Contents Lists Available At sddubidsjplm.com
Journal of Planning and Land Management
Journal homepage: www.sddubidsjplm.com
DOI:10.36005/jplm.v4i2.188

Farm-level agronomic practices among smallholder farmers in rural Ghana: Implications for climate change adaptation

[1,2*]Dordaa, F

Department of Community Development, University of Business and Integrated Development Studies, Wa, Ghana
*Corresponding author. Email: fdordaa@ubids.edu.gh

ARTICLE INFO

Article history:
Received: July 8, 2025
Received in revised form: May 4, 2026
Accepted: April 30, 2026

Keywords:
Smallholder farmer; local knowledge; agronomic practices; climate change; adaptation Planning, rural Ghana.

ABSTRACT

Climate change threatens smallholder agriculture in Ghana, leading to changes in traditional agronomic practices. Nonetheless, the dynamics and drivers of these changes appear to have outpaced scientific research. This article examines the dynamics of agronomic practice change and information adoption among smallholder farmers in rural Ghana and draws out the implications of these practices for climate change adaptation. The study used interviews and focus group discussions involving 48 participants. The findings show that climate change is driving profound shifts in smallholder agronomic practices. Early maturing maize varieties have become the most preferred crop, with their adoption linked to increased mechanization and the use of modern agricultural inputs. The diffusion and uptake of these practices are driven by social learning processes including farmer-to-farmer interactions, NGO-led extension, and local knowledge networks which have significant implications for climate change adaptation planning. The study advocates for an Endogenous Development (ED) approach to Climate Change Adaptation Planning (CCAP) to strengthen smallholder agricultural resilience.

1. Introduction

Climate change has become a central topic in development discourse in recent years because of its impact on humanity and sustainable development. Climate change has contributed to the increased frequency of dry spells, heat waves, and aggressive hurricanes in many places, and this has resulted in food production challenges (IPCC, 2022; Onyango & Nzengya, 2023). These changes have created uncertainty for farm-level production, especially among smallholder farmers in Sub-Saharan Africa (Cacho et al. 2020). Smallholder farmers in the region are vulnerable because of pre-existing challenges such as low soil fertility, and poverty (Cacho et al., 2020; Cairns et al., 2013; Mendelsohn, 2014). At the national level, many of sub-Saharan African (SSA) countries record low economic development (Food and Agriculture Organisation, 2023). Furthermore, smallholder farmers in the region remain highly dependent on rain-fed agriculture, with approximately 70% relying on increasingly erratic rainfall patterns (Nyoni et al., 2024). However, climate change projections for Sub-Saharan Africa point to a future where unpredictable rainfall patterns are expected to be more pronounced (Nyoni et al., 2024; Onyango & Nzengya, 2023). This will lead to far-reaching consequences on the agricultural sector (Ibe & Amikuzuno, 2022). The situation requires smallholder farmers to adapt to climate change (Serdeczny et al., 2017). This is because climate change adaptation provides a pedestal for smallholder farmers to sustain livelihoods (Shackleton et al., 2015). In doing so, smallholder farmers may utilise new knowledge and technologies alongside local knowledge to enhance adaptation efforts.

