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Constraints to Climate-smart Soil Management Practices in Ogun State, Nigeria: A Probit Model Approach

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Abstract

Climate change poses major threats to soil health and agricultural productivity, especially among smallholder farmers in Nigeria. Sustainable soil management is vital for maintaining fertility, enhancing resilience, and contributing to carbon sequestration. However, multiple socioeconomic and institutional barriers limit farmers' ability to adopt climate-smart soil management practices. This study examined the constraints affecting the adoption of climate-smart soil management practices among smallholder farmers in Ogun State, Nigeria, with a particular focus on the role of socioeconomic factors and access to information. Data were collected from 150 respondents through a structured questionnaire and analyzed using descriptive statistics and a probit regression model to identify factors influencing farmers' likelihood of encountering soil management constraints. Farmers adopted a mix of inorganic, organic, and biological practices, including NPK fertilizer (95.3%), green manure (100%), compost (83.3%), biofertilizers (55%), and seaweed extracts (70.6%). Major constraints were inadequate capital (100%), lack of soil conservation knowledge (91.3%), land-use competition (88.7%), and poor access to fertilizer (85.3%). The probit results showed that gender ($\beta = -0.02$, $p = 0.02$) and access to information sources ($\beta = 0.03$, $p = 0.05$) significantly influenced farmers' likelihood of encountering soil management constraints. Sustainable soil management in Nigeria requires integrated technical, institutional, and policy responses, including improved access to carbon credit markets and extension services to enhance climate resilience and equity.

Keywords

Carbon credit market; Climate-smart agriculture; Ogun State; Probit model; Smallholder farmers; Soil management practices

1. Introduction

Climate change has become one of the defining challenges of the 21st century, posing significant threats to food systems, livelihoods, and ecosystems worldwide [1, 2]. The agricultural sector, particularly in developing countries such as Nigeria, remains highly vulnerable to its impacts because of its dependence on rainfall, limited irrigation infrastructure, and poor adaptive capacity [3-5]. Increasing temperature, erratic rainfall, droughts, and flooding have intensified land degradation and soil fertility loss [6, 7], directly affecting crop yields and threatening the livelihoods of millions of smallholder farmers [8, 9]. Soil is the foundation of agricultural productivity and a critical component

of the global carbon cycle [4, 10]. It stores approximately twice as much carbon as the atmosphere and vegetation combined, making it central to climate change mitigation and adaptation efforts. Healthy soils with high organic matter content can enhance water retention, improve nutrient cycling, and act as carbon sinks, helping to offset greenhouse gas (GHG) emissions. Conversely, soil degradation through erosion, nutrient depletion, and deforestation contributes significantly to CO_2 emissions and undermines ecosystem resilience [11, 12].

In Nigeria, soil degradation has become a major threat to sustainable agriculture and food security [10, 12]. Declining soil fertility and poor soil management practices have resulted in yield reductions, particularly in key staples such as rice, maize, and cassava [13, 14]. Climate change exacerbates these problems through increased rainfall variability and temperature extremes that disrupt planting calendars and increase soil erosion [12-14]. For rice farmers in southwestern Nigeria, these climatic and edaphic challenges are compounded by socioeconomic barriers, including inadequate access to credit, limited knowledge of conservation practices, and high input costs [14, 15].

Over the last decade, the concept of climate-smart agriculture (CSA) has gained prominence as a holistic approach to enhance productivity, build resilience, and reduce greenhouse gas emissions. One important component of CSA is carbon credit systems, particularly through carbon markets. These mechanisms provide financial incentives for individuals or organizations that reduce or sequester carbon emissions. Farmers who adopt soil management practices that increase soil organic carbon (SOC), such as composting, green manuring, minimum tillage, agroforestry, and biofertilizer use, can theoretically earn carbon credits that are tradable in voluntary or compliance markets [16, 17].

Since the establishment of the European Union Emissions Trading Scheme (EU ETS) in 2005, the global carbon market has expanded rapidly, becoming one of the most significant instruments for reducing greenhouse gas emissions [18, 19]. As of January 2023, 32 carbon markets were operational worldwide, covering approximately 17% of global GHG emissions [18]. The expansion of these markets has enabled many countries and industries to pursue cost-effective emission reduction strategies, while carbon finance has emerged as a vital mechanism for enhancing market liquidity, managing risks, and attracting long-term investment [20].

