
Biochar increases crop yields	32	34	20	98	200	1552	4.04	0.58	2nd
Biochar improves the physico-chemical parameters of the soil	19	28	80	97	160	1503	3.91	0.44	4th
Biochar is less costly than chemical fertilizer	98	6	50	100	130	1310	3.41	0.49	11th
Biochar has no residual effects on crop cereals	9	40	57	100	178	1550	4.03	0.46	3rd
Biochar utilization poses no danger to farmers' and labourers' health	30	70	66	88	130	1370	3.56	0.63	9th
Biochar can sustain soil fertility more than chemical fertilizers	20	60	86	83	135	1405	3.65	0.47	7th
Biochar can store carbon in the soil for a long time	20	80	82	109	93	1327	3.45	0.66	10th

SD (Standard deviation)

Source: Field survey, 2022

respectively. In addition, many farmers' were of the view that biochar application had no residual effects on crop cereals (mean PI = 4.03); improved soil physicochemical properties (mean PI = 3.91); could sustain soil fertility better than chemical fertilizers (mean PI = 3.65); production of biochar requires technical skills (mean PI = 3.79); biochar use is labour intensive (mean PI = 3.77); can be produced from various feedstocks (mean PI = 3.61); posed no danger to the health of farm workers (mean PI = 3.56); and was less costly than chemical fertilizers (mean PI = 3.41). Another favourable perception held by farmers was that biochar can store carbon in the soil for a long time (mean PI = 3.45) and does not require any special skills (mean PI = 3.31).

A farmer stated, 'I have a problem with low yield and it is expensive to apply fertilizer these days, biochar can improve my crop yields.' Another farmer remarked, *'How come we have not heard about biochar and no one told us about it.'*

One farmer also narrated, *'I have heard from our farmer group that biochar is produced from agricultural waste. Although it does not look like fertilizer, it can help sustain the soil better.'* These quotes demonstrate farmers' perceived knowledge regarding biochar.

Despite these perceived benefits, biochar application was widely regarded by farmers as technically demanding (mean PI = 3.79) and labour-intensive (mean PI = 3.77). On the contrary, some farmers contended that biochar application does not require any special skills (Table 5). This opposing view, however, had the least mean PI of 3.31 and lowest rank (12th). Thus, only a limited number of farmers did not find biochar application to be technically demanding.

3.4 Socio-economic factors influencing small-scale farmers' acceptability of biochar as a soil amendment in the Tolon District

The findings from the probit regression model (Table 6) indicate factors influencing the acceptance of biochar as a soil amendment among small-scale farmers in the Tolon District. These factors were tested using the likelihood ratio chi-square (LR Chi^2) at significant difference of 1% indicating a stronger model in the explanation of the variations in the acceptability of biochar as a soil amendment by smallholder farmers in the district. The validity of the probit model in the assessment of smallholder farmers acceptance of biochar as a soil amendment is supported by the findings of Danso et al. (2017).The findings from the model indicate that six (6) of the predictor variables including educational level of household heads, farming experience, access to extension services, membership in farmer groups, access to biochar and access to credit had a significant positive influence on smallholder farmers acceptance of biochar in the Tolon district (Table 6). The Pseudo R^2 suggests that 56.83% of the variation in the independent variables is explained by the probit model in the acceptance of biochar in the district.

The results further indicate that compared to their base categories, formal education of the household head, farming experience, access to extension services, access to biochar, and membership in farmer groups and access to credit led to a positive acceptance of biochar as a soil amendment with coefficients of 0.279, 0.584, 0.356, 0.633, 0.473 and 0.223 respectively. Farming experience of the household heads had the highest effect on the probability

Table 6 The influence of socio-economic factors on small-scale farmers' acceptability of Biochar as a soil amendment in the Tolon district