While adaptation literature documents crop diversification and input use, critical gaps remain in understanding the socio-institutional pathways through which farmers adopt and modify agronomic practices within existing social networks and cultural contexts specifically, the interplay of mechanisation, early-maturing varieties, and input intensification in northern Ghana (Mensah, 2025; Opoku Mensah et al., 2025; Belay et al., 2017; Cooper et al., 2013; Fagariba et al., 2018; Tume et al., 2022). This article examined the agronomic practices of smallholder farmers in northern Ghana and analysed the information flow and social learning pathways that drive the adoption, drawing out implications for climate change adaptation planning. Hence, this study explores the dynamics of knowledge flow and change in agronomic practices for climate change adaptation among smallholder farmers in the Wa East District, Ghana. Specifically, the study addresses the following research objectives: (1) explore the ploughing types and preferred crops adopted by smallholder farmers for climate change adaptation. (2) examine the issues that inform smallholder farmers' choices of farm inputs for climate change adaptation and (3) examine the information sources and social learning pathways through which smallholder farmers adopt agronomic practices for climate change adaptation, and the implications of these for adaptation planning. This study examines how smallholder farmers in northern Ghana are adapting to climate change through tractor ploughing, early-maturing maize, and intensified chemical inputs. Its core contribution is showing that adaptation is embedded in social learning farmer-to-farmer interactions, kinship networks, and NGO supply chains not just technical inputs. Globally, the findings support SDG 13 (Climate Action) by demonstrating locally driven vulnerability reduction, SDG 2 (Zero Hunger) through maintained yields under shrinking rainfall windows, and SDG 1 (No Poverty) by highlighting an equity concern: poorer farmers and women cannot afford the very practices they recognize as beneficial, risking adaptation-driven poverty reinforcement. Nationally for Ghana, the paper advocates integrating Endogenous Development into Climate Change Adaptation Planning, formalizing NGO and extension roles as knowledge intermediaries. Locally, it recommends strengthening farmer learning networks and cooperative mechanisation. Contributing to broader adaptation literature, the paper moves beyond technical accounts to foreground socio-institutional dynamics, advancing three under-explored areas: mechanisation-driven agrarian differentiation, transitions to input-intensive farming creating new dependencies, and informal social learning as the primary diffusion mechanism for climate-resilient practices. The paper is divided into six sections with section one being the introduction. Section two reviews the literature and discuss the theoretical and conceptual framing. Section three presents context and methodology. The results are analysed, discussed, and concluded in sections four, five, and six, respectively.

2. Climate change adaptation in sub-Saharan Africa

The literature on climate change adaptation in sub-Saharan Africa reveals a complex, multidimensional landscape where smallholder farmers navigate climatic stressors through a combination of indigenous knowledge, technological innovation, and social learning mechanisms. Recent systematic reviews underscore that climate variability is projected to reduce agricultural productivity by 10–20% by 2050 across the region, despite smallholders contributing 75% of total agricultural output in countries like Kenya (Onyango & Nzengya, 2023). This vulnerability stems from heavy reliance on rainfed agriculture with approximately 70% of smallholder farmers depending on rainfall patterns that are increasingly erratic (Nyoni et al., 2024) coupled with limited access to adaptive resources and institutional support (Kombat et al., 2021).

Agroforestry emerges as a pivotal adaptation strategy, functioning both as a carbon sequestration mechanism and a microclimate stabilizer that enhances resilience to extreme weather events (Onyango & Nzengya, 2023). In Cameroon, agroforestry systems have demonstrated capacity to attenuate vulnerability while enhancing ecosystem services, though adoption remains uneven due to land tenure constraints and knowledge gaps (Awazi, 2022). Critically, the effectiveness of such practices is amplified when integrated with Indigenous Knowledge (IK), which offers time-tested, context-specific insights into seasonal forecasting, crop selection, and natural resource management (Siatwiinda et al., 2025; Zvobgo et al., 2023). For instance, in Chiredzi, Zimbabwe, farmers combine IK-based phenological indicators (e.g., bird migrations, plant flowering) with scientific seasonal forecasts to inform planting decisions, thereby reducing climate risks through hybrid knowledge systems (Zvobgo et al., 2023). However, IK remains underutilized in formal policy frameworks; despite its proven utility in Zambia's Agroecological Region I, national climate strategies in South Africa and Zimbabwe still marginalize IK integration, limiting scalability (Nyahunda & Louis, 2024).

Agricultural mechanization and agrarian transformation present a double-edged sword. While mechanization can alleviate labour bottlenecks and increase efficiency, it does not inherently enhance climate resilience. In fact, poorly designed interventions may exacerbate energy dependence or displace vulnerable labourers, particularly women (Awazi et al., 2024). Gender-differentiated analyses reveal that men and women "capture" agro-based adaptation packages differently, men often access mechanized tools and credit, while women rely more on seed diversity and soil conservation techniques (Awazi et al., 2024). This underscores the necessity of gender-responsive design in agrarian transformation policies to avoid reinforcing structural inequities.

