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The Adoption of Soil Bunding Technology (SBT) by Farmers on Rice Productivity in the Northern Savanna Zone of Ghana

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ABSTRACT

Rice farming is widespread in Ghana, with rising market demand stimulated by demographic pressures from urbanization. The problem in the Northern Savanna Zone is that rainfall is irregular and soils are poor. Soil Bunding Technology (SBT) has been recommended as a possible solution to enhance water retention and, therefore, production and productivity. This study aims to explore the factors that affect the adoption of SBT among rice farmers, the effects of the technology on productivity and revenue, and the barriers to adoption. This research used a mixed-methods approach, which combined both quantitative and qualitative data collection and analysis. A sample of 300 rice farmers was chosen using a multi-stage sampling method. The data were analyzed using descriptive statistics, profitability analysis, and regression models, including the Tobit and Heckman selection models. The results of the study indicate that the adoption of SBT leads to an increase in rice production and profitability. The results of the survey indicated that farmers who adopted SBT received an average yield of 1140.27 kg from an acre compared to 666.11 kg from the non-adopters. The gross margins were also higher for the adopters (GhC310.0) than the non-adopters (GhC13.0), thus indicating that the practice is economically viable. Factors that affected adoption included extension services, credit, and farm size. The study also revealed that the major constraints included low prices of outputs, limited access to credit facilities, and labor burden. It was also established that extension support and financial resources encouraged farmers to adopt and maintain SBT practices, which supports the idea of institutional support. To increase adoption, policymakers should offer financial rewards, enhance extension programs, and create better market links. Finally, experts should encourage farmer-based organizations and community-driven conservation initiatives. Further work should be directed towards the long-term effects of the practices and other forms of conservation practices to improve sustainability.

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INTRODUCTION

Agriculture remains the backbone of global food security, particularly as the world's population is expected to reach 9.1 billion by 2050. This growth highlights the urgency of enhancing food production to address the plight of over 870 million food-insecure people globally (International Finance Corporation, 2013). Studies suggest that agricultural production must increase by 60% by 2050 to meet global consumption demands (Konuma, 2018). In Sub-Saharan Africa, where smallholder farmers are the principal food producers, this demand necessitates the adoption of innovative agricultural technologies to mitigate challenges like erratic rainfall, low productivity, and food insecurity.

In Ghana, rice has become a critical staple crop, with its consumption rising significantly due to urbanization, rising incomes, and convenience. Local rice consumption in urban Ghana remains relatively low, for example, 38% of rice consumed in urban areas is locally produced. Using data from Amfo et al. (2023), this paper explores the factors that shape rice consumption patterns in Ghana, including urbanization, availability, and consumer preferences. By 2020, the country had a paddy rice production of about 987,000 metric tonnes, which is roughly equivalent to 622,000 metric tonnes of milled rice. Although there was an increase in domestic production, in 2020, domestic production accounted for about 43% of the total rice consumption in the country, the remaining 57% was met by import. These numbers show that although Ghana has somehow increased rice production, the country still imports most of the rice that is consumed in the country. This stagnation in productivity means that there is a need to come up with the right measures that can enhance the production of rice and thus guarantee food security.

The Northern Savanna Zone of Ghana faces unique agricultural challenges due to its unimodal rainfall pattern and low soil fertility. Rainfall variability often results in prolonged droughts or floods, leading to substantial crop yield losses (Wagaye et al., 2020). These conditions severely affect rice farming, which is highly sensitive to water stress (Haddjidi et al., 2022). Addressing water scarcity in rice production, therefore, presents an opportunity to improve productivity while conserving water resources.

Soil bunding technology for rice farming in Ghana has been emphasized through recent research findings. Owusu (2023) assessed the Sustainable Development of Rainfed Lowland Rice Production (SDRLRP) project that encouraged soil bunding along with other technologies. The research results revealed that farmers who adopted these practices saw better rice productivity and general improvement in their living standards. The project results included higher rice production, better income, and improved household welfare for the enrolled farmers. According to the study, more than 80% of farmers adopted between 7 to 11 of the project technologies. Soil bunding, a labor-intensive yet effective water conservation technique, aims to address erratic rainfall challenges and improve productivity. Despite its benefits, the adoption of bunding technology remains limited (Kumar et al., 2020), most probably because of its labor intensive nature.