Independent variables	Coefficient	Standard error	$P > \|z\|$	Marginal effect (dy/dx)
Sex of household head	−0.154	0.213	0.286	0.02
Age of household head	−0.046	0.117	0.452	−0.006
Education of household head	**0.279**	0.325	**0.000**	0.047
Marital status	−0.027	0.138	0.899	0.019
Farm size	−0.034	0.143	0.543	0.022
Household size	−0.021	0.139	0.288	0.017
Farming experience	**0.584**	0.689	**0.000**	0.055
Access to extension service	**0.356**	0.542	**0.000**	0.034
Membership in farmer groups	**0.473**	0.565	**0.000**	0.146
Access to credit	**0.223**	0.321	**0.000**	0.047
Access to biochar	**0.633**	0.354	**0.000**	0.186
Goodness of Fit and Performance of Model Statistics				
Observations	382			
Log-likelihood	−74.66			
LR Chi^2 (11)	345.76*			
Prob > chi^2	0.001			
Pseudo R^2	0.5683			

dy/dx (marginal effect after probit assessed at population average)

***Significance at 1% level (mean p values are in bold)

Source: Field survey, 2022

of biochar acceptability. For any unit increase in the farming experience of household head in the district led to a 5.8% increase in the probability of biochar being accepted by the smallholder farmers.

4 Discussion

The discussion section addresses three interconnected themes crucial to the understanding of biochar acceptance as a soil amendment in the Tolon district of Ghana. Firstly, we analyzed farmers willingness to accept and reasons for non-acceptance, grounded in empirical data. Secondly, we examined farmers perception of biochar's merits and drawbacks using a perception index model. Finally, we investigate socio-economic factors influencing smallholder farmers' acceptability of biochar using a probit model. The findings from the model indicate predictor variables including educational level of household heads, farming experience, access to extension services, membership in farmer groups, access to biochar and access to credit influencing farmers acceptance of biochar as a soil amendment. These subsections provide a holistic perspective on biochar acceptance, offering empirical evidence to inform best practices in agriculture.

4.1 Farmers' willingness to accept and reasons for not accepting Biochar as a soil amendment

Smallholder farmers exhibited high levels of biochar acceptance upon inquiry regarding their willingness to accept and use it as a soil amendment in their farmlands which aligns with the findings of Latawiec et al. (2017). These authors reported higher levels of farmers' willingness to accept and use biochar as a soil amendment technology. Likewise, the study revealed some sociocultural barriers of smallholder farmers not accepting the biochar technology. These barriers include farmers' lack of biochar awareness, farmers' inability to produce biochar and farmers' lack of trust in the technology thus leading to farmers being skeptical about the technology in solving soil fertility challenges in the area. These findings align with the findings of Müller et al. (2019) and Latawiec et al. (2017) who highlighted in their reports that the lack of trust in technology, lack of biochar awareness and the lack of knowledge of producing biochar by smallholder farmers affects the acceptance of biochar.

4.2 Small-scale farmers' perception of the merits and drawbacks of biochar production and application in the Tolon District

In general smallholder farmers in the district had diverse perceptions concerning the use of biochar as a soil amendment. Smallholder farmers generally held positive perceptions of the cost-effectiveness, agronomic and the ecological advantages biochar. The overriding perception by smallholder farmers that biochar application is eco-friendly supports the findings of Rahman et al. (2020) who reported that farmers strongly perceived biochar production and utilization to be eco-friendly owing to its carbon dioxide emissions reduction capabilities. Furthermore, Latawaiec et al. (2017) confirmed this finding by conducting a similar study. They found out that farmers who were more willing to adopt biochar as a soil amendment were environmentally conscious and more concerned about sustainable agriculture. The eco-friendliness of biochar emerging as the most perceived benefit suggests that smallholder farmers in the district were generally concerned about sustainable and best practices in agriculture. Also, the perception that biochar increases crop yields corroborates with the findings of Areal and Pede (2023). The authors reported that farmers adopt agricultural technology based on the technologies capacity to provide increased crop yields, returns, efficacy and the general wellbeing of the farmer. Furthermore, the majority of the smallholder farmers were of the view that that various feedstocks can be used to produce biochar. This finding is in line with Abukari et al. (2022), Yeboah et al. (2022) and Duku et al. (2011) who found that various feedstock can be used for the production of biochar in Ghana.

