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# Rural Agriculture and Poverty Trap: Can Climate-Smart Innovations Provide Breakeven Solutions to Smallholder Farmers?

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**Abstract:** Agriculture is widely recognized as a solution to food insecurity and poverty, especially in rural areas. However, 75% of the world's poor live in rural areas, and agriculture is the primary source of their livelihood. One may wonder if the observed correlation between agriculture and poverty also suggests causation. If that is the case, then what such causal relationship might exist? Is agriculture a vehicle for poverty alleviation or a source of poverty trap? The role of climate change is rather undisputed: associated extreme weather phenomena cause severe negative impacts on agriculture, exacerbating rural poverty. However, climate-smart agriculture (CSA) is acclaimed to potentially reverse the situation by eliminating poverty and food insecurity. Against this backdrop, the paper investigates whether smallholder farmers who adopt CSA could achieve food security and better income. This aim was approached through three key research objectives (i) to examine the effects of climate change on smallholder farmers, (ii) to examine the extent to which smallholder farmers adopt CSA and the barriers to adoption, and (iii) to investigate empirically the effects of CSA practices in terms of food security and poverty alleviation. The Upper West and Upper East regions in Ghana were selected purposively for the case study, and the data collected were analyzed using inferential and descriptive techniques. The results revealed no statistically significant positive relationship between the adoption of CSA with food security and income. Poor socioeconomic and market conditions marred the expected positive effects of CSA, hence the need for the provision of agricultural infrastructures and inputs as well as the creation of market for commodities.

**Keywords:** rural agriculture; poverty; food security; climate change; climate-smart agriculture; smallholder farmers

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## 1. Introduction

Notwithstanding the leaning towards diversification of the economy to other sectors such as manufacturing and service, agriculture remains vital to economic growth of most developing countries. In Ghana, agriculture serves as the backbone of the economy, employing about 45% of its workforce and contributing to 21% of GDP [1]. The sector is responsible for supplying over 70% of the country's national food requirements (ibid), highlighting the critical role that agriculture plays in meeting the food security needs of Ghana's population. Smallholder farmers (SHFs) in the country make a significant impact, producing approximately 85% of cereals, 40% of rice, and 100% of essential starch foods, including the provision of raw materials for local industries and export [2]. Agriculture and agribusiness account for a significant share of all economic activities and livelihood among SHFs [3]. Hence, the International Fund for Agricultural Development [4] affirms that one percent rise in GDP per-capita in agricultural sector reduces poverty gap by five times more than one percent rise in GDP per capita in other sectors, especially among the poorest. For this reason, policies directed towards developing smallholder farming are considered pro-poor [5]. This is because smallholder farming can play a transformative role in improving the lives and livelihoods of rural households, particularly those living in poverty.

Despite evidence of agriculture being a vehicle for actualizing food sufficiency and alleviating poverty [6], it is paradoxical to admit that an alarming proportion of rural people relying entirely on agriculture are living in abject poverty [7]. Facing this reality, one might wonder whether agriculture is a vehicle for poverty alleviation or a source of the poverty trap. The answer to this puzzle is not clear cut; several studies distinguish numerous constraints that hamper the potentially positive role of agriculture on livelihoods and attaining global sustainability goals.

The complex interaction of economic, social, and environmental conditions determines the attainment of a sustainable agri-food sector. It is argued that people working in traditional agriculture, a category to which many smallholder farmers (SHFs) belong, are often very poor because they have low marginal productivity of labor and therefore a weakened incentive to work [8]. In addition, their marginal productivity of capital is also low because the incentive to save is lacking (ibid). These farmers rely on factors of production (traditional knowledge, skill, or technology) that are outmoded (ibid). In such a frame, a vicious cycle of poverty perpetuates unless crucial investment is made in "non-traditional" inputs, namely knowledge and education, infrastructure, and institutions as well as a well-functioning market [8,9].

Agriculture is also known to witness a devastating impact resulting from climate change (CC). Climate change remains an existential threat to people and their means of livelihood. The Intergovernmental Panel on Climate Change (IPCC) has estimated that global warming could reach 1.5 °C between 2030 and 2052 given the current trend, and that human activities are responsible for the approximately 1.0 °C rise above pre-industrial levels [10]. Agriculture is considered to be one of the greatest contributors to global warming. Crop and animal production account for 10–12% of GHG emissions, with variations in land cover and land use patterns accounting for 8–10%. As the world's population is expected to exceed 10 billion by 2050, agriculture's contribution to GHG emissions and other environmental challenges is also expected to rise, due to the need to increase food production by at least 50% (ibid).

The CC phenomenon has introduced another layer to the pre-existing challenges facing traditional rural agriculture and further worsened the plight of farmers [11–13]. Despite global efforts to achieve food security targets, worsening climatic conditions, such as changing precipitation patterns, rising temperatures, and an increasing frequency of floods and droughts, are hampering progress [10]. These climatic variables are very concerning because they impact all four dimensions of food security—availability, access, stability, and utilization; however, the severity of the impact will depend on the socioeconomic situation of each country and can vary significantly across regions and over time [14]. The authors noted that besides the effect on productivity, demand for agricultural output, income distribution, and growth are constrained. In this context, CC makes achieving food security and poverty eradication particularly difficult for vulnerable rural households [11,15,16].

Farmers in developing countries suffer the most from CC since they rely heavily on agriculture as a means of subsistence; they also depend largely on rain-fed farming systems and possess weak adaptive capacities [10]. In Northern Ghana, dry spells, droughts, and "false starts" of rainfall pose threats to agriculture [17]. Similarly, water and heat stress, pest and disease outbreaks, yield reductions, as well as burdens to supply chains—causing increased post-harvest losses during storage and distribution, are well-known issues arising from CC in the country [18]. Climate variability presents a significant challenge to agricultural productivity and rural livelihoods, affecting approximately 2.5 billion people who depend on agricultural production systems [11].

Climate-smart agriculture (CSA) was introduced by the Food and Agriculture Organization (FAO) in 2010 to address the impact of CC [10]. It aimed to achieve three interconnected goals: boosting agricultural output and income (therefore alleviating poverty), increasing resilience to CC (therefore mitigating its impact on agriculture), and minimizing greenhouse gas emissions (hence reducing the contribution of agriculture to CC). In practice, there are synergies and trade-offs among the three pillars related to food security and income, adaptation, and mitigation [19]. Although we touch upon all three pillars, our focus is on the first pillar—food security and income—linking CSA with the pursuit of many African countries to meet the United Nations Sustainable Development Goals (SDGs) and especially SDG 2 to "end hunger, achieve food security, improve nutrition, and promote sustainable agriculture" [20,21].

