

Comparing the Impacts of Climate Risks and Climate Adaptation on Crop Yield among Smallholder Farmers in Ghana

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Abstract

Climate change has caused substantial underperformance in the Ghanaian agriculture sector. The presence of various climate risks and low adaptation capacity are affecting crop production and the wellbeing of smallholder farmers. The study identified the prevailing climate risks and adaptive strategies. We estimated the contribution of various climate risks to yield reduction, assessed how climate adaptation impacts yield improvement, and reported the impact difference between climate risk and adaptation. Using cross-sectional data, we engaged 679 farmers and employed difference-in-differences estimation and descriptive statistics to arrive at our findings. Climate adaptation improved crop yield by up to 32%, all things being equal. However, the reduction in yield due to climate risk was greater than the improvement in yield resulting climate adaptation where delayed rainfall, early rain, drought, pest and disease infestations, and heavy downpours of rain were the most contributing climate risks. The key adaptation strategies employed were adjusting the planting time, pest and disease management, crop variety selection, crop field selection, and organic fertilization. While adaptation efforts help to mitigate climate change impacts on farmers, these adaptive strategies cannot control climate change. Therefore, more attention and advocacy for enhancing and using climate mitigation strategies to control climate change and its effects are needed.

Introduction

As the years go by, the impact of climate change on the agriculture sector has become evident enough that the challenges are felt globally [1]. There has been a noticeable effect on farmers performance in hotspot areas, most especially in developing nations, due to climate change, reliance on rainfed agriculture, difficulty accessing resources, and low adaptive capacity [2]. Sub-Saharan Africa is one of the most vulnerable regions hit by the consequences of climate change, with countries like Ghana facing significant challenges in adapting to the changing climate [3]. The agriculture sector is the major contributor to economic development in Ghana; where it engages more than half of the active labour force in the country [4, 5]. The impact of the climate risks, therefore, poses a high impact on a large group of farmers and actors along the agricultural value chain. Farmers are faced with different risks in various stages of their crop production, from unpredictable onset of rain to prolonged rains, prolonged droughts, pests and diseases, unfavourable sunshine, windstorms, and more [6, 7]. These climate risks are noted to negatively impact food security, livelihoods, and impede development [8]. The climate has greatly threatened crop productivity, particularly maize, rice, cassava, yam, and cowpea, which are staple food crops in several countries [9–12]. Climate-change induced flood disasters in Ghana are apparently becoming more common, with disastrous effects on food production [13]. According to the literature, flood frequency and impact are likely to increase in the future. Floods swamp farms, pastures, and livestock, potentially reducing crop yields and animal productivity. It destroys physical infrastructure and affects socioeconomic activities related to the agriculture sector, potentially affecting food production. This ultimately reduces food supply, accessibility, utilization, and stability in the region [8].

Climate change is also expanding the geographic distribution of pests and diseases; through transformed interspecies interactions of plants and pest synchrony, it has increased the prevalence of pests, migratory pests, and pest-related diseases [14]. Pests increase by as much as 10–25% as the temperature rises by an additional degree [15], and the natural enemies like parasitic wasps, anaphes flavipes, and tetrastichus julis amongst others, that help to biologically control pests are reducing [14, 16, 17]. The stated climate risks and several others pose a serious risk to crop production as well as food and nutrition security. In averting this predicament, most studies have indicated that farmers use methods that affect the soil, plants, human health, and the climate [18]. While many adopt extensive chemical use, few adopt sustainable adaptation strategies. A study by Williams et al. [19] showed that the most used climate adaptive practices were intercropping, mixed cropping, crop rotation, irrigation, and integration of organic manure and inorganic fertilizer. Dagunga et al. [20] reported crop rotation, bush fallowing, pit planting, contour ploughing, and manure application as the leading conservation agricultural practices in Northern Ghana, but the rate of usage was not encouraging. It is revealed that effective implementation of climate adaptation in Ghana is constrained by technological barriers, institutional barriers, financial barriers, socio-cultural barriers, and limited climate information services [21]. Through multi-stakeholder efforts and collaborations to improve climate resilience, there have been several initiations of policies, projects, and programmes. Ghana has implemented policies like the National Climate-Smart Agriculture and the Food Security Action Plan, the National Climate Change Policy (NCCP), the Food and Agriculture Sector Development Policy (FASDEP). Planting for Food and Jobs (PFJ), the Comprehensive Africa Agriculture Development Programme (CAADP) and the Feed Ghana Programme, which provide measures that integrate climate adaptation into agricultural development. The national efforts are augmented by collaborations with international organizations, including the Food and Agriculture Organization (FAO), the World Bank, and several others, to implement the Food Systems Resilience Programme (FSRP), the Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA), and others to also help in addressing climate change. All these initiatives contribute to enhancing climate resilience through innovations, practices, and structural enhancement by increment, by improving climate adaptation in the presence of climate risks. It was realized that not much has been researched into the trade-off between climate risks and climate adaptation, thus how well the adaptation strategies can reverse or restore the impact of climate risks. This study then aims to identify the climate risks and their impact on farmers' yield; identify climate adaptation strategies used and their impact on farmers' yield; and lastly, compare the impacts of climate risks and adaptation among Ghanaian farmers.