Studies on soil bund adoption have highlighted several factors influencing farmers' decisions. Institutional factors such as access to extension services, credit, and membership in farmer-based organizations (FBOs) positively affect adoption (Awotide et al., 2016). He further noted that household characteristics, including education and labor availability, also play a role in the adoption of such technologies. However, the lack of awareness, financial constraints, and labor intensity associated with bunding have hindered its widespread adoption.

The Northern Savanna Zone offers a unique case study for examining the determinants of soil bunding adoption. Farmers in this region often face constraints like limited access to credit and technology, which exacerbate their vulnerability to erratic weather patterns. Understanding these constraints and identifying drivers of adoption are crucial for designing effective policies to promote bunding technology. This study aims to explore the factors influencing the adoption of soil bunding technology by farmers in the Northern Savanna Zone of Ghana. By analyzing adoption patterns, impacts on productivity and profitability, and the constraints faced by farmers, the research seeks to inform policy recommendations to enhance agricultural sustainability in the region.

METHODOLOGY

This study was conducted in Ghana's Northern Region, specifically in the Kumbugu, Tolon, and Sagnerigu districts, chosen for their high rice output and widespread use of soil bunding technology (SBT). These districts are located in a semi-arid region within the Guinea Savanna Agro-Ecological Zone, characterized by grasslands, drought-resistant vegetation, and a seasonal climate with average annual rainfall ranging from 750mm to 1200mm. Farmers in these districts primarily use soil bunds as a water conservation technique, which enhances rice yields and mitigates soil erosion. Soil bunds are preferred over stone bunds due to their space efficiency, short-term effectiveness, and reduced pest issues. These regions are heavily reliant on agriculture, with most households engaged in crop farming, particularly rice.

A multi-stage sampling technique was employed, beginning with the purposive selection of the Northern Region and the three districts due to their agricultural prominence. From the 1,223 rice farmers identified in these areas, the Yamane (1967) formula determined a representative sample size of 300. Respondents were proportionally distributed across the districts based on their rice farming population. Data collection utilized a mixed-methods approach, including semi-structured questionnaires, focus group discussions, and interviews with key informants. The study gathered both primary data (e.g., farmers' socio-economic characteristics, adoption history, production costs) and secondary data from extension officers, journals, and previous research.

To analyze the data, descriptive statistics, profitability analysis, and regression models were employed. Gross margins were calculated to assess the profitability of SBT adoption, while multiple regression identified factors influencing these margins. The Tobit model analyzed the intensity of SBT adoption, accounting for proportional adoption levels on farms. Heckman's two-step approach examined the determinants of SBT adoption and its effect on farmers' welfare, addressing potential selection bias. Finally, the Propensity Score Matching technique assessed the impact of SBT on productivity and welfare outcomes. Constraints to SBT adoption were ranked by farmers, with Kendall's Coefficient of Concordance measuring agreement among rankings, identifying key barriers such as land tenure insecurity, limited funds, and inadequate extension services.

RESULTS

Influencing Factors Soil Bund Technology Adoption

Table 1: Demographic Characteristics of Rice Farmer

Variable	Responses	Soil Bunding Technology Adoption Status			
		Adopted (N = 240)		Not Adopted (N = 60)	
		N	%	N	%
Household head is a rice farmer	No	82	34.2%	21	35.0%
	Yes	158	65.8%	39	65.0%
Sex of farmer	Female	18	7.5%	9	15.0%
	Male	222	92.5%	51	85.0%
Primary occupation of rice farmer	Full time rice farmer	151	62.9%	44	73.3%
	Part time rice farmer	89	37.1%	16	26.7%
Rice farmer's level of education	JHS	23	9.6%	6	10.0%
	No formal education	170	70.8%	44	73.3%
	Primary	36	15.0%	6	10.0%
	Secondary	9	3.8%	3	5.0%
	Tertiary	2	.8%	1	1.7%

Table 1 revealed that; majority of the rice farmers (both adopters and non-adopters) sampled for this study are the Heads of their household and this was indicated by 158 SBT adopters representing 65.8% and 39 SBT non-adopters representing 65.0%. it was also revealed that majority of the rice farmers in the study areas are Males; thus, about 222 SBT adopters representing 92.5% and 51 SBT non-adopters representing 85.0%. with regards to the primary occupation of respondents it was found that about 151 SBT adopters representing 62.9% ad 44 SBT non-adopters representing 73.3% indicated rice farming as their full-time occupation. The study's investigations further found that majority of the rice farmers (both adopters and non-adopters) did attain formal education and just about 36 SBT adopters representing 15.0% and 6 SBT non-adopters representing 10.0% attained primary school education; implying the high rate of illiteracy among rice farmers.