Technology diffusion hinges less on technical superiority and more on social embeddedness. Climate Information Services (CIS), for example, show low adoption rates when delivered without contextual tailoring. Success occurs when CIS aligns with local communication channels, literacy levels, and decision-making timelines (Nyoni et al., 2024). Local institutions such as farmer cooperatives, traditional leadership structures, and extension networks serve as critical intermediaries that bridge scientific innovations and community practices (Makate, 2019). Participatory Action Research (PAR) has proven effective in this regard, fostering co-creation of knowledge and iterative learning between researchers and farmers, thereby accelerating the uptake of climate-smart practices (Mapfumo et al., 2013).

Social learning operates as the connective tissue of adaptation. The concept of "social navigation" illuminates how pastoralists in Kenya's drylands adapt not merely to ecological shifts but to intersecting political-economic constraints land fragmentation, market volatility, and policy exclusion through everyday acts of negotiation and mobility (Stacey et al., 2025). Similarly, intra-household dynamics shape resilience outcomes; in northern Ghana, joint decision-making between spouses correlates with higher perceived climate resilience, yet patriarchal norms often exclude women from key agricultural choices (Batung et al., 2021). Psychological capital encompassing hope, self-efficacy, and resilience further influences adaptive behavior, suggesting that cognitive and emotional dimensions must complement material interventions (Maziya et al., 2024). Finally, adaptation strategies entail significant trade-offs. While drought-resistant crops may secure yields, they can reduce dietary diversity; agroforestry may improve soil health but compete with short-term food production needs (Akinyi et al., 2021). Synergies exist such as combining mulching with early-maturing varieties but require nuanced, place-based planning. The path forward demands transdisciplinary approaches that integrate biophysical, socio-cultural, and psychological dimensions, ensuring that adaptation is not only technically sound but also socially just and institutionally supported.

3. Methodology

3.1 Description of the study area

The study was conducted in the northern savanna ecological zone of Ghana. Specifically, four communities in the Wa East District in the Upper West Region (Figure 1) participated in the study. The district was chosen for this study because it is considered as the food basket of the region (Ghana Statistical Service, 2020). The district falls within the Guinea Savannah Ecological Zone with an annual rainfall of between 1000-1300 mm. The region experiences a single rainy season, between April and November (Dazé and Echeverría, 2016). It also experiences a minimum temperature of 27°C and a maximum of 30°C during the hot season (April to June) and from 25°C to 27°C during the coolest part of the year (July to September). The savannah ecological zone in Ghana is susceptible to the adverse effects of climate and ecological changes including drought, high temperature, and irregular rainfall pattern (Boafo et al., 2016).