Methodology

This study first reviewed literature, policy documents, programmes, and project reports to understand the existing initiative on climate-smart agriculture and climate adaptation in Ghana. There were the National Climate-Smart Agriculture and Food Security Action Plan, NCCP, PFJ, FASDEP, FSRP, AICCRA, and others [22]. Given the national design of the study, it narrowed down on the AICCRA project's reach as the reference point for this research.

The AICCRA project is an initiative that partnered with national and regional stakeholders to transform climate-smart agriculture and climate services to increase access to and use of the Consultative Group on International Agricultural Research (CGIAR) innovations to improve the lives of millions of small-scale farmers. The project, giving better access to innovations and advisories, the project also connects farmers with information that can help them effectively anticipate climate-related events and adapt preventive actions that will help and safeguard livelihoods and the environment. The AICCRA project was implemented in multiple districts across Ghana [23], making an ideal reference for this study.

Sampling design

The study employed both purposive and random sampling to select respondents. Purposively, the study was done in the 6 regions (Greater Accra region, Central region, Bono East region, Northern region, Upper East region, and Upper West region) as shown in Fig. 1 below. We randomly selected farmers at the community level. The treatment groups were respondents from the AICCRA participating communities. To control for spillovers from treatment communities, the control groups were selected from at least 12 km from the closest participating community. A total of 679 were sourced for this study through a structured questionnaire survey deployed using ODK.

Analytical techniques

This study used the treatment model “difference-in-differences estimation” to analyzed the repeated cross-sectional data obtained. Given that the cross-section of respondents i over time t . The adaptation (treatment) is represented by $\mathcal{D}$, where $\mathcal{D}_t = 1$, for all respondents that implemented an adaptative strategy at time t . Following Tian et al. [24], the model is specified as:

$$Y_{it} = \Upsilon_t + Z_{it}\mathcal{B} + \mathcal{D}_t\delta + \varepsilon_{it} \quad (1)$$

Where Y_{it} represents the dependent variable crop yield and Z_{it} is the respondent-based characteristics.

Descriptive statistics to achieve the demographic characteristic, climate risks and climate adaptations impact on crop yield.

Results and discussions

Demographic characteristics

This study found that the average age of farmers was around 47 years, with the youngest farmer being 21 years old and the oldest being 95 years old. About 82% of farmers were married, close to 7% were single, and about 11% were either separated or widowed. This indicates significant youth involvement in agriculture in Ghana. The gender representation also revealed that 67% of the farmers were male and 33%. The average number of people living in a household was around 8, with a maximum of 24.

Ghanaian farming households extend beyond the nuclear family, leading to increased household membership. This structure is a significant asset, providing extra hands (family labour) for labour-intensive activities and farming in general. The land holdings of the farmers were about 7 acres on average, with a maximum land size of 50 acres. The distance from the cultivated land to the farmers' residences averaged 3.75 km, with the longest distance being 15 km.

In relation to training and capacity development, the number of farmers who had access to extension services amounted to, on average, about 58%, and those who were part of farmer-based organizations were close to 63%. Given the level of formal education attained by the farmers, it was shown in Table 1 that about 46% of the farmers had not received any form of formal education, while about 26%, 20%, and 5% have primary, secondary, and tertiary education, respectively. The study also revealed that most farmers did not receive any form of credit assistance. About 42% had access to credit to augment their production process.

Table 1
Demographic characteristics

Variable	Description	Mean	Std. dev.	Min	Max
Age	Age of respondent	47.44	13.65	21	95
Gender	Sex of respondent (0 for Female and 1 for Male)	0.67	0.47	0	1
Household size	No. people in the household	8.69	4.71	1	24
Extension access	Access to extension services (0 for No and 1 for Yes)	0.58	0.49	0	1
Land size	Land size under cultivation in acres	6.93	6.45	1	50
FBO membership	Membership of FBO (0 for No and 1 for Yes)	0.63	0.48	0	1
Credit access	Access to financial support for farming. (0 for No and 1 for Yes)	0.42	0.49	0	1
Farm distance	Distance to farm (km)	3.75	2.73	1	15
Marital status	Single	6.58			
	Married	82.24			
	Separated/Divorced	4.61			
	Widowed	6.58			
Educational level	No formal education	48.36			
	Primary education	26.32			
	Secondary education	20.39			
	Tertiary	4.61			
	Other level	0.33			

Extent of climate risk among farmers

In the prevalence of climate change, it was revealed that the climate introduced several risks to Ghanaian smallholder farmers, given a total of 679 respondents. It was recorded that each respondent encountered at least one climate risk. The most observed risk was a delay in rainfall, reported by 230 farmers, followed by early rain cessation reported by 196 farmers, drought reported by 119 farmers, pest and disease infestation reported by 85 farmers, and heavy downpours of rain reported by 67 farmers.

Fewer than 20 farmers witnessed fire outbreaks, weeds, bad humidity, dry-standing crops, and windstorms.