In spite of these perceived benefits, biochar application generally was viewed as technically demanding and labour-intensive by the farmers in the district thus constituting barriers to biochar application in a smallholder context. Similarly, previous studies have revealed that biochar production is labour-intensive mainly in the feedstock collection, storage and transportation (Frimpong et al., 2021; Yeboah et al., 2022). Also, the perception viewed by smallholder farmers that biochar application is technically demanding corroborates with the findings of Pierson et al. (2024). These authors highlighted that collective knowledge and skills are pre-requisites for high-quality biochar production.

4.3 Socio-economic factors influencing small-scale farmers' acceptability of biochar as a soil amendment in the Tolon District

The findings from the probit regression model predicted a multiplicity of socio-economic factors that influenced smallholder farmers acceptance of biochar as a soil amendment in the study area. These factors include formal education, farming experience, access to extension services, membership in farmer groups, and access to biochar.

The findings from this study supports that the positive influence of farming experience is in line with existing literature. Obisesan et al. (2016), reported that farmers with extensive years of farming experience, as early adopters, gained an advantage from the technology. Furthermore, smallholder farmers with more experience have a better access to information and knowledge which are accumulated over time.

Furthermore, the positive effect of access to extension services aligns with the findings of Asule et al. (2023). These authors reported that smallholder farmers are more likely to accept an agricultural technology upon receiving consistent interactions with extension officers. Similarly, Dube-Takaza et al. (2023) reported that the consistent visitation of extension officers contributes to a heightened acceptance of agricultural technologies by farmers.

The positive influence of membership in an association could be due to the advantages and motivation smallholder farmers receive to achieving higher yields through enhanced access to soil amendment technologies (Nnahiwe et al., 2023). Therefore, existing farmer-centered associations could uplift the acceptance rate of biochar as a soil amendment in the study area. This aligns with the findings of Thomas et al. (2023) who reported that farmers affiliated with associations are inclined to accept improved agricultural technologies. The findings of Miine et al. (2023), suggest that farmers are driven to accept an agricultural technology based on the technology's ability to address their problems, thus resulting in enhanced acceptance of biochar as a soil amendment.

The positive effect of access to soil amendment suggests an empirical association between the availability and affordability of biochar and smallholder farmers' acceptance of biochar as a soil amendment in the area.

5 Conclusion

The findings imply that farmers generally had mixed perceptions regarding the production and utilization of biochar as a soil amendment. In general, farmers held positive perceptions of the cost-effectiveness, as well as on the agronomic and ecological merits of biochar. This could serve as an opportunity to promote biochar utilization in a smallholder context. The findings further imply that the acceptability of biochar as a soil amendment is influenced by a wide range of socio-economic factors such as formal education, farming experience, access to extension, membership in farmer groups, access to biochar and access to credit. The notion that biochar application is labour-intensive and technically demanding could, however, constitute barriers to adoption. The greater positive influence of farming experience on biochar acceptability suggests that farmers with limited experience are less likely to utilize biochar. The positive perception of biochar's cost-effectiveness, agronomic and ecological merits should be leveraged to promote its utilization among smallholder farmers. Consistent with the Sustainable Development Goals 2, 12 and 13, these findings can support the adoption of biochar application as a cost-effective and eco-friendly pathway to crop production, particularly in areas characterized by degraded soils. This approach promotes sustainable agriculture, enhance food security and support climate resilience.

5.1 Policy recommendations

The findings therefore underscore the need for technical support, formal education, group membership, and farm labour support as potentially effective entry points for promoting biochar adoption, particularly among farmers with limited experience. Smallholder farmers, especially those with limited experience, should be provided with training and support to address concerns about labour intensity and technical demands. Policymakers and stakeholders should promote formal education and awareness programs such as agriculture radio discussions, methods and result demonstrations and field days, highlighting biochar benefits, proper application methods and potential returns on investment. Farmer group members should be encouraged and supported to facilitate knowledge sharing, access to resources and collective bargaining power. Efforts should be made to ensure farmers have access to credit facilities and extension services to overcome financial constraints and receive guidance on biochar utilization. Targeted intervention should be developed for smallholder farmers with limited experience, focusing on building their capacity and confidence in biochar adoption.

Acknowledgements We are grateful to all the enumerators, community leaders and respondents in the Tolon District of Northern Ghana who accepted to participate in the survey.