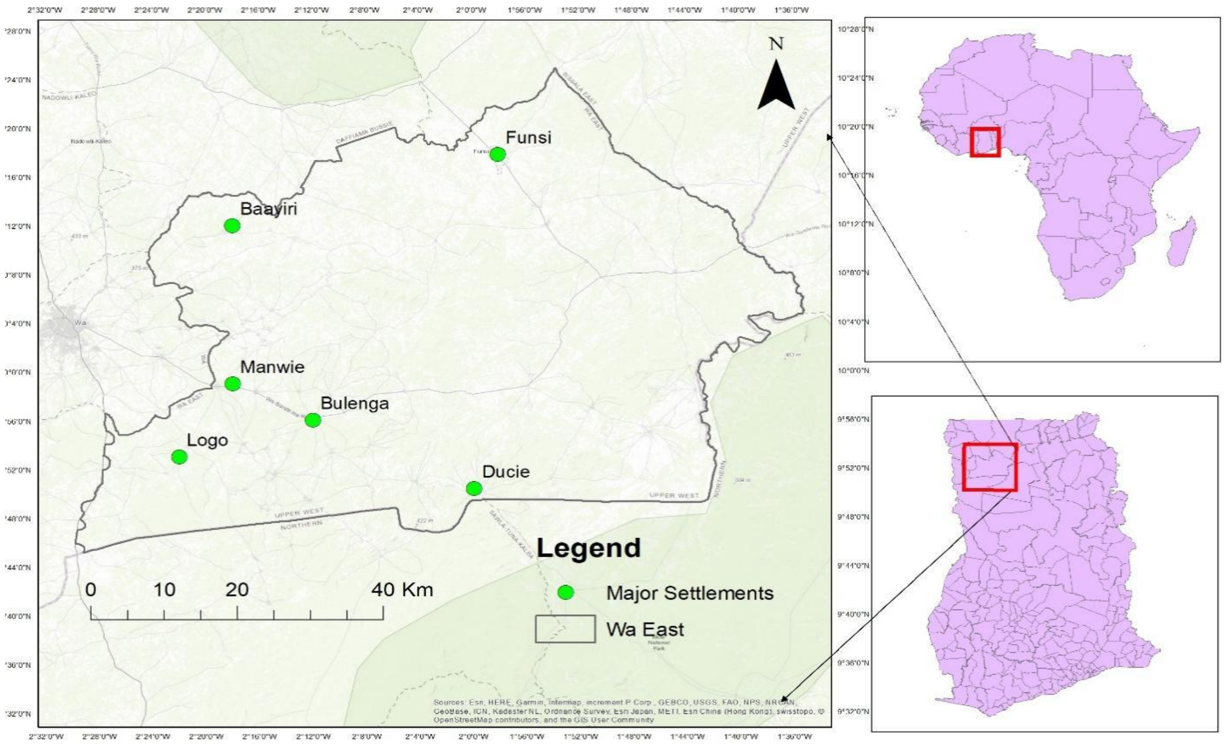

Fig. 1: Wa East District

Mixed cropping is the main cropping system and involves a combination of cereals, leguminous, and root crops (Callo-Concha et al., 2012). Like other parts of the region, agricultural production is rainfed (Nyoni et al., 2024; Kombat et al., 2021). Apart from that, the district is one of the poorest in Ghana, with a poverty rate of more than 70% (Ghana Statistical Service, 2018). Together, inadequate rainfall and the high poverty rate in the region worsen the plight of smallholder farmers.

3.2 Research approach and sampling

The study employed a qualitative research approach. The inquiry focused on the broader view of local knowledge, its application, and dynamics in smallholder agriculture for climate change adaptation (Terrell, 2012; Shorten and Smith, 2017; Slootman, 2018). In terms of sampling, a two-phased purposive sampling technique was adopted to select the communities and research participants. In the first phase, four communities, Bulenga, Kundugu, Bayiri, and Chagu were selected. The communities were purposively sampled because preliminary informal interviews and interactions with an agricultural extension agent (AEA) revealed that the four communities are some of the major producers of food. In the second phase, 48 participants were selected purposively. These included women group leaders, youth group leaders, heads of farmer households, chiefs, Assembly persons, and chief farmers. They were selected because of their knowledge and experience of climate change and food crop farming in the areas.

3.3 Data collection and analysis

Interviews and focus group discussions (FGDs) were strategically combined with participatory listing and diagramming exercises to comprehensively capture the multifaceted dimensions of climate change adaptation decision-making. FGDs served as the primary platform for exploring participants' perspectives on crop preferences, ploughing methods, and information sources regarding chemical fertilizers and other agricultural inputs under conditions of climate uncertainty. Given that FGDs are particularly effective for generating in-depth understanding of shared community perspectives and social norms (Batung et al., 2021), this approach was specifically selected to elucidate collective knowledge systems and decision-making processes related to adaptive agricultural practices. Each FGD comprised between six and twelve participants to ensure sufficient diversity of viewpoints while maintaining manageable group dynamics conducive to meaningful dialogue.

During FGD sessions, structured participatory activities were implemented following established protocols (Batung et al., 2021). Participants were provided with standardized materials including cardboard sheets, colored markers, sticky pads, pens, glue, and push pins. The participant pool comprised individuals with varying levels of formal education, including those with no formal schooling. The participatory visual methods, free-listing, diagramming, and graphic scoring were deliberately selected because they accommodate low-literacy contexts (Kesby, 2000; Umoquit et al., 2008). Bilingual research assistants fluent in the local Waali language facilitated all sessions. For participants unable to write, assistants recorded responses as participants verbally communicated their preferences, and symbolic and visual representations were used to ensure full and equal participation. They engaged in free-listing exercises where they individually documented their preferred crops, input types, and information sources on sticky pads. These individual contributions were then collectively organized through participatory scoring and categorization based on perceived similarities and differences, facilitating consensus-building and revealing priority rankings within the group. Critically, participants collaborated to construct visual diagrams that explicitly mapped their responses to two core research questions: "What are the sources of information on new crop varieties?" and "What are the sources of information on new farm inputs?" This graphic data collection methodology was deliberately employed because visual representations enhance data richness, accommodate varying literacy levels, and effectively capture spatial and relational knowledge that might be lost in purely verbal exchanges (Awazi et al., 2024).