However, despite global progress, Nigeria's carbon market remains nascent and far from achieving its "double carbon" goals. The experiences of mature markets underscore the potential of carbon finance to stimulate broader participation and support sustainable development. In this context, the neglect of smallholder farmers in existing carbon finance mechanisms represents a critical gap in the country's climate strategy. Integrating smallholders into carbon credit schemes could simultaneously promote adaptation and mitigation as well as reward sustainable agricultural practices, improve rural livelihoods, and advance Nigeria's commitments under the Paris Agreement and its Nationally Determined Contributions (NDCs) [21]. According to FAO [22], effective inclusion of smallholders in carbon markets could generate up to USD 50 billion annually for climate-resilient agricultural systems.

Previous studies on soil management in Nigeria have primarily focused on agronomic and socioeconomic determinants of adoption (access to credit, input cost, or education) [23, 24]. Few have examined how institutional and financial exclusion from carbon markets constrains sustainable soil management. Yet, soil carbon is not merely an agronomic concern but also a potential financial asset in the era of climate finance. This study, therefore, explores the constraints to soil management practices in the face of climate change among rice farmers in Ogun State, with special attention to poor access to carbon credit and carbon markets as an emerging institutional and financial barrier. By linking soil management to carbon credit, the study provides a novel perspective that contributes to understanding how adaptation and mitigation can be synergized within smallholder agricultural systems. It also offers insights into how integrating farmers into carbon markets could enhance soil productivity, promote sustainability, and support Nigeria's transition toward climate-smart agriculture.

1.1 The objectives of the study

This study was designed to investigate soil management practices among rice farmers in Obafemi Owode Local Government Area of Ogun State, Nigeria. Specifically, the objectives were to:

1. Identify the soil management practices adopted by the respondents.
2. Identify the constraints to effective climate-smart soil management practices under a changing climate among rice farmers in the study area.

2. Methods

2.1 Design and Sample

The study was carried out in Obafemi Owode Local Government Area of Ogun State. Obafemi Owode Local

Government Area (LGA) was created in 1976, with its headquarters located in the town of Owode at approximately 6°57′N and 3°30′E. The LGA covers an area of about 1,410 km² and had a population of 228,851 according to the 2006 national census. The region experiences a tropical climate characterized by an average annual temperature of 27.1°C and an average annual rainfall of approximately 1,514 mm. Rainfall is more prevalent during the summer months, while winters are relatively dry.

Obafemi Owode is recognized as one of the major rice-producing areas in Ogun State. The area possesses fertile and well-drained soils that support intensive rice cultivation and other arable crop production. These favorable soil and climatic conditions make it an ideal location for examining soil management practices in relation to climate change. This study adopted a descriptive survey research design to collect data from rice farmers within Obafemi Owode LGA. The design was appropriate for obtaining structured data on respondents' demographic characteristics, soil management practices, sources of information, and constraints under a changing climate. It also allowed for the use of standardized questionnaires and statistical tools to describe observed trends and test relationships among selected variables.

2.2 Population and Sampling Procedure

The target population comprised rice farmers residing in Obafemi Owode LGA. A multi-stage sampling technique was employed. In the first stage, six major rice-growing areas were randomly selected: Adigbe, Oba, Kobape, Obafemi, Ogunmakin, Iro Town, and Mokoloki. In the second stage, rice-farming households were identified within the selected areas, and a proportionate sampling technique was applied to select respondents from each community.

A total of 150 rice farmers were selected, ensuring proportional representation from all sampled areas. The distribution of the sample size across the selected rice-growing communities is presented in Table 1.