Author contributions Ammal Abukari: Writing of original draft, Investigation, Formal analysis, Data curation Conceptualization. Ishmeal Hashmiu: Conceptualization, Methodology, Review. James Kaba Seutra: Review, Supervision, Methodology, Conceptualization. Akwasi Adutwum Abunyewa: Review, Supervision, Methodology, Conceptualization. Olivia Agbenyega: Review, Supervision, Methodology, Conceptualization.

Funding The authors receive no funding for this study.

Data availability The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical considerations To ensure the ethical conduct of the study, informed consent was obtained from all participants prior to the interviews. To facilitate this process, a comprehensive document containing pertinent information about the data collection was read and distributed to all participants. This document included details about the study's purpose, the participant's right to withdraw from the study at any time, and the researcher's contact information in case of any concerns. Moreover, the interviewees were informed that their interviews would be recorded. The provision of this information enabled participants to make an informed decision regarding their involvement in the study, thereby fostering an environment of honesty and openness. Consequently, all participants provided their consent, leading to the audio recording of all interviews.

Competing interest The authors declare no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abdul-Rahman, A. (2018). Effects of climate change coping and adaptation strategies on food security among smallholder maize farmers in the Tolon district and Savelugu municipal (Doctoral dissertation, University for Development Studies). http://www.udsspace.uds.edu.gh/handle/123456789/2927

Abebe, G., & Debebe, S. (2019). Factors affecting the use of organic fertilizer among smallholder farmers in Sekela district of Amhara region, Northwestern Ethiopia. *Cogent Food & Agriculture,5*(1), Article 1669398.

Abukari, A., Kaba, J. S., Dawoe, E., & Abunyewa, A. A. (2022). A comprehensive review of the effects of biochar on soil physicochemical properties and crop productivity. *Waste Disposal & Sustainable Energy,4*(4), 343–359.

Acharya, B. S., Dodla, S., Wang, J. J., Pavuluri, K., Darapuneni, M., Dattamudi, S., & Kharel, G. (2024). Biochar impacts on soil water dynamics: Knowns, unknowns, and research directions. *Biochar*, *6*(1), 34.

Anang, B. T. (2016). A probit analysis of the determinants of fertilizer adoption by cocoa farmers in Ghana. *Asian Journal of Agricultural Extension, Economics & Sociology,8*(1), 1–8.

Anang, B. T., Dokyi, E. O., Asante, B. O., & Donkoh, S. A. (2022). Technical efficiency of resource-poor maize farmers in Northern Ghana. *Open Agriculture*, *7*(1), 69–78.

Arage, A. (2021). Assessment of farmer's perception and adoption of agroforestry practices: The case of Assosa district, western Ethiopia. *American Journal of Applied Scientific Research,7*(2), 15–21.

Areal, F. J., & Pede, V. O. (2023). Evaluating the adoption and impacts of agricultural technologies. *Frontiers in Sustainable Food Systems*, *7*, 1340035.

Aremu, T. B., Freeman, C. Y., Laamari, A., Iddrisu, Y., Atakora, W. K., & Bindraban, P. S. (2023). Informing the design of a multistakeholder platform in Ghana using stakeholder analysis and social network analysis. *Outlook on Agriculture*, *52*(2), 126–139.

Asule, P. A., Musafiri, C., Nyabuga, G., Kiai, W., Ngetich, F. K., & Spurk, C. (2023). Determinants of simultaneous use of soil fertility information sources among smallholder farmers in the central highlands of Kenya. *Agriculture*, *13*(9), 1729.

Atakora, W. K., Fosu, M., Safo, E. Y., Tuffour, H. O., and Tetteh, F. M. (2014). Response of Maize Growth and Development to Mineral Fertilizer and Soil Characteristics in Northern Ghana. *International Journal of Advance Agricultural Research, 2,*67–76.

Babasola, O. J., Olaoye, I. J., Alalade, O. A., Matanmi, B. M., & Olorunfemi, O. D. (2018). Factors affecting the use of organic fertilizer among vegetable farmers in Kwara State. *Nigeria. Tanzania Journal of Agricultural Sciences, 16*(1), 46–53.