Climate risks effect on yield

In this study, Table 2 shows that climate risk variation on farmers' yield reductions ranged from a minimum of 1% to a maximum of 100%. This implies that some farmers lost all their yields to climate change.

Delayed rainfall, being the most observed risk, on average caused a farmer to lose up to 29.3% of their crop yield. Some of the farmers lost all their yield because of this risk, and the least affected experienced a 2% yield loss. Empirically, a study by Mertinez et al. [25] showed that rainfall variations, especially the delay in rainfall, have a negative impact on the performance of farmers. The delayed rainfall distorts preparations to guarantee some yield.

In the era of climate change, this study in Table 2 brought forth the water-limiting risks and their effects on yield. Early rain cessation reduced farmers' yield by 31.6% on average, from a minimum of 1% to a maximum of 100%, because of the shortened rainy days. Drought, which in this study included dry spells, also contributed to an average yield loss of 39.4% for the farmers, with minimum and maximum yield losses of 1.5% and 100%, respectively. The drought and dry spells limited the availability of the required water for the proper growth of the crops, resulting in the stated losses.

Heavy downpours, being an extreme climate effect, caused a 43.1% yield reduction, with a minimum of 5% and a maximum of 100%. The heavy downpour of rain causes severe damage to the soil and mostly stresses the planted crops as it covers the soil, displaces the air content in the soil, and leaches the nutrients necessary to support plant growth. These findings are in line with the following studies of Martínez-Mena [26]. Such rainfall accounts for the substantial decrease in yield for its victims.

Similarly, as an extreme climate effect, a fire outbreak in this study damaged the crops of its victims, and they averaged a loss of 54.1% of their yield, with a minimum of 8% and a maximum of 100%. The unfortunate families lost everything to the fire outbreak. Other groups of farmers who were affected by the windstorm lost 41% of their yield on average, but some lost as much as 80% of their yield, and the least was a 2% yield loss.

Pest and disease outbreaks have contributed to about 90% yield loss. Donatelli et al [27] and Kusi et al [28] reported a significant level of yield reduction. This result is so different from the findings of the studies shown in Table 2. On average, farmers who faced pest and disease infestations experienced a yield loss of up to 25.3%. The least affected farmer recorded 2%, and the most affected farmer recorded a 90% yield loss. Farmers who were affected by weeds or striga lost about 15.6% of their yield on average, with a minimum loss of 3% and a maximum loss of 90%. This variation is due to the sharing of available nutrients for the crop's growth [29, 30].

The last set of climate risks were dry crops and unfavorable humidity. The presence of dry crops on a farmer's farm causes an average yield loss of 46%. The least loss at this risk was 20%, and the maximum was 90%. Farmers who reported the presence of bad humidity had an 11.2% reduction in their yield on average, with a minimum of 1% and a maximum of 50%.

Table 2
Climate risks effect on yield

Variable	Yield reduction proportion	Std. dev.	Min	Max
Windstorm	0.410	0.552	0.020	0.8
Weeds striga	0.156	0.268	0.030	0.9
Pests and diseases	0.253	0.208	0.020	0.9
Dry crop	0.46	0.270	0.200	0.9
Fire	0.541	0.335	0.080	1
Humidity	0.112	0.191	0.010	0.5
Drought	0.394	0.303	0.015	1
Heavy downpour	0.431	0.238	0.050	1
Early cessation	0.316	0.211	0.010	1
Delayed rain	0.293	0.230	0.020	1
Overall mean	0.337			

Extent of CSA adaptative strategies use

In a natural order, the farmers, after being hit with climate risks, adjusted or adopted changes that would avert their risks. The farmers, in their adaptation effort, took the following actions: As shown in Fig. 3, the leading action taken by the farmers was adjusting the planting time, and up to 459 farmers engaged in this action. Pest and disease management were practised by 274 farmers as the second most common adaptation strategy. Crop variety selection and crop selection that can cope with the climate were used by 257 and 252, respectively. Field selection and use of organic fertilizer were used as adaptation strategies by 132 and 92 farmers, respectively. Weed management and soil management were also used by 84 and 82 farmers, respectively. The least effective strategy used was planting trees, which was practiced by only six farmers.

Climate risk adaptations effect on yield

Table 3 below displays how the various adaptive strategies impacted the farmer's yield. The study found that the farmers' largest impacting strategy was fertilization of the farmland, in which they employed

mixed approaches like organic manure, compost, and inorganic fertilizer. This strategy averagely increased farmers' yield by approximately 20.1%. This finding is in line with Cai et al. [31] and Maccarthy et al. [32] where the use of organic soil improvement practices like composting and organic manure significantly improves crop performance.

Farmers who considered the selection of crop varieties that can withstand climate risks experienced a 13.5% yield increase on average. There were some farmers who did not realize the yield increase, but others also achieved as much as a 100% improvement in their yield. Some of these farmers used stress-tolerant varieties and pest- and disease-tolerant varieties in adapting to climate risks.

Pest and disease management were also employed by some of the farmers to adapt to climate risks. Table 3 showed that there was an average of 13.2% yield improvement for farmers who managed pests and diseases. Agula et al. [33] and Owusu et al. [34] also asserted that better pest and disease management significantly increases crop yield.