Table 2: Rice Acres Cultivated and Yield Harvested in Kilograms

Rice Acres Cultivated and Yield Harvested in Kilograms	**Soil Bunding Technology Adoption Status**			
	Adopted (N = 240)		Not Adopted (N = 60)	
	Mean	Standard Deviation	Mean	Standard Deviation
Rice Area Cultivated in Acres	1.4	.5	1.4	.4
Yield in Kg Harvested	1140.27	314.98	666.11	234.05

It was estimated, according to Table 2 that; the mean rice area cultivated in acres for SBT adopters and non-adopters was 1.4 acres (for both) with the standard deviation of 0.5 acre from SBT adopters and a standard deviation of 0.4 acres from non-adopters of SBT, farmers' rice yield was also estimated and it was found that the mean yield of paddy rice harvested from the farms of SBT adopters was 1140.27kg with a standard deviation of 314.98kg, whereas, the mean yield of rice paddy estimated from the farms of non-adopters of SBT was 666.11kg with a standard deviation of 234.05kg; with this SBT adopters harvest higher yield than those who do not adopt SBT.

Table 3: Factors Influencing the Adoption of Soil Bund Technology

Variables	**Tobit Model**	**Heckman Model**
	Coef. (Std. Err)	Coef. (Std. Err)
Sex of Rice Farmer	0.05 (0.09)	0.30 (0.34)
Age of Rice farmer	-.01 (0.00**)	-.02 (0.01)
Employment Status of Rice Farmers	-0.18 (0.06**)	-0.60 (0.32)
Total Household Size	0.020 (0.030)	-0.010 (0.02)
Acres Cultivated	-0.25 (0.05***)	-0.79 (0.25***)
Total Cost of Rice Production	0.00 (0.00***)	.00 (0.00**)

Total Revenue of Rice Production	0.00 (0.00***)	0.00 (0.00***)
Experience in years of Rice Cultivation	-0.010 (0.030)	-0.012 (0.016)
Extension Services Accessed	0.20 (0.09**)	0.90 (0.47)
Educational Status	0.017 (0.05)	0.16 (0.25)
Access Credit	0.24 (0.12**)	
Off-Farm Income	-.00 (0.00**)	-.00 (0.00)
Welfare Level of Household	0.00 (8.03**)	0.00 (0.00***)
Number of Observations	300	300
/Sigma	0.41 (0.02)	716.20
Lambda		-716-20 (164.52***)
Prob > chi2	0.0000	0.0000

*** *Significant at 1%* level; ** significant at 5% significance.

According to Table 3, several key factors significantly influence the intensity of soil bund technology (SBT) adoption among smallholder rice farmers in the Northern Region of Ghana. Age negatively impacts adoption, as older farmers are less likely to intensify their use of SBT, with a unit increase in age reducing adoption intensity by 0.01. Similarly, farmers who do not rely on rice farming as their main occupation are 0.18 less likely to adopt SBT. Larger farm sizes also decrease adoption intensity, with a unit increase in acreage lowering adoption by 0.25. On the other hand, higher production costs and increased revenue from rice farming both slightly boost adoption intensity, demonstrating the economic motivation to adopt SBT. Access to extension services and credit are also critical, as they increase adoption intensity by 0.20 and 0.24, respectively. However, higher off-farm income negatively affects adoption, reducing intensity by 0.00. Finally, improved household welfare positively influences adoption, albeit modestly, with a unit increase in welfare leading to a 0.00 increase in adoption intensity. These findings emphasize the role of both demographic and economic factors in shaping SBT adoption decisions.