Table 1. Distribution of Sample Size by Administrative Area

S/N	Rice Grown Area	Estimated No. of Farming Households	Sample Size
1	Adigbe	51	8
2	Oba	502	50
3	Kobape	349	35
4	Obafemi	249	25
5	Ogunmakin	102	20
6	Iro town and Mokoloki	41	12
	Total	**1,290**	**150**

2.3 Data Collection Method

The actual empirical data collection was conducted in the months of April to July 2022. Primary data were collected through the administration of a structured questionnaire. The questionnaire captured information on the demographic characteristics of the respondents such as age, gender, educational level, household size, and years of farming experience. It also covered the soil management practices employed by the farmers, sources of information on soil management, constraints faced in adopting soil management practices under a changing climate, and farmers' perceptions of climate change adaptation strategies. Questionnaires were administered through face-to-face interviews with the support of trained enumerators. Where necessary, the enumerators provided clarification or translated questions to ensure participants' full understanding. Prior to the main survey, the questionnaire was pretested in Shagamu Local Government Area of Ogun State, and a reliability coefficient of 0.73 was obtained, indicating an acceptable level of instrument reliability.

2.4 Data Analysis

Data were analyzed using both descriptive and inferential statistical methods. Descriptive statistics, including frequency counts, percentages, means, and standard deviations, were used to summarize and describe the respondents' characteristics and responses. Inferential statistics, particularly the probit regression analysis, were employed to test

hypotheses regarding the relationships between respondents' characteristics, constraints, and their soil management practices. A 5% level of significance was adopted for hypothesis testing.

2.4.1 Regression Equation

$$Y = \beta 0 + \beta 1X1 + \beta 2X2 + \ldots + \beta 16X16 + \mu \quad (1)$$

2.4.2 Dependent Variable

Y: Use of soil management practices
1 = Use
0 = Not use

2.4.3 Independent Variables

X1: Sex (1 = Male, 0 = Female)
X2: Age (years)
X3: Marital status (1 = Married, 0 = Not married)
X4: Access to information (1 = Yes, 0 = No)
X5: Knowledge level (1 = High, 0 = Low)
X6: Education (1 = Formal education, 0 = No formal education)
X7: Years of farming experience (years)
X8: Farm size (hectares)

3. Results

3.1 Soil Management Practices under Climate Change

Table 2 shows the results of soil management practices adopted by the respondents.

Table 2. Soil Management Practices among Rice Farmers Under Climate Change

Practice	Always		Occasionally		Never	
Inorganic Fertilizers	Freq	%	Freq	%	Freq	%
NPK	143	95.3	5	3.3	2	1.4
Urea	49	32.7	81	54.0	20	13.3
Muriate	84	56.0	60	40.0	6	4.0
Organic Fertilizers						
Compost	125	83.3	17	11.3	8	5.4
Green Manure	150	100.0	0	0.0	0	0.0
Farmyard Manure	78	52.0	62	41.3	10	6.7
Organomineral/Biofertilizers						
Compost + Urea	150	100.0	0	0.0	0	0.0
Mycorrhiza	75	50.0	75	50.0	0	0.0
Rhizobium	90	60.0	60	40.0	0	0.0
Blue-Green Algae	83	55.3	67	44.7	0	0.0

Source: Field Survey, 2022

3.2 Constraints to Soil Management under Climate Change

Table 3 depicts the results of the constraints faced by the respondents.

Table 3. Constraints to Soil Management under Climate Change

Constraint	Highly Severe		Severe		Not a Constraint	
	Freq	%	Freq	%	Freq	%
Poor access to carbon credit/ carbon market	150	100.0	0	0.0	0	0.0
Inadequate Capital	150	100.0	0	0.0	0	0.0
Lack of Soil Conservation Knowledge	137	91.3	13	8.7	0	0.0
Land Use Competition due to Population Pressure	133	88.7	11	7.3	6	4.0
Poor Access to Fertilizer	128	85.3	20	13.3	2	1.3
High Cost of Fertilizer	134	89.3	12	8.0	4	2.7
Shortage of Farm Labour	134	89.3	12	8.0	4	2.7
Inadequate Extension Information	122	81.3	15	10.0	13	8.7

Source: Field Survey, 2022

3.3 Probit analysis of constraints to soil management practices under climate change

Table 4 shows the results of the Probit regression analysis.