Based on the existing and potential climate risks that the farmers were exposed to, some of them resulted in the selection of crops that would suit their land. Those who used their risks to consider crop selection obtained an 11.7% average yield increase and, at maximum, a 100% increase by some farmers. In accounting for this, some farmers cultivated different crops like cowpea and pepper, which could relatively survive less rainfall and to an extent, dry spells.

Farmers who managed weeds or striga had an 11.1% improvement in their yield on average. They were able to reduce the parasitic weeds and others that compete with their crops for nutrients. This improved their yield, as also shown by Martey et al. [29].

Some of the farmers strategically selected their fields to help adapt to the climate risks. In the situation of low rains, they focused on cultivating in lowlands and locations where they could practice water-smart practices. The field selection led to an average yield improvement of about 10.4% for the farmers.

The study revealed that the farmers who adjusted their planting time to meet a relatively favorable condition for crop growth had good yields. They had about a 9.6% increase in their yield on average. They mostly planned their planting time to coincide with the onset of the rain and considered seasonal length, together with the crop requirements.

Crop performance heavily depends on soil health [35–38]. The findings showed that the farmers who paid attention to managing their soil for cultivation had an average improvement of about 7.9%.

Lastly, planting trees, intercropping, and timely sourcing of inputs for farming all improved the crop yield of the respective farmers who employed such strategies. On average, yield improvement was around 6.7%, 2.5%, and 1.2%, respectively.

Table 3
Climate risk adaptations effect on yield

Variable	Yield improvement proportion	Std. dev.	Min	Max
Sourced inputs	0.012	0.054	0	0.3
Soil mgt	0.079	0.198	0	1
Pest disease mgt	0.132	0.236	0	1
Fertilization	0.201	0.337	0	1
Weed mgt	0.111	0.223	0	1
Field selection	0.104	0.229	0	1
Intercropping	0.025	0.118	0	0.667
Variety selection	0.135	0.264	0	1
Crop selection	0.117	0.271	0	1
Planted trees	0.067	0.163	0	0.4
Planting time	0.096	0.226	0	1
Overall mean	0.106			

Impact differences

The treatment model estimation below in Table 4 indicated that farmers who adopted at least one adaptive strategy after being affected by climate risk released approximately a 32% yield increment. The time coefficient (-0.203) shows that in the time period when the adaptation took place, there was a 20.3% reduction in yields on average. But this is offset by the constant coefficient (0.203), which showed that if there is no adaptation at all, the yield will increase by 20.3% on average, cancelling out the time variable (-0.203). This cancellation occurred because the yield for the unaffected respondents remained the same in the adaptation phase.

Also, the comparative impact of climate risk and climate adaptation on farmers' yields from the overall means indicated in Table 2 that, on average, a farmer who is affected by climate risk is likely to record a 33.7% yield reduction. Table 3 also showed that farmers who practiced climate adaptation strategies after the climate risk were, on average, likely to record a 10.6% yield improvement. Comparing the magnitude of the impacts, the farmers were experiencing a net yield loss. They lost one out of three of their yields to climate risks, and in adapting to the climate risks, they only realized one-fifth of their yield improvement. This indicates that the effects of climate risk on the farmers were greater than the gains they had from the adaptation process.

Table 4
Difference-in-differences estimation of adaptations impact on yield

Yield	Coefficient	Std. err
Time	-0.203	0.0126***
Treatment (Adaptation)	0.320	0.0784***
Interaction	0.061	0.0789
Constant	0.203	0.0079***
N = 1,358: Prob > F = 0.000: R-squared 0.2941: Adj R-squared = 0.2925		
***, represent significant level at 1%		

Conclusion and recommendation

This study, in assessing the impact of climate risks and adaptation strategies on farmers' yields, revealed that climate adaptation improved crop yield by up to 32%, all things being equal. The detrimental effects of climate risk remain greater than these gains. The farmers were significantly faced with delayed rainfall, early rain, drought, pest and disease infestations, and heavy downpours of rain. Although adaptation strategies like adjusting the planting time, pest and disease management, crop variety selection, crop field selection, and organic fertilization have helped improve yield, they only account for a small portion of the losses. Hence, there is a net continuous yield reduction, demonstrating that present adaptation efforts being beneficial are unable to fully address climate risk.

Subject to the continuous yield reduction despite employing some adaptation strategies, it is ideal to supplement the adaptation strategies with effective mitigation strategies to improve the yield of the smallholder farmers. Enhanced climate-smart agricultural mitigation strategies, like sustainable water management, agroforestry, and soil carbon management practices (biochar), can reduce greenhouse gas emissions to improve the resilience of the ecosystem to climate risk. Also, investment in climate information, early warning systems, improving credit options and access, and extension services must be ensured to improve mitigation and adaptation efforts. There should be encouragement for the more effective integration of adaptation and mitigation by policymakers and stakeholders to create sustainability in farmers' productivity and livelihoods in the face of climate change.