To ensure methodological triangulation and enhance credibility, complementary in-depth interviews were conducted with key informants across three distinct community categories. Specifically, three interviews per community were completed with household heads identified as chief farmers, alongside specialized interviews with traditional authorities including earth priests and women leaders (Magazia). This purposive sampling strategy targeted individuals possessing unique knowledge domains, household-level decision-making experience, spiritual-ecological knowledge, and gender-specific agricultural insights, thereby ensuring comprehensive coverage of the social landscape influencing adaptation choices.

The selection of a total of 48 participants (comprising both FGD members and interview respondents) was determined through theoretical saturation principles rather than arbitrary quotas. This sample size represents the minimum number required to achieve data adequacy and control data redundancy across diverse demographic and knowledge categories while maintaining feasibility within resource constraints typical of rural field research. The composition specifically included chiefs and elders (providing historical and institutional perspectives), women's farmer groups (capturing gendered agricultural knowledge), and mixed-gender youth groups (representing emerging adaptation approaches), ensuring intergenerational and gender-balanced representation essential for understanding differential vulnerability and adaptive capacity (Awazi et al., 2024; Batung et al., 2021).

Figure 2: Free listing of preferred crops

Figure 3: Participatory diagramming information sources

Data analysis followed a rigorous thematic analysis protocol grounded in iterative coding procedures. All FGDs and interviews were audio-recorded with participant consent and subsequently transcribed verbatim in the original local languages before being translated into English by bilingual research assistants. Transcripts underwent multiple rounds of review to ensure translation accuracy and contextual fidelity. The analytical process began with open coding, where initial codes were generated directly from the data without predetermined categories. These codes were then systematically organized into broader categories through constant comparison, ultimately coalescing into overarching themes that captured patterns across the dataset. Methodological triangulation was achieved by cross-validating findings across multiple data sources: consistency between individual interview narratives, collective FGD outputs, and participatory visual diagrams strengthened the reliability of emergent themes. This multi-layered analytical approach aligns with best practices demonstrated in recent studies examining intra-household decision-making dynamics and gender-differentiated adaptation strategies in similar contexts (Awazi et al., 2024; Batung et al., 2021), thereby enhancing the methodological credibility and trustworthiness of the findings.

4. Results

4.1 Ploughing methods and farmers' preferred food crops: Implications for climate change adaptation

The farmers identified four ploughing methods that aids them to adapt to climate uncertainty: tractor ploughing, bullock ploughing, ridge raising, and mounds. From the farmer's perspective, these approaches enable them to conserve moisture in the soil to support plant growth and subsequently adapt to the negative consequences of climate change. In the case of tractor ploughing, it emerged that the method helps in improving soil drainage and moisture conservation, which supports crop growth and maturity during drought. Farmers explain this in terms of depth: deep tractor ploughing breaks up compacted topsoil layers, allowing rainwater to infiltrate and be stored at lower soil horizons rather than running off the surface. Additionally, the buried plant residues and grasses incorporated during ploughing decompose over time, improving soil organic matter content and the soil's capacity to retain moisture between rainfall events. In farmers' own understanding, this means that even when the rains stop early or become irregular, crops can continue drawing on subsurface moisture and nutrient reserves to complete their growth cycle. Good soil drainage and moisture conservation are therefore critical because of their role in supporting vegetation and crop growth in any region, particularly under shortened rainfall regimes. Within the context of climate change adaptation, soil moisture conservation is particularly crucial because it serves as the medium for the supply of nutrients to support growing plants. The approach also makes it easy for the farmers to till the soil before and after planting. Tractor-ploughed fields do not typically require re-tilling before planting as the deep plough adequately loosens the seedbed. It also aids the farmers to plough large farm sizes in a relatively short time. A land priest during an interview explained that:

> *The use of tractors helps us to adapt to climate uncertainty in the sense that we can plough large parcels of land in a relatively short time. This method helps especially when the rain delays and eventually begins, we can quickly get large parcels ploughed within the time so that we can plant to meet the rains so that our crops will do well* (Interview with earth priest from Bayiri, 10th July 2022)

However, cost of hiring tractor services is a barrier to access tractor services among most farmers who do not have the financial means. Farmers who have the financial means use tractor services while those without the means use labour intensive methods such as the hoe. A synthesis of the results from KIIs and FGDs (Table 2) revealed that it enabled adaptation to a shortening rainfall regime and quicker means of ploughing large parcels of land within a short time albeit high cost of its services.