Effect of Soil Bund Technology Adoption on Rice Productivity and Profitability

Table 4: Rice Profitability Analysis

Rice Profitability variables	**Soil Bunding Technology Adoption Status**			
	Adopted (N = 240)		Not Adopted (N = 60)	
	Mean	Standard Deviation	Mean	Standard Deviation
Total Cost Rice Production (Gh¢)	848	233	692	229
Total Revenue (Gh¢)	1157	486	705	252
Gross Margins (Gh¢)	310	477	13	332

Table 4 depicts that rice farms that adopted soil bund technology (SBT) earned significantly higher profits compared to non-adopters. The mean gross margin for SBT adopters was estimated at Gh¢310.0 (SD = Gh¢477.0), while non-adopters earned a much lower mean gross margin of Gh¢13.0 (SD = Gh¢332.0), indicating a substantial profit gap favoring adopters. In terms of revenue, SBT adopters achieved a mean revenue of Gh¢1157.0 (SD = Gh¢489.0), compared to Gh¢705.0 (SD = Gh¢252.0) for non-adopters. Additionally, the study revealed that the mean total cost of rice production for SBT adopters was Gh¢848.0 (SD = Gh¢233.0), which was higher than the Gh¢692.0 (SD = Gh¢229.0) incurred by non-adopters. These results demonstrate that while SBT adopters incur higher production costs, their increased revenue and gross margins make the technology more profitable overall.

Table 5: Effect of Soil Bunding Technology on Rice Productivity

Variables	**Soil Bunding Technology Adoption Status**				**Mean Difference**	**T-statistic**
	Adopted (N = 240)		Not Adopted (N = 60)			
	Mean	Standard Deviation	Mean	Standard Deviation		
Rice Area Cultivated in Acres	1.4	0.5	1.4	0.4	0.0	-0.2
Yield in Kg Harvested	1140.3	315.0	666.1	234.1	474.2	10.9***

*** *Significant at 1%* level; ** significant at 5% significance.

Table 5 presented some rice production factors (such as; cultivated acres and yield harvested) mean difference between SBT adopters and non-adopters; yield harvested was predicted at 1% significant level estimating a mean difference of 474.2kg of rice yield harvested between SBT adopters and non-adopters and this implies a positive correlation with SBT adoption.

Table 6: Effect of Soil Bunding Technology on Rice Profitability

Rice Profitability Variables	Soil Bunding Technology Adoption Status				Mean Difference	T-statistic
	Adopted (N = 240)		Not Adopted (N = 60)			
	Mean	Standard Deviation	Mean	Standard Deviation		
Total Cost Rice Production	848.0	233.1	692.2	228.5	155.8	4.6***
Total Revenue	1157.5	486.3	705.2	252.3	452.3	7.0***
Gross margins	309.5	477.0	13.0	331.8	296.5	4.5***

*** *Significant at 1%* level; ** significant at 5% significance.

In Table 6 it is indicated that; the Gross margin mean difference between SBT adopters and non-adopters is estimated to be Gh¢296.5 and this is predicted at 1% significant level implying that Gross margin a positive correlation with SBT adoption, also, total revenue is predicted at 1% significant level estimating a mean difference of Gh¢452.3 between SBT adopters and non-adopters; this also implies that total revenue has a positive correlation with SBT adoption, the total cost of rice production mean difference between SBT adopters and non-adopters is estimated to be Gh¢155.8 predicted at 1% significant level implying that the total cost of rice production is positively correlated with SBT adoption.

Challenges to Adopting Soil Bunding Technology

Table 7: Chanllenges Facing Small-Holder Rice Farmers in Adopting the Soil Bund Technology

Constraints	Mean Score	Rank
Low market price for rice	2.45	1st
Difficulty in access to credit	3.46	2nd
Lack of funds	3.58	3rd
Poor irrigation potential	4.24	4th
Insecure land tenure	5.39	5th
Soil conditions and nature of land	6.29	6th
Low labour availability	6.32	7th
Low access to information and extension services	6.75	8th
Lack of skills	7.94	9th
Inadequate farm size	8.57	10th
Test Statistics		
N	299	
Kendall's W[a]	0.450	
Chi-Square	1212.070	
Df	9	
Asymp. Sig.	0.000***	

*** *Significant at 1%* level; ** significant at 5% significance.

In Table 7, the study found the constraints faced by smallholder rice farmers in adopting the soil bund technology. Low market price for rice was ranked (first), thus the most oppressing constraint hindering adoption of soil bund technology with a ranking score of 2.45, difficulty in access to credit was the second most oppressed constraint hindering adoption of soil bund technology with a ranking score of 3.46 and the third most oppressed constraint hindering adoption of soil bund technology was lack of funds for rice production which also score a rank score of 3.58. Furthermore, the test statistics (Kendall's Coefficient of Concordance) of ranked constraints was significant at $p < 0.001$ estimating 45% of the rice farmers in the sample agreeing to this ranking.