We investigate CSA as a vehicle for helping vulnerable farmer households overcome the negative impact of CC. We further focus on agricultural innovation as an enabler for addressing a number of interconnected issues: achievement of zero hunger, elimination of poverty, reduction of land degradation, and mitigation of CC impacts [22]. The main research objective is to investigate the relationship between the adoption of CSA practices with food security and income of SHFs in two vulnerable regions in Ghana, the Upper West and Upper East regions. Addressing this objective requires meeting three secondary objectives, namely: (i) to examine the effects of CC on SHFs, (ii) to examine the extent to which SHFs adopt CSA practices, and (iii) to investigate the barriers to adoption of CSA practices.

Based on the main objective and informed by the literature we formulate the following hypothesis:

**H0:** *There is no significant relationship between the adoption of CSA practices with food security and income of SHFs in the regions.*

By attaining the aim of the research and addressing the objectives, we explore CSA and its interlinkages as a potential solution for "achieving pathways for meeting increasing food demand through improved agricultural processes that can co-exist with environmental conservation objectives" and, therefore, directly contribute to the research topic of the journal.

## 2. Theoretical Background

Agriculture is critical to achieving sustainable development in all three dimensions—environmental, economic, and social [23]. However, it presents various challenges such as land use change, natural resource depletion, and income inequality (ibid). Sustainable agriculture and food systems are crucial drivers of economic development and play a significant role in global environmental change [24]. In this frame, (sustainable) food systems are essential for meeting the needs of the present, while also ensuring that future generations can meet their own needs without compromising the environment [25].

A key characteristic of agriculture is its high vulnerability to the impacts of climate change due to its dependence on weather conditions and environmental variability [23]. Changes in temperature and rainfall patterns can lead to decreased crop yields, increased pest and disease pressure, and soil degradation [23,26]. To address this challenge, sustainable agricultural practices offer a pathway towards more resilient and adaptive farming systems. Reference [26] suggests that soil conservation and management, water conservation and management, crop diversification, agroforestry, conservation agriculture, and knowledge management can enhance climate resilience by improving soil health, water retention, nutrient cycling, and other ecosystem services. To achieve more effective outcomes, the authors suggest integrating all these practices into a unified management approach, which can help farmers create a sustainable agrosystem that balances all sustainability goals.

Similarly, Reference [23] calls for prioritizing sustainable practices and renewable energy to reduce greenhouse gas emissions, enhance productivity, and improve livelihoods. The authors emphasize the importance of adopting practices, such as precision agriculture, conservation tillage, cover cropping, and integrated pest management, to reduce the environmental impacts of agriculture while improving productivity and income. By prioritizing sustainable practices and renewable energy, farmers can reduce their reliance on fossil fuels and contribute to mitigating climate change while maintaining and improving their livelihoods.

In an attempt to address several of these challenges posed primarily by climate change, climate-smart agriculture (CSA) provides a framework that builds on sustainable agriculture, sustainable intensification, agroecology, and other practices [10]. CSA incorporates existing methods of sustainable land management [27,28], and it often involves making incremental changes, such as the efficient provision of information, timely access to inputs, adjustments in production techniques to promote ecosystem services, and sustaining productivity amidst climatic shocks [19]. The authors emphasize that the CSA framework recognizes the need to improve market governance to reduce price volatility and expand insurance and safety net programs. By adopting the CSA approach, farmers can improve their resilience to climate change, enhance productivity, and reduce greenhouse gas emissions while promoting sustainable agriculture and rural development.

Refocusing on West Africa, we should note that agroforestry, soil and water conservation, and climate information services are among the most highly valued CSA methods [29]. Besides the conventional conservation-type CSA practices, precision farming has revolutionized the agricultural sector, and it is described as modern-day CSA strategy [30]. It involves the use of drone technology and big data applications, including artificial intelligence and machine learning, to achieve more accurate and better performance in planning, implementation, and outcomes of agricultural activities. Precision agriculture captures land variability on a microscopic scale and deploys efficient management practices at the optimal place and time (ibid) Therefore, successful adoption of technology has the potential to minimize wastage of farm inputs such as fertilizer, pesticides, and seeds, as well as to optimize the use of water and land resources for agricultural purposes. It can further enhance productivity and profitability and ensure the reduction of agricultural-related activities responsible for increased greenhouse gas emissions (ibid).

Three key drawbacks emanate from the limited conceptual understanding of CSA [10]. Firstly, the lack of a clear definition makes it challenging to determine which agricultural techniques constitute an acceptable CSA practice. As a result, farmers tend to incorporate some agricultural methods that fail to accomplish the stated objectives. Secondly, there is indeed a poor understanding of the relationships between the three pillars (increase output and income, mitigate impact of CC, reduce GHG emissions), so project execution frequently focuses on one pillar to the exclusion of the others. A typical risk derives from the fact that CSA shares characteristics with industrial agriculture, which relies heavily on agro-chemicals, such as fertilizers, pesticides, and other yield improvement chemicals, thus potentially jeopardizing the achievement of environmental sustainability. Thirdly, CSA efforts are mainly centered on the farm, whereas stakeholders from important sectors, such as water, food, and energy, are excluded from policy implementation processes.

On the other hand, Reference [31] points out that the climate-smart agriculture (CSA) framework is narrowly focused on technological solutions and does not adequately address social and institutional issues. For instance, access to markets, credit, and other resources are critical for small-scale farmers to adopt climate-smart practices. However, these issues are often neglected in discussions of CSA. Additionally, social and cultural factors, such as gender norms and power dynamics, can affect the adoption and success of climate-smart practices (ibid). As highlighted by [32], the sole focus on technology-oriented approaches within the narrow scope of CSA is responsible for poor investment performance in climate change adaptation projects, as innovations are often handed to farmers with an inadequate understanding of the realities within the local farming context. Therefore, it is essential to broaden the focus of CSA beyond just technological solutions and to address the underlying social and institutional issues that may hinder the adoption and success of CSA. This may involve improving access to markets, credit, and other resources for small-scale farmers, as well as addressing social and cultural factors that may affect their ability to adopt new practices. By taking a more holistic approach, CSA can achieve greater success in promoting sustainable agriculture, enhancing resilience to climate change, and improving the livelihoods of farmers.

Despite the shortcomings, the benefits of CSA have been well-established by various studies globally. In Ghana, Reference [33] found an improvement in income, food security, and wellbeing among farmers who practice dry season farming in semi-arid regions. CSA strategies such as irrigation and agricultural water management could guarantee continuous food production and income in regions with harsh environmental conditions [34]. There is already empirical evidence arguing that farmers who implemented CSA strategies achieved higher output and returns compared to those who did not comply [35].