Table 4. Probit Regression Estimates of Constraints to Soil Management Practices under Climate Change

	Parameter Estimates		Estimate	Std. Error	Z	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
PROBIT[a]	Age		0.00	0.00	1.05	0.29	-0.00	0.01
	Gender		-0.02	0.05	-0.34	0.02	-0.12	0.08
	Education		0.010	0.03	0.37	0.72	-0.04	0.06
	Marital status		-0.03	0.05	-0.54	0.59	-0.13	0.07
	Occupation		0.02	0.04	0.37	0.71	-0.07	0.10
	Religion		0.03	0.05	0.62	0.54	-0.06	0.11
	Income		0.01	0.01	-0.22	0.84	0.01	0.01
	Information sources		0.03	0.01	1.87	0.05	-0.01	0.05
	Knowledge of management Practices		-0.01	0.01	-0.80	0.43	-0.03	0.01
	Intercept[b]	Not used	-2.46	0.19	-12.78	0.01	-2.65	-2.26
		Used	-2.44	0.19	-12.61	0.01	-2.64	-2.25

a. PROBIT model: PROBIT(p) = Intercept + BX

b. (Note: Significant variables at p < .05 are shown in bold.)

Chi-Square Tests

		Chi-Square	df[a]	Sig.
PROBIT	Pearson Goodness-of-Fit Test	614.049	148	0.01

4. Discussion

As presented in Table 2, farmers in the study area adopted a combination of inorganic, organic, and biological soil management practices to sustain productivity under changing climatic conditions. The high use of NPK fertilizer (95.3%) and green manure (100%) underscores farmers' continued reliance on both synthetic and organic nutrient sources. Smallholder farmers integrate diverse fertility management strategies to maintain soil productivity and adapt to climate variability. The adoption of compost (83.3%) and biofertilizers such as Rhizobium (60%) and Mycorrhiza (50%) indicates a growing awareness of sustainable soil management practices that enhance soil health and resilience [10, 11].

The combination of organic and inorganic inputs reflects an adaptive strategy that not only sustains yields but also contributes to soil carbon sequestration. These practices have significant carbon storage potential, suggesting that farmers are already engaged in ecosystem-enhancing activities that align with global climate mitigation goals. However, despite their contribution to carbon sequestration, farmers in the study area remain largely disconnected from institutional mechanisms that facilitate access to carbon credit schemes or carbon markets. This institutional gap limits their ability to monetize ecosystem services and benefit financially from their sustainable soil management practices. Strengthening these linkages could transform soil management from a subsistence necessity into a viable climate-smart economic strategy.

A notable finding from this study is that a subset of farmers relies exclusively on organic soil management practices, including composting, green manure application, and biological nitrogen fixation, without the use of synthetic fertilizers. This approach substantially reduces greenhouse gas emissions associated with chemical fertilizer production and use, particularly nitrous oxide (N_2O) emissions. By improving soil structure, enhancing microbial diversity, and increasing soil organic matter, these farmers make measurable contributions to carbon sequestration and climate change mitigation. Within the context of carbon finance, such practices represent low-emission, climate-positive activities that could qualify for carbon credit compensation under emerging carbon market frameworks [17, 23, 24]. According to the Africa Carbon Markets Initiative [25], several digital MRV (Measurement, Reporting, and Verification) platforms are being developed across Africa to lower participation costs and improve the integrity of carbon accounting. Reliable MRV systems are foundational to credible carbon markets; without them, smallholder projects struggle to meet verification standards [26].

In Nigeria, many smallholder farmers practice organic or low-input agriculture by constraint rather than by design, primarily due to limited access to inorganic fertilizers and weak extension support. Yet, these low-emission systems represent a valuable but underutilized pathway for participation in global carbon markets. Integrating such farmers into carbon credit frameworks could not only enhance household income and livelihood security but also support Nigeria's progress toward achieving its Nationally Determined Contributions (NDCs) [27]. Nigeria's most recent NDC highlights the role of land use, agriculture, and carbon farming in its mitigation portfolio [27].

However, even as global discussions on carbon trading and soil carbon sequestration accelerate, most smallholder farmers in Africa and Nigeria in particular remain excluded from carbon markets. This exclusion stems from a combination of institutional, technical, and informational barriers. For example, MRV systems require technical expertise, comprehensive baseline data, long-term monitoring, and often expensive certification processes, factors beyond the reach of many small farms [28]. In addition, pilot programs in Nigeria suggest that farmer awareness about carbon credit opportunities is extremely limited, and extension agents often lack training on how soil management contributes to emission reductions [28]. Furthermore, weak regulatory frameworks, a lack of credible institutional intermediaries, and underdeveloped carbon registries reduce trust and hinder smallholder entry into the market [29]. Consequently, while Nigerian farmers may already be improving soil health and sequestering carbon through sustainable management practices, they receive no financial recognition for these ecosystem services. Bridging this gap is crucial both for equity and for scaling climate-smart agriculture.