DISCUSSION

The study highlighted that the majority of rice farmers, both adopters and non-adopters of Soil Bund Technology (SBT) are men household heads. This is in conformity with other studies which have established that in rural areas, men are usually the decision makers in terms of agriculture due to cultural beliefs (Ren et al., 2023). Mcharo and Waswa (2022) found that most farmers are men, and they have more chances to get extension services and credit facilities, which can affect the adoption of agricultural technologies. Moreover, studies reveal that a high level of illiteracy among rice farmers is a major factor that hinders the adoption of technology (Alemayehu, 2020). Similarly in the same study it was noted that farmers with high levels of education are more likely to adopt new farming technologies because they can easily understand and internalize the new information. This paper therefore calls for more extensive education programs to be directed towards the target respondents who are likely to have low level of understanding of SBT.

As the findings indicate, SBT adopters and non-adopters have the same land size of 1.4 acres but the adopters get a higher rice yield. The average quantity of paddy rice produced by adopters is 1140.27kg as compared to 666.11kg for the non-adopters. Mwadalu et al. (2020) observed that conservation farming technologies such as SBT increase soil moisture retention consequently increasing yields. Earlier studies have shown that other conservation farming technologies such as bunding, mulching and minimum tillage increase productivity because they reduce soil erosion and improve soil fertility which can lead to increased yields in semi arid areas (Kumar et al., 2021).

Moreover, the study identifies several demographic and economic factors that affect the level of SBT adoption. The inverse relationship between age and adoption intensity, where older farmers are less likely to adopt SBT, is in agreement with the findings of Peddi and Ks (2021) who indicated that younger farmers are more likely to engage in new technologies. Again, the findings suggest that farmers with more land are unlikely to adopt SBT. This findings, in harmony with other studies have established that small holder farmers are more likely to adopt yield improving technologies owing to the limited land size (Asefa & Muluken 2024). The positive effect of extension services and credit on the adoption intensity has been widely established in the literature, as credit enables farmers to purchase the new technologies to enhance adoption (Iyilade et al., 2020). Xie and Huang's (2021) support the claim that off-farm income is a deterrent to adoption. Their study suggested that farmers with other sources of income may not rely on rice farming and, therefore, may not be interested in improving production through technologies

SBT adopters have a considerably higher gross margin of Gh₵310.0 than the non-adopters, Gh₵13.0, despite the higher production costs. These findings are in agreement with other studies which have established that although conservation farming techniques may cost more to implement, they are profitable in the long run due to the improved yields and soil health (Pooniya et al., 2021). Furthermore, the results show the correlation between SBT adoption and gross margin, revenue, and production cost, which are in agreement with previous studies which have established that sustainable agriculture practices, though costly in the short run, are profitable in the long run (Moojen et al., 2024). This means that there should be financial incentives or subsidies for SBT adoption to cover the high initial costs of adoption. The lowest market price of rice is the greatest barrier to SBT adoption as price uncertainty and poor market opportunities discourage farmers from adopting new technologies. The limited access to credit and production funds also hampers adoption, which is in conformity with the literature that financial barriers are among the key impediments to the adoption of agricultural technologies (Iyilade et al., 2020).

The study's findings have important implications for the broader literature on agricultural technology adoption, and the evidence from Ghana. The consistency with other studies stresses the importance of focused efforts to improve the adoption of SBT. Efforts should be made to enhance the availability of extension programs and credit facilities and also solve issues that are related to markets to achieve sustainable adoption. Additionally, enhancing the levels of farmers' understanding of the long term advantages of SBT may be an important lever to increase adoption.

CONCLUSION

This study aims at assessing the effect of Soil Bunding Technology (SBT) on rice farming in the Northern Savanna Zone of Ghana. The results show that farmers who use SBT get higher productivity and profits as compared to those who do not use SBT, despite the expense of the same. Nevertheless, the current situation is that only a few farmers have adopted the technology because most of them are poor, do not know much about the technology, and the process is labor-intensive. This therefore means that removing these barriers is essential for boosting the adoption of SBT and therefore enhancing food security in the area. In order to encourage the adoption of the SBT, policies that enhance access to credit, extension services and market incentives will be crucial.

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