Declarations

Competing interests

I declare that the authors have no competing interests as defined by Discover, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

Ethics Approval

The study adhered to the ethical guidelines of social science research and was approved by the University for Development Studies - Institutional Review Board (CSIR-IRB). The research was conducted in accordance with the ethical principles of the Declaration of Helsinki and all applicable institutional and national ethical guidelines and regulations for research involving human participants. All study procedures were carried out in compliance with these ethical standards. Participants' privacy, anonymity, confidentiality, and rights were rigorously protected throughout the research process.

Consent to Participate

Informed consent was obtained from all participants before data collection. Participants were informed about the research objectives, procedures, and their rights. All participants agreed to be part of the study voluntarily.

Consent to Publish

Not applicable

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Author Contribution

Obed Kwaku Mahama: Conceptualisation, Data collection, Formal analysis, original draft preparation, Review and editing. Powell Mponela PhD: Data curation, Software/Programming. Osman T. Damba PhD: Supervision, Methodology, Review and editing. Mustapha Alasan Dalaa: Conceptualisation, Literature review, Data collection. Urcil Papito Kenfack Essougong PhD: Literature review, Review and editing. Ghislain T. Tapa-Yotto PhD: Conceptualisation, Supervision, Funding acquisition. All authors read and approved the final version of the manuscript.

Data Availability

The AICCRA surveys supporting the findings of this study are available from the World Bank-funded AICCRA project, hosted by the International Institute of Tropical Agriculture (IITA) Ghana. However, restrictions apply to the availability of these data, and they are not publicly accessible. The data are, nevertheless, available upon request.

References

1. Prajapati HA, Yadav K, Hanamasagar Y, et al. Impact of Climate Change on Global Agriculture: Challenges and Adaptation. *Int J Environ Clim Chang*. 2024;14:372–9. <https://doi.org/10.9734/ijecc/2024/v14i44123>.
2. IPCC. Climate Change 2021—The. Physical Science Basis; 2021.
3. Loboguerrero AM, Campbell BM, Cooper PJM et al. (2019) Food and earth systems: Priorities for climate change adaptation and mitigation for agriculture and food systems. *Sustain* 11:. <https://doi.org/10.3390/su11051372>
4. Nyamekye A, Tian Z, And FC-OJ, of B. 2021 U (2021) Analysis on the contribution of agricultural sector on the economic development of Ghana. *scirp.org*.
5. Teye ES, Quarshie PT. Impact of agricultural finance on technology adoption, agricultural productivity and rural household economic wellbeing in Ghana: a case study of rice farmers in Shai-Osudoku District. *South Afr Geogr J*. 2022;104:231–50. <https://doi.org/10.1080/03736245.2021.1962395>.
6. Mizik T, Gyarmati G. Climate-smart agriculture on small-scale farms: A systematic literature review. 2021•mdpi.com: mdpi.comT MizikAgronomy; 2021.
7. Capps Herron HN, Waylen PR, Owusu K, et al. Spatial and temporal variability in the characteristics of extreme daily rainfalls in Ghana. *Springer*. 2023;117:655–80. <https://doi.org/10.1007/s11069-023-05876-4>.
8. Atanga RA, Tankpa V. Climate Change, Flood Disaster Risk and Food Security Nexus in Northern Ghana. *Front Sustain Food Syst*. 2021. <https://doi.org/10.3389/FSUFS.2021.706721/FULL>. 5:.
9. Syed A, Raza T, Bhatti TT, Eash NS. Climate Impacts on the agricultural sector of Pakistan: Risks and solutions. *Environ Challenges*. 2022;6:100433.
10. Wang D, Jenkins K, Forstenhäusler N, et al. Economic impacts of climate-induced crop yield changes: evidence from agri-food industries in six countries. *Clim Change*. 2021;166:30.
11. Kassaye AY, Shao G, Wang X, et al. Impact of climate change on the staple food crops yield in Ethiopia: implications for food security. *Theor Appl Climatol*. 2021;145:327–43.
12. Farooq A, Farooq N, Akbar H, et al. A critical review of climate change impact at a global scale on cereal crop production. *Agronomy*. 2023;13:162.
13. Mensah H, Ahadzie DK. Causes, impacts and coping strategies of floods in Ghana: a systematic review. *SN Appl Sci*. 2020. <https://doi.org/10.1007/S42452-020-2548-Z>. 2:.
14. Skendžić S, Zovko M, Živković I, et al. The impact of climate change on agricultural insect pests. *Insects*. 2021;12:440.
15. Shrestha S. Effects of climate change in agricultural insect pest. *Acta Sci Agric*. 2019;3:74–80.
16. Abd-Elgawad MMM. (2021) Optimizing safe approaches to manage plant-parasitic nematodes. *Plants* 10:1911.
17. Bajwa AA, Farooq M, Al-Sadi AM, et al. Impact of climate change on biology and management of wheat pests. *Crop Prot*. 2020;137:105304.