Notwithstanding the enormous potential benefits associated with CSA, some farmers face significant challenges to adopt and take full advantage of the innovative practices. Although there are several studies on the drivers of CSA adoption, results remain fragmented. For instance, Reference [36] highlights some determinants of adoption, including farm size, tenure status, education, access to extension services, market access, and credit availability. Likewise, agro-climatic conditions, topographical features, and the availability of water are essential factors that influence the adoption of CSA (ibid). Reference [19] also identify constraints, such as water scarcity, inadequate financial assets, and difficulties in acquiring inputs such as seeds and fertilizers, which are affected by factors such as cost, availability, and timeliness. Reference [26] suggest that policies and incentives that promote sustainable agricultural practices can help address barriers to adoption including lack of knowledge, financial resources, and market access. Reference [37] maintains that the effective training of farmers, family labor, and the provision of agricultural insurance influence the adoption intensity of CSA practices. They emphasize that agricultural insurance builds resilience to climatic risks and shocks and fosters investment in CSA (ibid). Subjective variables, such as farmers' awareness of new practices, their willingness to adopt, perceptions of benefits, and the overall level of concern about the problem of climate change, also affect adoption [28]. As CSA technology becomes more sophisticated and expensive, affordability and the technical capabilities to utilize the technology become key issues for rural farmers. Several authors [13,33] cluster the drivers for CSA adoption into technological, social, economic, and institutional factors. To improve the benefits of CSA in sub-Saharan Africa, [38] call for meaningful actions to promote context-specific CSA technologies, increase funding to farmers, encourage investment, and implement pro-CSA policies.

In such a frame, a context-dependent in-depth socioeconomic analysis that considers varied characteristics associated with the farmers' environment and draws on the capacities of agricultural households could enhance the implementation of CSA in small-scale farming [32]. Reference [39] stresses the need for collaboration among various stakeholders to address complex issues in sustainable development. This includes examining issues related to production, procurement, distribution, and consumption to establish a shared understanding and adoption of sustainable practices among producers. Such collaboration can result in improved efficiency, increased innovation, and enhanced sustainability performance, in addition to promoting the adoption of climate-smart agriculture in small-scale farming and enhancing resilience to climate change. In a similar line of inquiry, findings from other studies suggest that widespread standards like ISO 22000 can considerably enhance the effectiveness of food supply chain management processes. The introduction and adoption of such standards, perhaps in parallel to CSA practices, can potentially enhance distribution, production, development, control, and purchase [40].

The literature reviewed underscores the critical role of agriculture in achieving sustainable development, as well as the challenges and vulnerabilities it faces in the face of climate change. Sustainable agriculture practices, such as CSA, have been identified as potential solutions to promote resilience and adaptation to CC. However, the successful implementation of such practices requires a holistic and collaborative approach that considers the social, economic, and institutional factors that influence farmers' adoption of sustainable practices. Through collaboration among various stakeholders, including farmers, producers, retailers, and consumers, a shared understanding and adoption of sustainable practices can be established, resulting in enhanced sustainability performance and improved efficiency in the agricultural sector.

Based on the literature review, this paper hypothesizes that there is a clear relationship between the adoption of CSA practices and food security as well as income generation by SHFs. In this frame, our main goal is to advance our knowledge of the complex role of agriculture in poverty alleviation and food security by shedding light on the conditions under which agriculture can allow rural populations to break free from the poverty cycle, while protecting them from CC impacts and in a non-environmentally destructive manner.

## 3. Research Design and Methods

The field study (Figure 1), which was carried out from 18 November to 15 December 2019, adopted a mixed-method approach. Based on a typical multistage sampling technique, the Nandom and Bongo districts located in the Upper West and Upper East regions of Ghana were selected purposively for two reasons: (i) they are in the northern part of the country whose population is highly vulnerable to CC [18]; and (ii) the predominant occupation is agriculture, in which the majority are SHFs engaged primarily in crop farming. The SHFs in the selected rural communities are rather typical of those living in extreme poverty with worsened vulnerability due to CC (see Appendix A for a detailed description of the study area).


**Figure 1.** Map of Ghana showing the Upper East and Upper West regions. Source: [41].

To ensure that the sample of participants in the survey was representative of the farmers in the districts, a combined sampling strategy was employed, which involved the use of both cluster and convenience sampling techniques. The agricultural zones demarcated by the Ministry of Food and Agriculture were used as clusters, and a subset of these clusters was randomly selected for inclusion in the study. Within each selected cluster, convenience sampling was used to select individual farmers to participate in the study. This sampling strategy was chosen because the target population of smallholder farmers was geographically dispersed across the study area, and this approach helped to ensure that a representative sample was obtained while keeping the costs and logistical challenges of the study manageable. In total, 150 agricultural households were surveyed in the two districts, for which 80 were drawn from the Nandom district and 70 from the Bongo district. The research used purposive sampling to select 10 experts for interviews: 6 persons were interviewed in the Nandom District and 4 from Bongo district. They included officers of the Ministry of Food and Agriculture (MOFA), including extension officers; officers of the Environmental Protection Agency; officers of the Centre for Indigenous Knowledge and Organisational Development (CIKOD), OCP Africa, and Tieme Ndo—an agro-service company. Twelve farmers experienced in CSA participated in the focus group discussions. The compositions were five and seven farmers from the Nandom and Bongo districts, respectively.

A semi-structured questionnaire was used for the survey (Appendix B). Questions covered include the effects of CC, CSA practices, and barriers to adoption, as well as food security and income of farmers' households. Reference [42] and other key literature provided the guide to questions on the effect of CC on farmers. A 3-point Likert scale was used to capture the effects of CC on farmers: 1—insignificant, 2—somewhat severe, and 3—severe. The various climate-smart practices considered in this study were adapted from [28] with a slight modification to align with the common CSA practices in the regions. Barriers to adoption of CSA were also assessed with a 5-point Likert scale: 1 = never, 2 = fairly serious, 3 = serious, 4 = very serious, and 5 = I do not know. Nevertheless, the focus was on ranking barriers that seriously affected the farmers in the various districts.

Two proxies were chosen to investigate poverty among the agricultural households—food security and income. Food security is the availability and access to adequate and nutritious food at all times [43], which is a basic need and serves as an important indicator of poverty. The four pillars of food security are availability, access, utilization, and stability [44]. This study focuses on access, which can be influenced by factors such as income, employment opportunities, social protection programs, food prices, and geographical location [45]. Rural households face unique challenges to access, including limited access to markets, higher transportation costs, and reliance on seasonal agriculture; studying food security access in rural households can identify specific factors contributing to food insecurity and inform targeted interventions [46]. The household food insecurity access prevalence (HFIAP) model was adopted to evaluate the level of household food insecurity [43]. The model groups households into four categories of food insecurity: food secure, mild insecure, moderately insecure, and food insecure. Rating the frequency of food insecurity (access) on a scale of 1–3: 1 = rarely, 2 = sometimes, and 3 = often. The respondents were assessed based on the degree of food insecurity they experienced in the past four weeks. Conversely, the average annual income of the farmers from farming activities, as well as the extent to which the income caters for all expenses of their households including healthcare and children's education, were examined. Focus group discussion (FGD) and interviews were carried out in both districts to complement the survey result (see Appendix C for discussion guide). A pilot study was conducted with 15 randomly selected rural SHFs supported by Tie Mendo, an agro-service company based in the Nandom district. The objective was to check the internal consistency of various domains in the questionnaire. Item-by-Item reliability analysis was performed using Cronbach's Alpha. At a probability value of 0.05, the following estimates were achieved: effects of CC on farmers (0.714), barriers to adoption of climate-smart agricultural practices (0.691), household food insecurity access score (0.823), and income domain (0.710). These estimates met the recommended benchmark of item reliability for scientific research [47].