Bationo, A., Fening, J. O., & Kwaw, A. (2018). Assessment of soil fertility status and integrated soil fertility management in Ghana. *Improving the Profitability, Sustainability and Efficiency of Nutrients Through Site Specific Fertilizer Recommendations in West Africa Agro-Ecosystems* (Vol. 1, pp. 93–138). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-58789-9_7

Bjerregaard, P. P., & Georg, S. (2011). The social shaping of technology: a case study of Biochar in Denmark: Insights for businesses, researchers, investors and policy makers (Master thesis, Copenhagen Business School)

Blanco-Canqui, H. (2017). Biochar and soil physical properties. *Soil Science Society of America Journal,84*(4), 687–711. https://doi.org/10.2136/sssaj2017.01.0017

Bruckman, V. J., & Pumpanen, J. (2019). Biochar use in global forests: opportunities and challenges. *Developments in soil science, 36*, 427–453.

Cochran, W. G. (1977). Sampling techniques. (3rd.). In Bartlett, J. E., Kotrlik,J. W., Higgins, C. C. (2001) Organizational Research: Determining appropriate sample size in survey research. *Information Technology, Learning, and Performance Journal* 19(1), 43–50.

Daadi, B. E., & Latacz-Lohmann, U. (2022). Composting municipal solid waste for agriculture in Northern Ghana: Rural farmers' willingness to pay for compost quality and access attributes. *Q Open,2*(1), qoac012.

Danso, G. K., Otoo, M., Ekere, W., Ddungu, S., & Madurangi, G. (2017). Market feasibility of faecal sludge and municipal solid waste-based compost as measured by farmers' willingness-to-pay for product attributes: Evidence from Kampala, Uganda. *Resources,6*(3), Article 31.

Dube-Takaza, T., Maumbe, B. M., & Parwada, C. (2023). Agricultural technology adoption for smallholder small grain farmers in Zimbabwe. Implications for food system transformation and sustainability. *International Food and Agribusiness Management Review,26*(5), 882–903.

Duku, M. H., Gu, S., & Hagan, E. B. (2011). Biochar production potential in Ghana—A review. *Renewable And Sustainable Energy Reviews,15*(8), 3539–3551.

Frimpong, K. A., Phares, C. A., Boateng, I., Abban-Baidoo, E., & Apuri, L. (2021). One-time application of biochar influenced crop yield across three cropping cycles on tropical sandy loam soil in Ghana. *Heliyon*. https://doi.org/10.1016/j.heliyon.2021.e06267

Ghana Statistical Service. (2013). *2010 population and housing census: National analytical report*. Ghana Statistics Service.

Greene, W. H. (2001). Fixed and random effects in nonlinear models. Working papers 01-01, New York University, Leonard N. Stern School Business, Department of Economics.

Gujarati, D. N. (2004). Basic Econometrics, 4th Edition. The McGraw-Hill.

Hounnou, F. E., Houessou, A. M., Kasim, O. F., & Yabi, J. A. (2024). Cotton farmers' intention to adopt biochar as climate change adaptation and sustainable land management strategy in Benin. *Journal of Cleaner Production, 438*, 140685. https://doi.org/10.1016/j.jclepro.2024.140685

Huang, Z., & Karimanzira, T. T. P. (2018). Investigating key factors influencing farming decisions based on soil testing and fertilizer recommendation facilities (STFRF)—a case study on rural Bangladesh. *Sustainability*, *10*(11), 4331.

Khan, S., Irshad, S., Mehmood, K., Hasnain, Z., Nawaz, M., Rais, A., & Ibrar, D. (2024). Biochar production and characteristics, its impacts on soil health, crop production, and yield enhancement: A review. *Plants*, *13*(2), 166.

Kumar, A., & Bhattacharya, T. (2021). Biochar: A sustainable solution. *Environment, Development and Sustainability,23*, 6642–6680.

Larweh, S., & Abukari, A. (2022). Small-scale farmers' perception of the adoption of agroforestry practices in Tolon district, Ghana. *Turkish Journal of Agriculture-Food Science and Technology*, *10*, 2899–2902.