Table 1: Analysis of farmer uptake of tractor services

Reasons for uptake	Challenges and issues
Speed in ploughing enables adaptation to shortening rainfall.	Some farmers lack the financial means to hire tractor services.
Plough large size farms quickly	Poor farmers resort to using hoe which lacks speed for adaptation.
Increase the size of farmlands.	High cost of hiring tractor services compels farmers to depend on hired labour for farming.
Enables adaptation to delayed rains /little rainfall.	Difficulty in accessing tractor services/limited number of tractors.
Enables adaptation to erratic rainfall pattern.	High cost of hiring tractor services.
Speed in plough for better timing of the rains	Lack of credit in hiring tractor services.
Complement the use of hoe and bullocks.	
Hoe and bullock slow and unsuitable for adaptation	
Declining bullock availability in some communities due to cattle losses through theft and disease; some farmers who previously used bullocks now rely on hoes or hire tractor services.	

From the analysis, farmers express preference for tractor services for the purpose of adapting to climate change. For instance, the FGDs reveal that drought had led to some compacting of soils and soil fertility losses. Thus, tractor ploughing loosens the soils and restores soil fertility and soil moisture through the decaying of plant residues and grasses buried in the process. This, the results reveal, is important for sustaining cropping and guaranteeing some harvest amid climate uncertainty. Further quotes from FGD sessions highlight how tractor ploughing services have become critical for enabling climate change adaptation among smallholder farmers. The narration of a discussant during a FGD session a male farmer illustrates the preference for tractor services in Kundugu community:

> *In recent times, most farmers in this community rely on tractor services to plough their farms. This is because the rains are unpredictable and any delay in ploughing the land will lead to crop failure. When the rains start, we must quickly plough so that the crops will grow well*

*before the drought sets in. Without the tractor, we cannot plough large parcels of land quickly for planting. However, there are still some farmers who do not have the financial means to hire tractor services. Such farmers also rely on labour-based methods and the use of simple tools such as the hoe. They depend on their strength and or hire wage labour for tillage to enable planting (*Male Farmer, 20th August 2022, Kundugu*).*

The overriding preference for tractor services for climate change adaptation is corroborated by other FGD sessions. For instance, a female farmer during a FGD session with women in Bulenga community opined that:

The rains are not predictable anymore. Sometimes they come early, and at other times they delay in starting. So, for us to cope with such uncertainty in timing of rains, we depend on the services of tractor operators to plough our farmlands when we have the first rains. We do this in preparation for planting at the next rains. If the ploughing is not done early and the rains start late, many farmers may not secure a tractor to plough. Tractors are limited and the cost is high and unaffordable for most farmers. Some of us cannot afford to pay for tractor services because of the cost. This year, the tractors charged us GH₵. 300.00[1] to plough an acre which a lot of us could not afford (Female Farmer, FGD session, 17th August 2022).

So far, the results show that tractor services have become critical to climate change adaptation among majority of smallholder farmers. However, the cost is a barrier to its utilisation among poor farmers who employ other methods of ploughing, which points to a blend and some level of diversification in ploughing practices among smallholder farmers. For bullock ploughing, the farmers shared similar benefits associated with the tractor ploughing method, while in the case of mounds raising, the farmers opined that it helps in the growth of roots especially for tubers. The farmers explained that the mounds conserve moisture in the soil longer than other methods of ploughing and helps in the development of plant roots especially for tubers. This way, the crops can withstand drought and do well. Ridge ploughing also enables farmers to adapt their farming to climate uncertainty. This is achieved through the reduced soil erosion. During FGD session with women farmers in Chagu, it emerged that:

The greatest benefit of ridge ploughing as a climate change adaptation strategy is that when it over rains, the water is unable to carry the crops away and is also able to reduce soil erosion especially when the farm is along a slope. The water is rather retained in the gutters and later seep into the soil for future use by the crops and that helps them to grow even when there is drought (FDG session with women group in Chagu, 12th July 2022).