18. Garcia SN, Osburn BI, Jay-Russell MT. One Health for Food Safety, Food Security, and Sustainable Food Production. *Front Sustain Food Syst.* 2020;4.
<https://doi.org/10.3389/FSUFS.2020.00001/FULL>.
19. Williams PA, Crespo O, Abu M. Adapting to changing climate through improving adaptive capacity at the local level – The case of smallholder horticultural producers in Ghana. *Clim Risk Manag.* 2019;23:124–35. <https://doi.org/10.1016/J.CRM.2018.12.004>.
20. Dagunga G, Amoakowaa A, Ehiakpor DS, et al. Interceding role of village saving groups on the welfare impact of agricultural technology adoption in the Upper East Region, Ghana. *Sci Afr.* 2020;8:e00433. <https://doi.org/10.1016/j.sciaf.2020.e00433>.
21. Antwi-Agyei P, Dougill A, Development LS-C. and, 2015 undefined (2014) Barriers to climate change adaptation: evidence from northeast Ghana in the context of a systematic literature review. *Taylor Fr* 7:297–309. <https://doi.org/10.1080/17565529.2014.951013>
22. Dziwornu MG, Mponela P, Inusah SS, et al. Institutional efforts and regional distribution of climate-smart agriculture (CSA) initiatives in Ghana. *Clim Smart Agric.* 2025;2:100038.
<https://doi.org/10.1016/j.csag.2024.100038>.
23. International Institute of Tropical Agriculture (IITA) C for S and, For IR-CRI (CSIR-C and U, UDS) DS., ((2022) ACCELERATING IMPACTS OF CGIAR CLIMATE RESEARCH FOR AFRICA (AICCRA) (P173398) Pilot of Climate Smart Agricultural Innovations and Climate Information Services in Ghana.
24. Tian X, Engel BA, Qian H, et al. Will reaching the maximum achievable yield potential meet future global food demand? *J Clean Prod.* 2021;294:126285.
<https://doi.org/10.1016/j.jclepro.2021.126285>.
25. Martínez MJ, Fürst C. Simulating the capacity of rainfed food crop species to meet social demands in sudanian savanna agro-ecologies. *Land.* 2021;10:1–27. <https://doi.org/10.3390/land10080827>.
26. Martínez-Mena M, Carrillo-López E, Boix-Fayos C, et al. Long-term effectiveness of sustainable land management practices to control runoff, soil erosion, and nutrient loss and the role of rainfall intensity in Mediterranean rainfed agroecosystems. *CATENA.* 2020;187:104352.
27. Donatelli M, Magarey R, Bregaglio S, Systems LW-. Modelling the impacts of pests and diseases on agricultural systems. Elsevier; 2017.
28. Kusi F, Nboyine J, Abudulai M, ... AS- (2019) Cultivar and insecticide spraying time effects on cowpea insect pests and grain yield in northern Ghana. *Ann Agric* 64:121–127.
29. Martey E, Etwire PM, Wossen T, et al. Impact assessment of Striga resistant maize varieties and fertilizer use in Ghana: A panel analysis. *Food Energy Secur.* 2023;12:e432.
30. Scheiterle L, Häring V, Birner R, Bosch C. Soil, Striga, or subsidies? Determinants of maize productivity in northern Ghana. *Agric Econ.* 2019;50:479–94.
31. Cai A, Xu M, Wang B et al. (2019) Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. Elsevier.
<https://doi.org/10.1016/j.still.2018.12.022>

32. Maccarthy DS, Adiku SG, Kamara AY, et al. Evaluating maize yield variability and gaps in two agroecologies in northern Ghana using a crop simulation model. *Taylor Fr.* 2018;35:137–47. <https://doi.org/10.1080/02571862.2017.1354407>.
33. Agula C, Akudugu MA, Dittoh S, Mabe FN. Promoting sustainable agriculture in Africa through ecosystem-based farm management practices: evidence from Ghana. *Agric Food Secur.* 2018;7:1–11.
34. Owusu V, AA-J of EP. 2019 undefined (2019) Examining the economic impacts of integrated pest management among vegetable farmers in Southern Ghana. *Taylor Fr* 62:1886–1907. <https://doi.org/10.1080/09640568.2018.1517085>
35. Shah AN, Tanveer M, Shahzad B, et al. Soil compaction effects on soil health and cropproductivity: an overview. *Environ Sci Pollut Res.* 2017;24:10056–67.
36. Chahal I, Hooker DC, Deen B, et al. Long-term effects of crop rotation, tillage, and fertilizer nitrogen on soil health indicators and crop productivity in a temperate climate. *Soil Tillage Res.* 2021;213:105121.
37. Van Meijl H, Havlik P, Lotze-Campen H, et al. Comparing impacts of climate change and mitigation on global agriculture by 2050. *Environ Res Lett.* 2018;13. <https://doi.org/10.1088/1748-9326/aabdc4>.
38. Amponsah-Doku B, Daymond A, Robinson S, et al. Improving soil health and closing the yield gap of cocoa production in Ghana–A review. *Sci Afr.* 2022;15:e01075.