Latawiec, A. E., Królczyk, J. B., Kuboń, M., Szwedziak, K., Drosik, A., Polańczyk, E., & Strassburg, B. B. (2017). Willingness to adopt biochar in agriculture: The producer's perspective. *Sustainability,9*(4), Article 655.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, *22*(140), 55.

Luo, L., Wang, J., Lv, J., Liu, Z., Sun, T., Yang, Y., & Zhu, Y. G. (2023). Carbon sequestration strategies in soil using biochar: Advances, challenges, and opportunities. *Environmental Science & Technology*, *57*(31), 11357–11372.

Miine, L. K., Akorsu, A. D., Boampong, O., & Bukari, S. (2023). Drivers and intensity of adoption of digital agricultural services by smallholder farmers in Ghana. *Heliyon*. https://doi.org/10.1016/j.heliyon.2023.e23023

Müller, S., Backhaus, N., Nagabovanalli, P., & Abiven, S. (2019). A social-ecological system evaluation to implement sustainably a biochar system in South India. *Agronomy for Sustainable Development,39*, 1–14.

Nnahiwe, P., Hejkrlík, J., & Bavorová, M. (2023). Adopting modern agricultural technologies and impact on economic performance: Evidence from cashew farmers in Kenya. *International Food and Agribusiness Management Review*, *26*(4), 615–639.

Noreen, E. (1988). An empirical comparison of probit and OLS regression hypothesis tests. *Journal Account Resources*, *1*(1), 119–133.

Obisesan, A. A., Amos, T. T., & Akinlade, R. J. (2016). Causal effect of credit and technology adoption on farm output and income: The case of cassava farmers in Southwest Nigeria. https://doi.org/10.22004/ag.econ.246443
Otte, P. P., & Vik, J. (2017). Biochar systems: Developing a socio-technical system framework for biochar production in Norway. *Technology in Society,51*, 34–45.
Owusu, S., Yigini, Y., Olmedo, G. F., & Omuto, C. T. (2020). Spatial prediction of soil organic carbon stocks in Ghana using legacy data. *Geoderma*, *360*, 114008.
Pierson, D., Anderson, N., Brewen, J., Clark, N., Hardy, M. C., McCollum, D., & Tirocke, J. (2024). Beyond the basics: A perspective on barriers and opportunities for scaling up biochar production from forest slash. *Biochar,6*(1), 1.
Rahman, M. S., Karim, M. R., Barman, J. K., & Islam, M. M. (2020). Farmers' attitude towards production and utilization of biochar as ecofriendly practice. *Advances in Research,21*(2), 38–46.
Rogers, P. M., Fridahl, M., Yanda, P., Hansson, A., Pauline, N., & Haikola, S. (2021). Socio-economic determinants for biochar deployment in the Southern highlands of Tanzania. *Energies,15*(1), 144.
Roy, B. S. (2009). Farmers' Perception of the effect of IPM for sustainable crop production. M.S. Thesis, Department of Agricultural Extension Education. Bangladesh Agricultural University, Mymensingh.
Saletnik, B., Zaguła, G., Bajcar, M., Tarapatskyy, M., Bobula, G., & Puchalski, C. (2019). Biochar as a multifunctional component of the environment—a review. *Applied Sciences*, *9*(6), 1139.
Scholz, S. B., Sembres, T., Roberts, K., Whitman, T., Wilson, K., & Lehmann, J. (2014). Biochar systems for smallholders in developing countries: leveraging current knowledge and exploring future potential for climate-smart agriculture. World Bank Study. https://hdl.handle.net/10986/18781
Thomas, R. J., O'Hare, G., & Coyle, D. (2023). Understanding technology acceptance in smart agriculture: A systematic review of empirical research in crop production. *Technological Forecasting and Social Change*, *189*, 122374.
Yeboah, E., Dugan, E., Nartey, E., Lawson, I. Y. D., Frimpong, K. A., Obiri, B. D., & Adiku, S. G. K. (2022). Biochar systems in Ghana. *Agricultural and Food Science Journal of Ghana,15*(2), 1553–1577.
Zhang, Y., Wang, J., & Feng, Y. (2021). The effects of biochar addition on soil physicochemical properties: A review. *Catena,202*, 105284.

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