It is, however, important to mention that some benefits cut across all the ploughing methods identified by the farmers including convenience in tilling the soil, increased crop yield, soil moisture conservation and increase farm sizes that enable climate change adaptation. Raising of mounds and ridges as ploughing methods yielded similar results even though it involves drudgery.

In the case of preferred crops among smallholder farmers, smallholder farmers planted a variety of crops, including cereals, legumes, roots and tubers within the context of climate change. However, farmers are increasingly expressing preference for early maturing maize varieties. Some farmers also cultivate beans, groundnuts, and yam within the context of climate change and variability. As such some farmers were dropping traditional staple crops, especially, those with long maturity duration such as millet and guinea corn (Table 2).

Table 2: Preferred choice of crops among farmers for climate change adaptation

Community	Preferred crop	Sample supporting quotes
Kundugu	Early maturing maize	*Masara (NGO) usually gives us maize seeds including fertilizer and weedicides/insecticides to farm.* *Masara provides us with seeds, farm inputs, and even some financial support as a credit facility to cultivate maize.* Maize does better these days under the short rainfall regime.
Chagu	Early maturing maize, rice, beans and soybeans	*Farmers here cultivate early maturing maize (75 days) because it is the only crop that thrives well under the short rainy season, we now experience.* Five years ago, an NGO introduced us to new maize and bean varieties that are early maturing. Since then, they have become our major food crops in the community. They fare better under the shortening rainfall regime.
Bulenga	Early maturing beans and groundnuts	*Beans and groundnuts fare better under the current rainfall regime without fertilizers. Therefore, we plant these crops because we do not have money to buy fertilizer.*
Bayiri	Early maturing sweet potatoes and yam	*Masara supplies us with a new maize variety to cultivate and when we harvest, they come to buy from us.* *Masara provided us with maize and weedicides to apply. Therefore, we do not suffer when we cultivate maize.*

[1] At the time of the study, USD $1.0 = GH₵ 10.20

The main reason for this choice is that early maturing varieties are more adaptable to a shortening rainfall regime than traditional crops. A chief (8th July 2022) explains that "traditional crop varieties take long period of time to mature and so, when the rains delay farmers are unable to plant them because they do not survive the current short rainfall regime".

4.2 Farmers' choice of farm inputs: Determinants and implications for climate change adaptation

The farmers identified four main inputs: chemical fertilizer, weedicides, insecticides/pesticides, and organic manure as inputs used on their farms. It is important to note that while other options exist including lime for soil pH correction, compost, and biochar promoted in the region free-listing exercises consistently showed these four as the most utilised. Several interacting determinants shape farmers' input choices beyond simple awareness of agronomic benefits. First, NGO supply chains particularly Masara N'Dera play a decisive role: farmers in Kundugu, Bayiri, and Chagu reported that their access to improved seeds, fertilizer, and weedicides was largely mediated through this NGO, which supplied inputs on credit or in exchange for produce. Second, the shortening rainfall season acts as the primary climatic driver pushing farmers toward fast-acting inputs that accelerate crop maturity within the narrowing planting window. Third, credit access constraints limit application to sub-optimal quantities despite farmers' awareness of recommended dosages a barrier that disproportionately affects women farmers and poorer households. Fourth, the market availability of chemical fertiliser compared to organic manure makes it the default choice for most farmers, even where organic alternatives exist. The free listing conducted with the farmers confirmed that they rely more on chemical fertiliser to improve soil nutrients and to adapt to climate change. The farmers intimated that fertilizer application enables farmers to adapt to shortening rainfall season because it facilitates rapid growth and maturity of crops and subsequently increases crop yields. Therefore, most farmers apply fertiliser to their crops, but in small quantities because they are unable to procure enough for their farms. Although the fertilizer application may fail to meet standard application requirements, the small quantities applied made a difference in adaptation outcomes. For example, a female farmer and women's leader, during an interview explained that the application of chemical fertiliser to crops guarantees increased harvest under climate uncertainty. The following illustrates the point in an interview with a female farmer who expresses preference for fertilizer for adaptation:

> *In this unpredictable rainfall era, it is better to use fertiliser to cope with the situation than to sit here and do nothing. The farmers are guaranteed a higher yield when they apply fertiliser to the crops because they will get more than what the farmer puts in the soil at harvest. On the other hand, those who do not apply fertiliser do not harvest much because their crops cannot mature quickly before the rains stop these days* (Female farmer from Bayiri, 18th August 2022).