Results presented in Table 3 reveal that farmers face multiple and interrelated constraints affecting their ability to manage soils effectively under changing climatic conditions. The two most critical challenges identified were poor access to carbon credits or carbon markets and inadequate capital, each cited as highly severe by 100% of respondents. This finding suggests that financial exclusion and lack of integration into climate-finance mechanisms represent the most binding constraints to sustainable soil management. It also highlights a missed opportunity to leverage carbon markets to reward farmers for their ecosystem services a point consistent with the earlier discussion emphasizing the carbon-sequestration potential of farmers' soil management practices [10, 18].

Furthermore, lack of soil-conservation knowledge was reported as highly severe by most of the respondents, indicating that many farmers lack adequate technical awareness or training on climate-smart soil practices. This

constraint underscores the need for targeted extension education, demonstration projects, and farmer field schools to improve understanding of soil-health restoration techniques [31, 32]. Land-use competition due to population pressure, and shortage of farm labour were also identified as severe constraints, reflecting broader socio-economic pressures on smallholder farming systems. These findings align with data from the National Bureau of Statistics [33]. Similarly, poor access to fertilizer and high fertilizer costs remain persistent challenges that limit soil-fertility management and adaptive capacity [34]. Collectively, these findings suggest that even when farmers are aware of appropriate soil-management practices, economic barriers often hinder their implementation [34].

In addition, inadequate extension information (81.3%) was also reported as a major challenge. This emphasizes the importance of strengthening agricultural extension systems to disseminate locally relevant information on soil conservation, composting, and organic-matter management under climate stress [10, 32].

The Probit regression model was used to identify the socioeconomic and institutional factors influencing farmers' experience of constraints to soil management under climate change. Results indicate that most socioeconomic variables did not significantly influence the likelihood of experiencing soil management constraints [31] ($p > 0.05$). However, access to information sources was statistically significant ($\beta = 0.03$, $p = 0.05$), suggesting that better-informed farmers are more aware of both opportunities and limitations [10-32]. Knowledge of soil management practices was negative but not statistically significant, implying technical knowledge alone may not overcome perceived constraints [31]. The regression results underscore that institutional and informational factors, rather than demographic characteristics, play a decisive role in determining farmers' ability to manage soils under climate change. Limited access to carbon credit and carbon markets remains a major missed opportunity for integrating adaptation and mitigation efforts [18, 19]. Policy reforms to expand access to carbon finance could compensate farmers for sustainable soil practices and strengthen Nigeria's contribution to global emission reduction commitments [10, 20].

5. Conclusion

This study examined the major constraints to climate-smart soil management practices among smallholder farmers in Ogun State, Nigeria, using a probit regression model. Findings revealed that farmers face multiple, interrelated constraints spanning financial, institutional, and knowledge dimensions. The most severe challenges were poor access to carbon credit or carbon markets and inadequate capital, both identified by 100% of respondents as highly severe. These constraints reflect the financial exclusion of smallholder farmers from emerging carbon finance systems that could otherwise reward them for soil carbon sequestration and sustainable land management practices.

Furthermore, lack of soil conservation knowledge (91.3%), high fertilizer costs (89.3%), and limited labour availability (89.3%) remain critical barriers to sustainable land use. Results of the probit model confirmed that access to information sources significantly influenced farmers' capacity to adopt climate-smart soil management practices. This underscores the importance of strengthening agricultural extension systems to facilitate knowledge transfer and promote sustainable innovation among smallholders.

In addition, the constraints to climate-smart soil management are systemic and multidimensional. Addressing them holistically through improved access to finance, extension support, and integration into carbon markets is essential to enhance soil productivity, strengthen livelihood resilience, and support Nigeria's commitments under the Paris Agreement and its Nationally Determined Contributions (NDCs). Greater inclusion of smallholder farmers in carbon credit programs will not only incentivize climate-friendly practices but also contribute to national emission reduction targets and food system sustainability.

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