This analysis follows a rather exploratory empirical approach where descriptive and inferential analytical techniques were performed with SPSS and Microsoft Excel. Spearman's rank correlation was used to investigate the relationship between the adoption of CSA with food security and income of the farmers, enabling us to provide an initial framework for understanding the phenomenon under study. Compelling views from some participants in the focus group discussions and interviews were included in the analysis to provide further insights.

Before presenting the results of our research, we wish to draw the reader's attention to the fact that our analysis offers a starting point for further investigation, but caution is needed in generalizing the findings beyond the scope of the study. Further research is needed to fully explore the complexities involved, particularly as our findings are based on a limited dataset and a specific methodological approach.

## 4. Results

### 4.1. The Negative Effects of Climate Change on Smallholder Farmers

The adverse effects of CC on farmers varied among districts, as shown in Figure 2. In the Nandom district, 88.8% of farmers reported being severely affected by uncertain rainfall patterns and reduction in cropping season, increased frequency of drought and crop failure (84.6%), post-harvest losses (71.3%), disease prevalence (70.1%), low yield (66.3%), erosion (61.3%), and increased frequency of flood and farm destruction (55.0%). Only 36.3% of farmers in the district alluded that rural-urban migration had a severe negative effect. In the Bongo district, 80.6% of farmers were severely affected by increased frequency of flood and farm destruction, disease prevalence (79.1%), low yield (75.4%), increased frequency of drought and crop failure (73.5%), reduction in cropping season (72.0%), uncertain rainfall patterns (71.4%), and post-harvest losses (71.4%). While 70.4% reported rural-urban migration had a severe effect, erosion was also reported to have a severe effect by 60.9% of the farmers in the district.

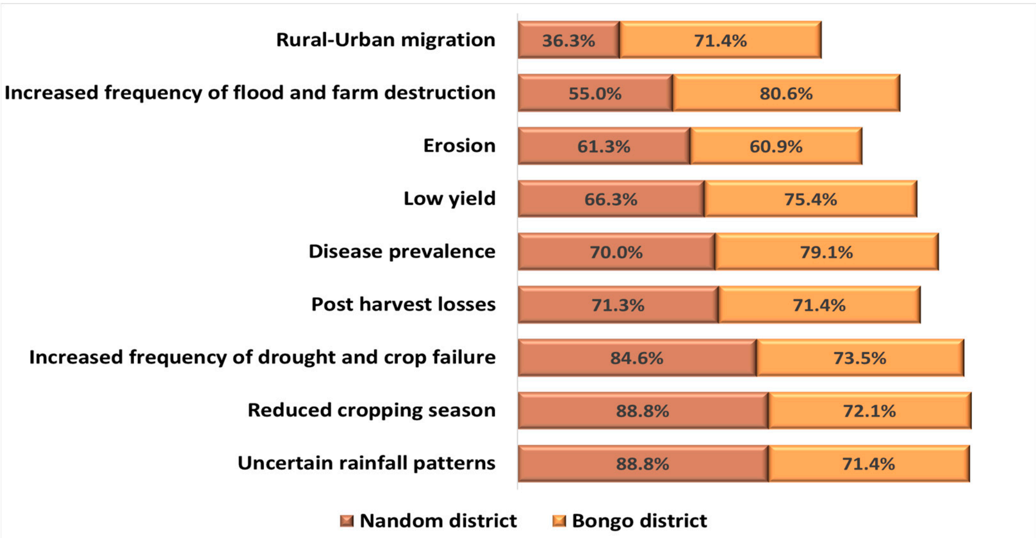


**Figure 2.** Negative effects of climate change on farmers in the districts.

Many farmers strongly emphasized that unpredictable rainfall pattern has a significant effect on their farming activities, leading to delays and uncertainty about when to begin cultivating.

> "In the past years, we usually start sowing in April, but now we sow from June." (Respondent from Bongo district)

Miscalculating the start of the rainy season can lead to excessive crop failure. The uncertainty of rainfall patterns also resulted in post-harvest losses, as tons of grains were reported to have spoiled due to prolonged rain during the harvest period, preventing proper drying for storage. Respondents expressed concerns about the frequent occurrence of heavy rainfall, as farmers in the Bongo district reported widespread flooding. In low-lying areas, mature crops such as rice and groundnuts were submerged in water for days, destroying the crops and causing significant income loss. The uncertainty in rainfall patterns also caused some farmers to switch the type of crops they typically cultivate, opting for fastermaturing crops such as pepper, tomato, and vegetables. In more extreme cases, farmers have transitioned from crops to livestock farming or non-agricultural activities.

> "Many farmers are shifting from crops to livestock production [because of climatic variations and its effect on crops farming], if nothing is done, in about 20 years, almost everyone in the community will move into livestock production." (Respondent from Nandom district)

Additionally, some farmers observed a declining tree population and deteriorating vegetation cover, resulting in a reduction in biomass. This loss of vegetation leads to decreased soil fertility and lower crop yields. Respondents also highlighted that dams and dugouts often dry up shortly after the rainy season ends. As a result, the lack of alternative water sources for irrigation means that many farmers can only engage in farming during the short rainy season (typically three to four months) and remain idle for a significant portion of the year.

> "Almost every household has a farm, and there is only one natural farming season, so when there is a prolonged dry season, every household is affected." (Respondent from the Nandom district)

### 4.2. Adoption of Climate-Smart Agricultural Practices by Smallholder Farmers

Farmers were classified based on their adoption of 18 selected practices (Appendix D). Those who implemented 1–6 practices were considered low adopters, while those who adopted 7–12 practices were moderate adopters, and those who implemented 13–18 practices were high adopters. Figure 3 shows that, in the Nandom district, 57.5% of farmers were high adopters, 40.0% were moderate adopters, and only 2.5% were low adopters. In the Bongo district, 50.0% of farmers were high adopters, 42.9% were moderate adopters, and 7.1% were low adopters. Overall, the adoption of climate-smart agricultural (CSA) practices was high in both districts.