Figures

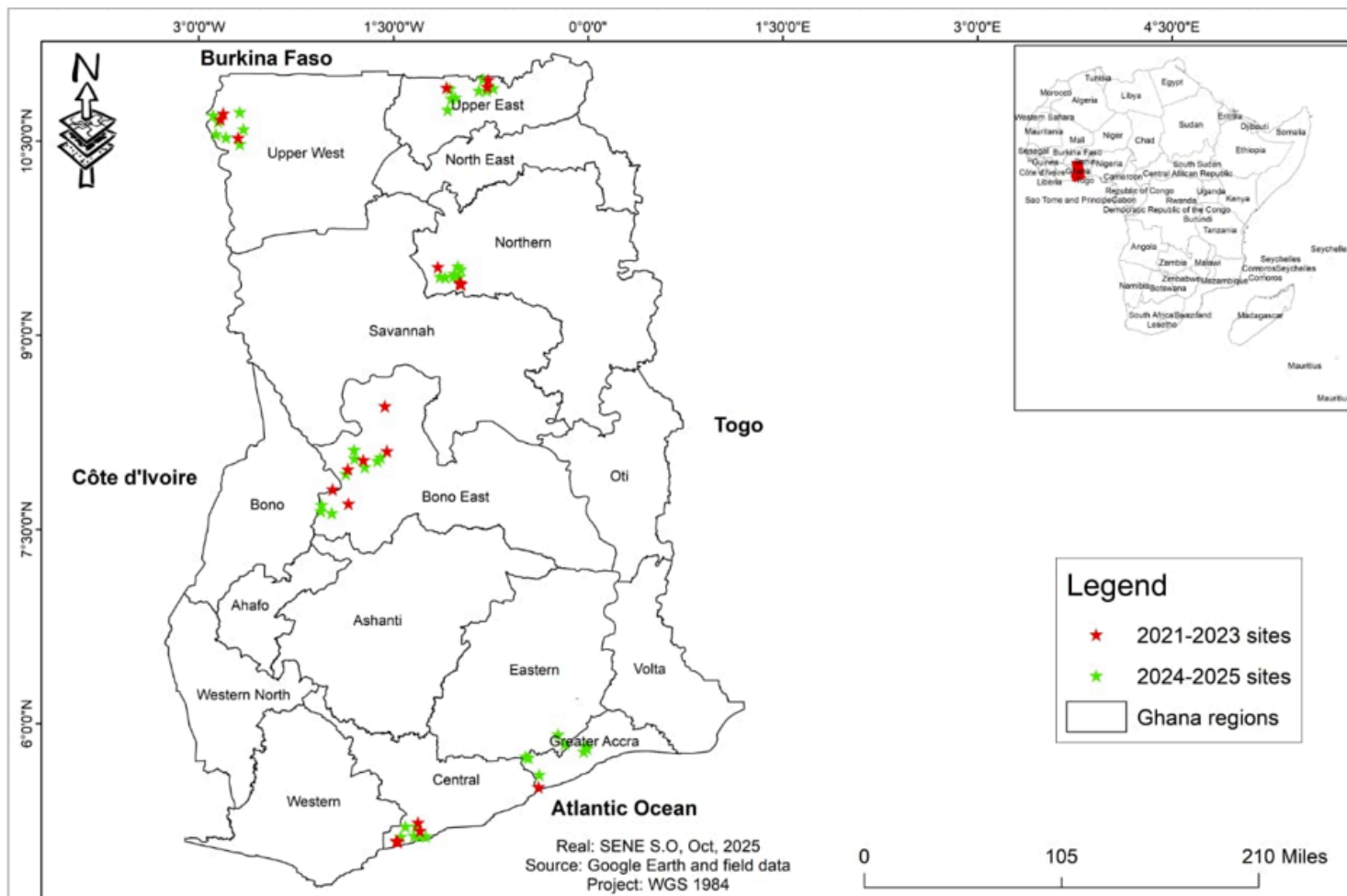


Figure 1

Map of the Study area

Source: AICCRA Construct, (2025).