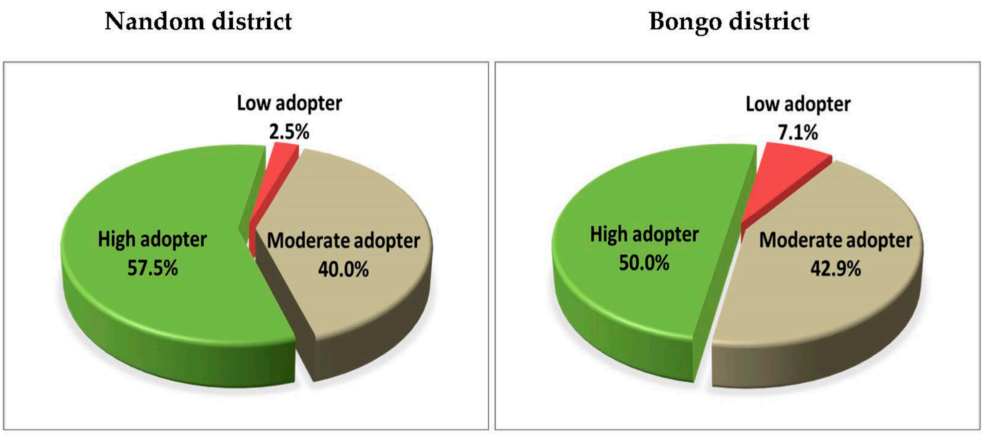


**Figure 3.** Rate of adoption of CSA practices in the districts.

Appendix D provides a granular analysis of all CSA practices considered. It indicates that the most practiced CSA techniques in the Nandom district were residue management (94.6%), chemical fertilizer use (93.8%), and planting on ridges and contours (93.6%). On the other hand, the least practiced techniques were water harvesting and storage (46.5%), dry season farming and sunken beds (48.1%, respectively), and irrigation (5.4%). While in the Bongo district, planting on ridges and contour (97.1%), manure management (95.7%), and sunken beds (94.1%) were the most practiced. The least practiced techniques in this district were the use of improved and stress-tolerant seed varieties (49.3%) and water storage and harvesting (19.0%).

### *4.3. Barriers to the Adoption of Climate-Smart Agricultural Practices*

Figure 4 displays the severity of adoption barriers as perceived by farmers. In the Nandom district, farmers faced three major challenges: insufficient capital (90.0%), no access to credit (83.8%), and no access to water for irrigation (81.3%). Although the remaining barriers still posed significant impediments, land tenure (57.5%) and physical characteristics of land (43.8%) were considered minor obstacles. In the Bongo district, inadequate capital (90.0%), no access to credit (82.9%), and low level of educational (71.4%) were also significant barriers to the adoption of CSA practices. Similarly, farmers considered land tenure (20.0%) and the physical characteristics of land (8.6%) as minor obstacles.

| Barriers | Nandom district |
|---|---|
| *Inadequate capital* | 90.0% |
| *No access to credit* | 83.8% |
| *No access to water for irrigation* | 81.3% |
| *Infertile soil* | 78.8% |
| *Educational level* | 76.3% |
| *Labour intensive* | 73.8% |
| *No access to information* | 66.3% |
| *Lack of Extension Services* | 65.0% |
| *Land tenure* | 57.5% |
| *Physical characteristics of land* | 43.8% |

| Barriers | Bongo district |
|---|---|
| *Inadequate capital* | 90.0% |
| *No access to credit* | 82.9% |
| *Educational level* | 71.4% |
| *No access to information* | 65.7% |
| *No access to water for irrigation* | 51.4% |
| *Lack of Extension Services* | 50.0% |
| *Labour intensive* | 32.9% |
| *Infertile soil* | 21.4% |
| *Land tenure* | 20.0% |
| *Physical characteristics of land* | 8.6% |

**Figure 4.** Barriers to the adoption of CSA practices in the districts.

Some respondents maintained that several farmers cannot afford the financial burden of setting up irrigation and acquiring necessary inputs such as fertilizer and improved seed variety. They added that implementing labor-intensive practices like planting on ridges and contours, managing manure, and building stone bunds could further increase labor costs.

The difficulty faced by SHFs in accessing credit was also seen as a key issue.

> " ... SHFs associations are weak: they cannot attract support. Financial institutions are not willing to provide loans to them and can only do so under very tough conditions." (Respondent from the Nandom district)

Some observed a trend in the growing cultivation of economic trees, such as mango and cashew, both for generating income and for soil conservation purposes. Others believe that poverty has impacted tree conservation (agroforestry) as many are making a living from the sale of firewood and charcoal for cooking, leading to indiscriminately cutting down of trees. Additionally, bush burning was also identified as setback to soil conservation and related practices.

### *4.4. The Relationship between Climate-Smart Agricultural Practices with Food Security and Income*

#### 4.4.1. Climate-Smart Agricultural Practices and Food Security

Figure 5 displays the results of the Household Food Insecurity and Access Prevalence (HFIAP), which indicates that only 12.5% of farmers' households in the Nandom district were found to be food secure. Of the remaining households, 3.8% experienced mild food insecurity, 26.3% were moderately food insecure, and 57.5% were food insecure. Similarly, the Bongo district also exhibited a low level of food security, with only 11.4% of farmer households being considered food secure. Meanwhile, 5.7% of households experienced mild food insecurity, and 41.4% of households experienced moderate to severe food insecurity. To examine the relationship between the adoption of climate-smart agricultural practices and food security, Spearman's rho correlation was employed. The results revealed that at an alpha level of 0.05, there was no statistically significant correlation between the adoption of CSA practices and food security in either the Nandom district (rs (78) = 0.04, $p = 0.760$) or the Bongo district (rs (68) = −0.17, $p = 0.153$). These findings suggest that the adoption of CSA practices may not have a significant impact on enhancing farmers' food security in either district.

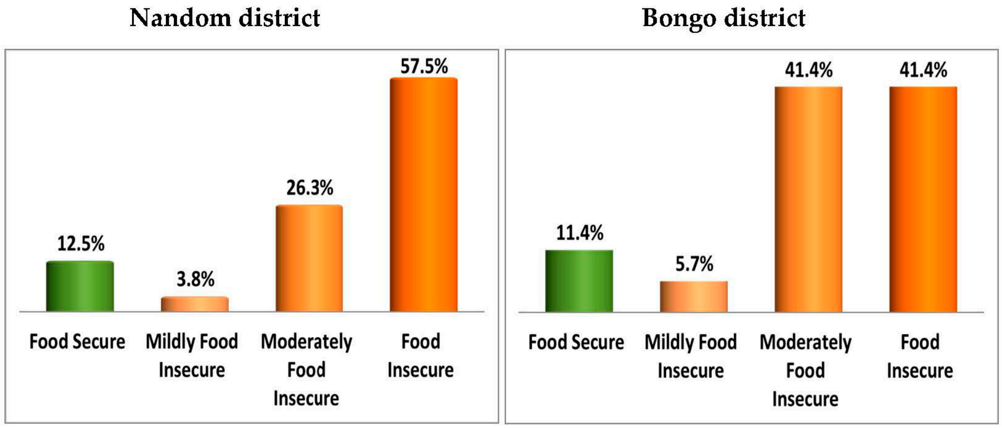


**Figure 5.** Household food insecurity access prevalence (HFIAP) in the districts.

### 4.4.2. Climate-Smart Agricultural Practices and Income

As seen in Figure 6, the average annual income generated by farmers in both districts is heavily skewed towards the lower end. The survey showed that only 25.1% of farmers from the Nandom district and 30.3% in the Bongo district generated an average annual income of more than 2000 GHS (356.67 US dollar, 27 January 2020) from their farming activities. This suggests that most farmers in both districts struggle to generate significant income from farming alone.

| Income | Nandom district | Bongo district |
|---|---|---|
| *Above 5000 cedis* | **7.5%** | **1.4%** |
| *4001 - 5000 cedis* | **2.5%** | **7.2%** |
| *3001 - 4000 cedis* | **3.8%** | **11.6%** |
| *2001 - 3000 cedis* | **11.3%** | **10.1%** |
| *1001 - 2000 cedis* | **18.8%** | **21.7%** |
| *0 - 1000 cedis* | **56.3%** | **47.8%** |

**Figure 6.** Average annual income from farming in the districts.

To gain better understanding of the income data presented in Figure 6 and given the differences in household characteristics, it was necessary to assess whether the income generated from farming activities was sufficient to cover all essential household expenses, including education and healthcare. This information is presented in Figure 7. In the Nandom district, 66.3% of farmers (those who strongly disagree and disagree) suggested that farm income is insufficient to meet all essential household expenses. On the other hand, 30.1% (those who strongly agree and agree) believed that it was sufficient. The Bongo district has a high prevalence of farmers whose incomes are insufficient to cover all essential household expenses. Specifically, 78.2% of farmers reported that their farming income was not enough to cover all essential expenses, while only 17.4% believed that their income was sufficient. These findings suggest that a significant proportion of farmers in both districts struggle to make ends meet with the income generated from farming activities alone.

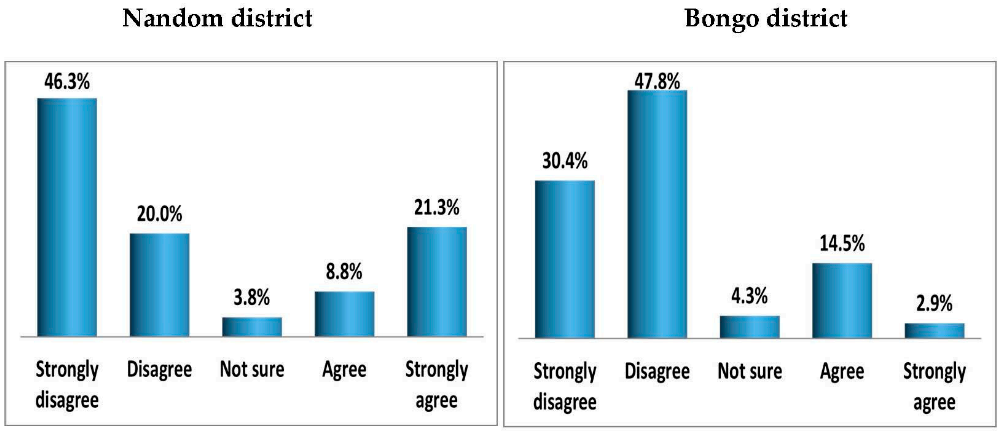


**Figure 7.** Farming income and the ability to pay for all household expenses in the districts.

The study used Spearman's rho correlation to also examine the link between the adoption of CSA practices and farming income. Results showed that there was no significant correlation between the variables in the Nandom district, with an alpha level of 0.05 (rs (78) = −0.02, $p$ = 0.855). In contrast, the Bongo district demonstrated a significant relationship between the variables (rs (68) = −0.28, $p$ = 0.019). Surprisingly, both districts displayed a negative correlation coefficient (−0.02, −0.28), indicating that the more farmers adopted CSA practices, the lower their income. This is an atypical relationship.

Farmers who participated in the FGDs generally agreed to the positive impact of CSA on their productivity, but not much could be said about their incomes. Many farmers cited low demand for their produce as the primary issue, which forces them to sell at significantly reduced prices. Some farmers explained:

> "All farmers harvest at the same time and sell at the same local market, prices during this time are usually meagre. We do not have where to store the produce [ . . . ] and as such sell at very low prices." (Respondent from the Bongo district)

> "Some farmers are still struggling with how to sell maize and sorghum they harvested over a year ago [ . . . ] the main problem of SHFs is not low productivity but the lack of market for what is produced." (Respondent from the Nandom district)

A significant proportion of farmers in both the Nandom and Bongo districts struggle to make ends meet with the income generated from farming activities alone. Although the adoption of CSA practices did have some positive impact on productivity, the negative correlation with income was unusual and unexpected. The need for interventions beyond CSA practices by addressing both productivity and market access to improve farmers livelihoods are important takeaways.

## 5. Discussion and Limitations

The effects of climate change on farmers are not uniform across all locations and can differ in their severity and frequency as seen in this study. Farmers in the Nandom district were severely affected mainly by uncertainty in rainfall patterns, reduced cropping season, and an increase in the frequency of drought. Whereas farmers in the Bongo district experienced adverse effects such as increased frequency of flood and farm destruction, disease prevalence, and low yield. Climate change can have a chain of negative consequences, resulting in food shortages and income loss [15]. Rural smallholder farmers have limited resources to manage climate risks, making them more vulnerable. For example, an unexpected drought and reduced cropping season, if not managed effectively, could lead to crop failure and low yield.

In adopting CSA, farmers consider factors such as perceived benefits of the practices, prevailing climatic conditions, and resources to implement the methods [28,36]. Despite the remarkably high overall adoption of CSA by farmers in the two districts, the adoption of irrigation as well as water storage and harvesting methods was significantly low. The benefits of these specific practices and the limitation of relying on rain-fed agriculture are well-known. Therefore, one can safely argue that the low adoption of these practices is not the result of low perceived benefit; rather, farmers are deterred by the excessive implementation costs. This finding largely explains why the farmers and experts in the study areas identified inadequate capital and no access to credit as most critical barriers to the adoption of CSA. In line with [33], farmers' financial difficulties were a primary barrier to implementing certain practices including irrigation, use of chemical fertilizer, seeds, pesticides, and acquiring adequate labor and land.