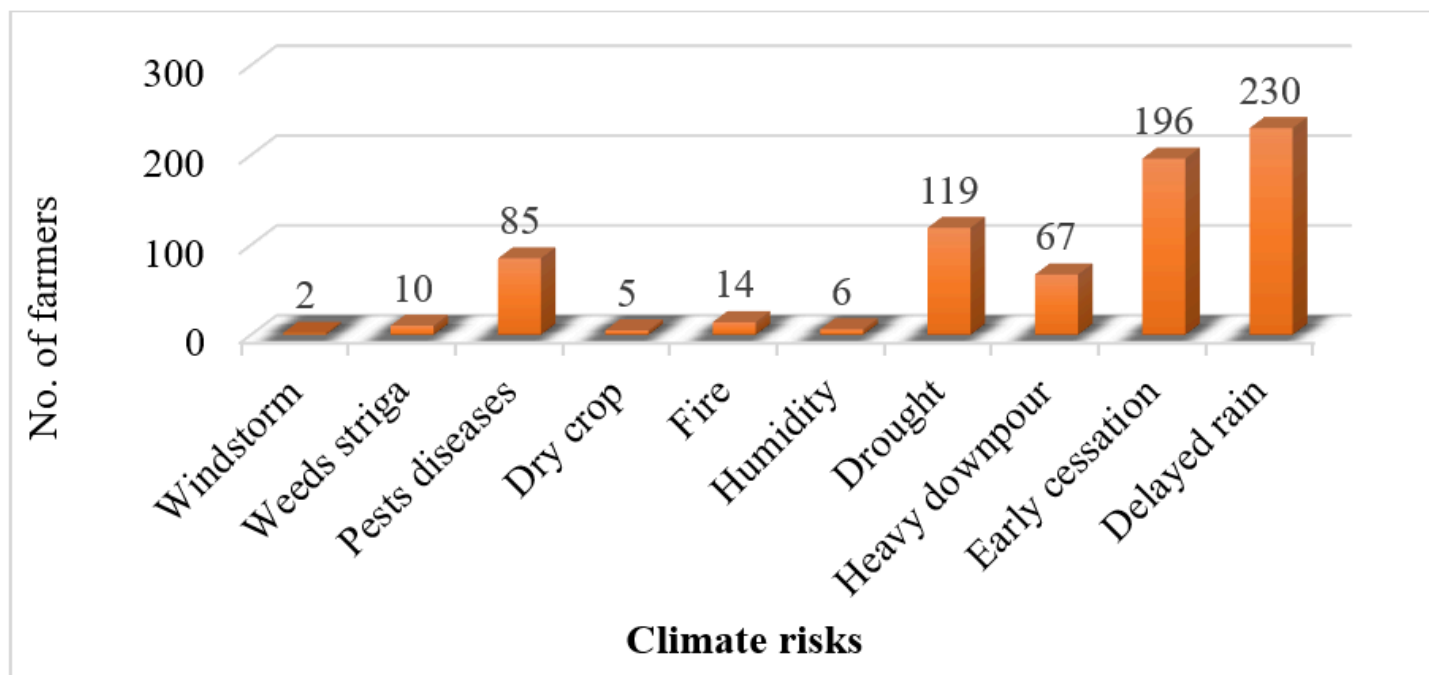


Figure 2

Climate risk experienced by farmers

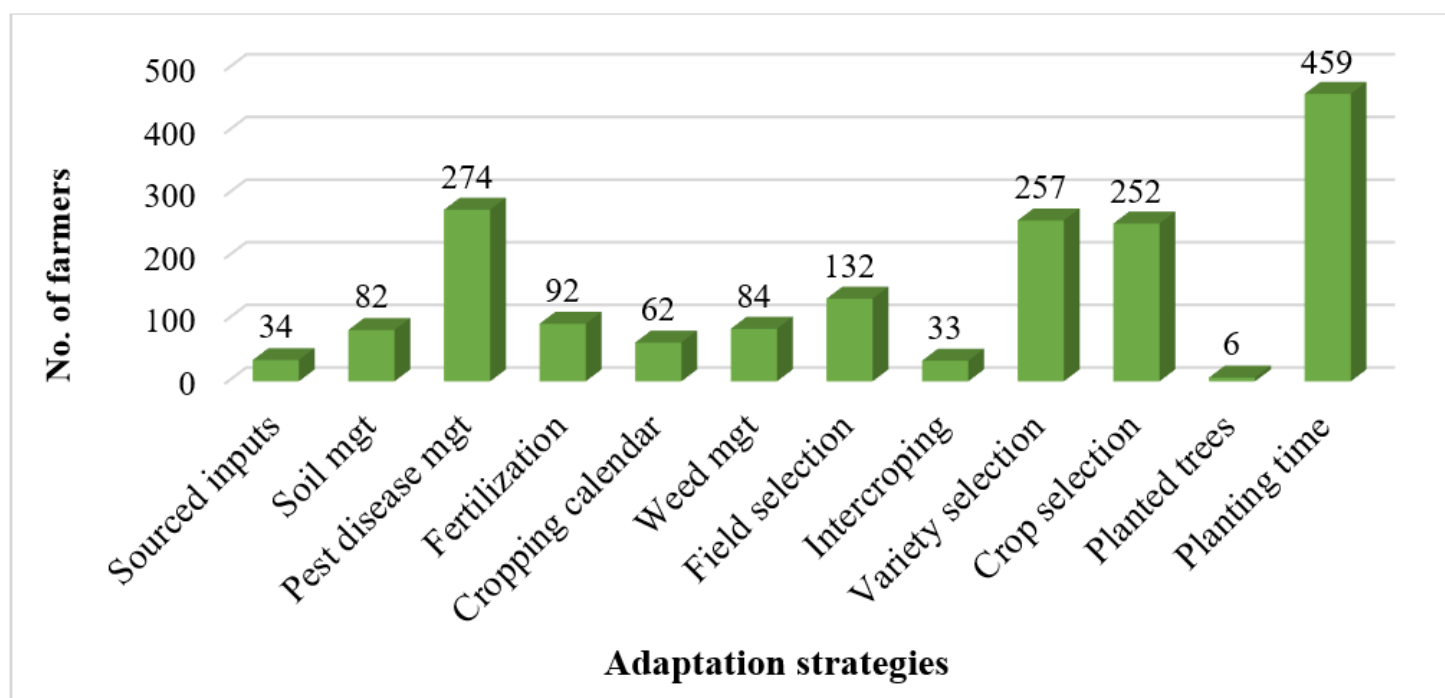


Figure 3

Adaptive strategies used by farmers