The quality of life of farmers adopting CSA in the two districts remained low—most farmers were neither food secure nor could cover all essential household expenses such as healthcare and children's education from farm income. This outcome questions the capacity of CSA to zero hunger and eliminates poverty [15,22]. Conversely, the correlation between the adoption of CSA and food security were not statistically significant in the Nandom and Bongo districts, which is very instructive given the heightened food insecurity recorded despite the high adoption of CSA in the districts. There was mixed result on the correlation between adoption of CSA and income. The relationship was not statistically significant in the Nandom district but was significant in the Bongo district. However, the correlation coefficients in both cases were negative, implying that the adoption of CSA practices lowers income, which contradicts the claim made in [35] that the adoption of CSA results in increased output and return. Two fundamental issues influenced the observed outcomes. First, the limited access to irrigation facility causing most farmers to resort to mainly rain-fed farming. On average, they farm between three to four months yearly (during rainy season) and are idle the remainder of the year. Notwithstanding the quantity of harvest in the period they farmed; the output could not sustain a reasonable living standard over the year. Second, contextual factors and most notably poor market conditions (low prices and demand) for their produce result in low returns. Overall, the situation might potentially lead to maladaptation as the incentive for farmers to invest their meagre resources in more efficient and productive CSA techniques is eroded. This finding largely confirms the plight of SHFs as discussed in the literature [8,9]: SHFs face enormous challenges due to low marginal productivity of labor and capital, and due to absolute reliance on outdated factors of production. This perpetuates a cycle of poverty that can only be broken through investment in non-traditional inputs, a solution hampered by disincentivized farmers.

Although our findings do not allow for generalizations, our study strongly hints that, despite the limitations of our results, some specific characteristics exhibited in certain farmer groups illustrate a higher potential to follow CSA as a mitigation and/or adaptation strategy. Increased environmental variability due to CC has been argued as a potential driving force for farming communities to innovate, especially in the institutional arena [48]. This, in turn, might allow for a better fit of context-dependent CSA practices to West African countries and/or untap the potential of CSA practices as vehicles of new ideas that could initiate a process of institutional change in the field of agriculture [49]. Institutions can indeed be crucial to foster collaboration between farmers in order to address challenges crosscutting the food supply chain [39]. In our study, however, we viewed institutional factors beyond financing as outside the scope of our research, and we must acknowledge that this is a potential major limitation. Similarly, evidence from a European context suggests that widespread standards like ISO 22000 can significantly improve the effectiveness of food supply chain management processes regardless of the geographical setting. In practical terms, introducing and adopting such standards, perhaps in parallel to CSA practices, can possibly enhance distribution, production, development, control, and purchase processes for farmers in the long run [40]. Still, future research could explore further the topic and the synergies between relevant practices, enabling the better alignment of strategies for CSA adoption in Ghana and elsewhere.

The scope of this study was to determine if the adoption of CSA practices alone is a sufficient condition to improve food security and reduce poverty among smallholder farmers in rural areas. Despite the contradicting outcome, the authors cannot entirely dismiss the argument that CSA has a positive impact on food security and income. Other factors may have contributed to household poverty that dampened the potential benefits of CSA. Further research should control for these factors in order to generalize if CSA practices have a positive effect on farmers in the regions. Additionally, researchers have emphasized the importance of quantitatively measuring the changes in output and income resulting from adopting specific CSA practices. This will enable farmers to make informed choices on which practices to adopt. Treating all CSA practices as one group may obscure the positive effect of the efficient ones. For example, the researchers selected traditional CSA practices, which are mostly practiced in the regions. There are other high-tech practices like the use of drones and precision agriculture, which supports CSA strategies that were not captured, which could otherwise change the outcome of the study.

It is important to note that this study was conducted in a rural context, specifically targeting smallholder farmers who face numerous and persistent challenges. The impact of climate change and other factors may differ from place to place and depend on socioeconomic status [14]. Therefore, the study's results may not be applicable to commercial urban farmers who adopt similar practices as economies of scale, access to infrastructure, and better market conditions may influence the outcome. Conducting research in other contexts could be helpful for comparisons.

Finally, HFIAP was used to evaluate food insecurity at the household level based on respondents' ability to recall the degree of food insecurity they experienced in the past four weeks [43]. This measure may be influenced by memory recall bias or the tendency to report more food insecurity. Therefore, future research could consider using other objective measures of household food insecurity to validate the findings.

## 6. Conclusions

In this paper, we explored CSA and its interlinkages as a potential solution for achieving food security and ensuring poverty alleviation in two regions of Ghana. CSA has been promoted indeed as a very promising solution in line with the main target of SDG 2 to "end hunger, achieve food security, improve nutrition, and promote sustainable agriculture".

However, agricultural activities take place in a complex social, economic, and physical environment, which influences the benefits accrued to farmers. In this frame, CC is a major example of an environmental crisis with severe negative effects on the farmers. The implicit assumption in most CSA models, that the adoption of the practices is always linked in a deterministic linear way with financial benefits and increased food security for farmers, needs to be approached with caution; most notably, market failures and the absence of other enablers could erode such a causal relationship.

The empirical results of our study revealed that a significant proportion of adopters of CSA were still trapped in poverty: food security remained an elusive target, while their income was still low, if not worsened. This suggests that the adoption of CSA practices alone is not enough to positively turn around the socioeconomic conditions of farmers.

Our findings further suggest that initiating the needed transformation in the livelihood of SHFs, further measures should complement CSA practices. In addition to ramping up investment in agricultural infrastructures, such as irrigation and storage, as well as in modern CSA technology, equipment, and inputs, the introduction of institutional structures that would allow for setting up an effective system to facilitate the processing and marketing of farm products and ensuring that SHFs can access credit to enhance productivity are pertinent.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** A summarized description of the study area.

| Characteristics | Nandom District | Bongo District |
|---|---|---|
| Total estimated land area | 404.6 sq. km | 459.5 sq. km |
| Population | 46,040 | 84,545 |
| Mean household size | 6 persons | 5.5 persons |
| Coordinates | Longitude 2°25 W, 2°45 W, Latitude 10°20 N, and 11°00 S | Longitudes 0.45° W and Latitude 10.50° N to 11.09 |
| Common boundaries | Lambussie and Lawra Districts on the East and South, respectively; with the Republic of Burkina Faso on the North and West | Burkina Faso on the North, Kassena-Nankana East on the West, Bolgatanga Municipal on the southwest, and Nabdam District on the southeast. |
| Vegetation | Guinea Savannah vegetation | Guinea Savannah vegetation |
| Average monthly temperature | Between 21 °C and 32 °C | About 21 °C |
| Average annual rainfall | 865 mm | Between 600 mm and 1400 mm |
| Common crops | millet, maize, sorghum, groundnut, and cowpea, including root tuber crops, such as yam | millet, sorghum, rice, groundnuts, guinea corn, and maize |
| Estimated agricultural households: district/rural | 85.3%/93.2% | 95.7%/97.3% |
| Agricultural households involved in crop farming | 98.0% | 98.8% |

Source: [50–52].

## Appendix B

Survey Questions:

*Appendix B.1. Effect of Climate Change on Farmers*

I. What negative effects have you observed due to long-term changes in climate over the past 10 years?

Please indicate your response by selecting the appropriate option from the scale below. Scale: *1. Insignificant 2. Somewhat severe 3. Severe*

| S/No. | Effect (Negative Impact) | Scale | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 1. | Uncertain rainfall pattern | | | |
| 2. | Reduced cropping (growing) season | | | |
| 3. | Increased frequency of drought and crop failure | | | |
| 4. | Increased frequency of flood and farms destruction | | | |
| 5. | Post-harvest losses | | | |
| 6. | Disease prevalence | | | |
| 7. | Low yield | | | |
| 8. | Erosion | | | |
| 9. | Rural-urban migration | | | |

Other negative effects (please specify): . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .. . . .

*Appendix B.2. Climate-Smart Agricultural (CSA) Practices*

I. Please indicate *'1' for 'Yes' or '0' for 'No'* in response to each of the following practices:

| S/No. | CSA Practices | Are You Familiar with This Practice? | Have You Implemented This Practice on Your Farm within the Last 12 Months? |
|---|---|---|---|
| 1. | Agroforestry or tree planting | | |
| 2. | Chemical fertilizer | | |
| 3. | Composting | | |
| 4. | Crop rotation | | |
| 5. | Dry season gardening | | |
| 6. | Erosion control | | |
| 7. | Improved or stress-tolerant crop variety | | |
| 8. | Integrated pest management | | |
| 9. | Intercropping | | |
| 10. | Irrigation | | |
| 11. | Manure management | | |
| 12. | Minimal tillage | | |
| 13. | Mulching | | |
| 14. | Planting on contours and ridges | | |
| 15. | Residue management | | |
| 16. | Stone bunds | | |
| 17. | Sunken beds | | |
| 18. | Water storage or harvesting | | |

II. Other practices (please specify): . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

III. State your main reason for adopting these practices: . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

*Appendix B.3. Barriers to Adoption of Climate-Smart Agriculture*

I. What are the challenges that have made it difficult for you to practice certain farming methods?

Please select the appropriate option for each question from the scale below.
Scale: *1. Never 2. Fairly serious 3. Serious 4. Very serious 5. I do not know*

| **S/No.** | **Barriers** | **Scale** | | | | |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| 1. | Educational level | | | | | |
| 2. | No access to information | | | | | |
| 3. | Lack of extension services | | | | | |
| 4. | Inadequate capital | | | | | |
| 5. | No access to credit | | | | | |
| 6. | Land tenure | | | | | |
| 7. | Physical characteristics of the land | | | | | |
| 8. | Infertile soil | | | | | |
| 9. | Labor intensive | | | | | |
| 10. | No access to water for irrigation | | | | | |

II. Other challenges (please specify):.. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

*Appendix B.4. Food Security*

I. Household Food Insecurity Access Scale (HFIAS) Measurement Tool

Please indicate the appropriate option by entering the corresponding code in the 'Code' column below.

| **S/N** | **Question** | **Response Options** | **Code** |
|---|---|---|---|
| 1. | In the past four weeks, did you worry that your household would not have enough food? | 0 = No (skip to Q2)<br>1 = Yes | |
| 1a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) | |
| 2. | In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources? | 0 = No (skip to Q3)<br>1 = Yes | |
| 2a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) | |
| 3. | In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources? | 0 = No (skip to Q4)<br>1 = Yes | |
| 3a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) | |

| | | |
|---|---|---|
| 4. | In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food? | 0 = No (skip to Q5)<br>1 = Yes |
| 4a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) |
| 5. | In the past four weeks, did you or any household member have to eat less portion of meal than would satisfy you because there was not enough food? | 0 = No (skip to Q6)<br>1 = Yes |
| 5a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) |
| 6. | In the past four weeks, did you or any other household member have to eat fewer than three meals in a day because there was not enough food? | 0 = No (skip to Q7)<br>1 = Yes |
| 6a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) |
| 7. | In the past four weeks, was there ever no food to eat of any kind in your household, and there was no resources to acquire food? | 0 = No (skip to Q8)<br>1 = Yes |
| 7a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) |
| 8. | In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food? | 0 = No (skip to Q9)<br>1 = Yes |
| 8a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) |
| 9. | In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food? | 0 = No (completed)<br>1 = Yes |
| 9a. | How often did this happen? | 1 = Rarely (once or twice in the past four weeks)<br>2 = Sometimes (three to ten times in the past four weeks)<br>3 = Often (more than ten times in the past four weeks) |

*Appendix B.5. Income*

I. My average annual farm income (in cedi) is between 0–1000 ☐ 1001–2000 ☐ 2000–3000 ☐ 3001–4000 ☐ 4001–5000 ☐ 5001+ ☐

II. The income I generate from farming is always enough to pay for all my household expenses.

Strongly Agree ☐ Agree ☐ Not sure ☐ Disagree ☐ Strongly disagree ☐

III. The income I generate from farming is always enough to pay for the healthcare services of everyone in my household.

Strongly Agree ☐ Agree ☐ Not sure ☐ Disagree ☐
Strongly disagree ☐

IV. The income I generate from farming is enough to send my children to school.
Strongly Agree ☐ Agree ☐ Not sure ☐ Disagree ☐
Strongly disagree ☐

## Appendix C

Focus Group Discussion Guiding Questions:

1. What is your understanding of climate change, and how do you think it affects the agricultural sector?
2. How have farmers in the district been affected by climate change, and what are the specific challenges they face?
3. Can you describe some of the farm practices that farmers adopt to cope with the effects of climate change, and how effective are these practices?
4. What are the advantages and disadvantages of the farm practices used by farmers to cope with the effects of climate change?
5. How have these practices impacted the productivity and income of farmers, and are there any other outcomes worth noting?
6. What are the primary barriers that farmers face in adopting climate-smart agricultural practices, and how can these barriers be overcome?
7. In your opinion, what are other critical challenges that farmers in the district face in achieving food security and increased income through climate-smart agriculture, and how can these challenges be addressed?

## Appendix D

**Table A2.** Rate of Adoption of the CSA Practices.

| Types of CSA Practices | Rate of Adoption (%) | |
|---|---|---|
| | Nandom District | Bongo District |
| Agroforestry or tree planting | 70.7% | 62.3% |
| Chemical fertilizer | 93.8% | 81.4% |
| Composting | 69.9% | 78.5% |
| Crop rotation | 93.6% | 69.0% |
| Dry season gardening | 48.1% | 53.6% |
| Erosion control | 88.6% | 66.1% |
| Improved or stress-tolerant crop variety | 79.7% | 49.3% |
| Integrated pest management | 78.8% | 58.1% |
| Intercropping | 86.1% | 73.4% |
| Irrigation | 5.4% | 50.0% |
| Manure management | 89.7% | 95.7% |
| Minimal tillage | 72.5% | 94.2% |
| Mulching | 70.5% | 84.1% |
| Planting on contours and ridges | 93.6% | 97.1% |
| Residue management | 94.6% | 85.3% |
| Stone bunds | 52.6% | 84.1% |
| Sunken beds | 48.1% | 94.1% |
| Water storage or harvesting | 46.5% | 19.0% |

Source: Authors' illustration based on field survey.

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