Similarly, for herbicides, the farmers explained that the main purpose for its application is to control weed in production as a response to climate change. Weedicides are applied in different ways to achieve this goal. First, weedicides may be applied as a weed control for planting. Secondly, weedicides aids in the fast clearing of land, and early planting of crops to be in sync with the changing climatic elements, rainfall, and temperature. When rains delay and farmers suspect that the rainy season will be shorter than expected, they apply weedicides on farms and plant without ploughing. The rationale is to speed up planting as an adaptation mechanism to shortening rainfall seasons. When the crops germinate, they may then weed. Thirdly, farmers sometimes apply weedicides after ploughing and planting if the conditions support this. This was meant to speed up the weeding process in support of a faster and healthier growth process for crops. Again, the rationale is to support adaptation to a shortened rainfall regime. Focus group discussions with chief and elders in Kundugu (11th July 2022), revealed that fertilizer is needed for crops such as the new maize variety and Dorado, a new guinea corn variety. Some farmers also utilise animal manure to fertilise their farms due to its cost-effectiveness and its ability to enhance and sustain soil fertility. However, the adoption of manure is constrained by limited availability and supply. A chief farmer intimated the following during an interview.

> *These days, people don't rear livestock and so it is difficult to get animal manure. This is why manure is not a major input, (*Interview with a chief from Bayiri, 17th July 2022).

Also, the farmers use herbicides for weed control to maximize crop production. Chemical weed control via herbicide application was favoured because it enabled the farmers to clear of large parcels of land for cultivation as they attempt to adapt to the shortening of the rainfall regime and other negative consequences of climate change. It emerged that the use of the herbicides helps to kill the weeds on the farm, making it easy for the farmers to plant their crops without ploughing. The benefits associated with the use of herbicides is that the dead grasses and plants tend to decay and improve the soil fertility which subsequently supports plant growth. It also aids in clearing large parcels of land on time to coincide with the onset of the rains under climate uncertainty. It emerged from a FGD session with men from Bulenga that.

> *The unpredictability of rainfall patterns makes it difficult for the farmers to rely on the conventional hoe and cutlass to farm. To adapt to climate uncertainty, the farmers resort to herbicides to plant their crops to coincide with the rainfall anytime it comes. This is because the use of the herbicides enables them to plant large parcels within a short time to benefit from the limited rainfall regime being experienced* (20th July 2022).

The interviews and FGDs revealed that farmers resorted to insecticides and pesticides to adapt to climate change. The farmers explained that the application of insecticides and pesticides helps them to improve crop harvest through seed and crop growth improvement as well as the prevention of diseases from insects and pests. However, the relative high cost of farm inputs is an obstacle to its wider utilisation among the smallholder farmers. The study revealed that fertiliser cost was so prohibitive that about half of the farmers could not afford to purchase it for application purposes.

However, the farmers devised several ways to access fertiliser and other inputs for their farms to enable them to adapt to climate change. First, the farmers relied on out grower companies to provide them with the farm inputs on credit so that they can repay after the farm harvest. Second, the farmers also relied on friends and relatives to provide them with cash or farm inputs such as fertiliser so that they can repay with farm harvest or cash based on the agreement between the parties. Finally, market women and men also supply fertiliser and other farm inputs, and this permits the farmers to repay after they have harvested their crops.

4.3 Information sources and social learning pathways for agronomic practice adoption

The results reveal two key issues on the application of knowledge and technologies for climate change adaptation among smallholder farmers. First, that farmers were adopting and adapting agronomic practices including mechanised ploughing, improved seed varieties, and agricultural inputs in response to climate change pressures, while generally complementing these with traditional practices of production. Secondly, the uptake of these practices was primarily driven by farmer-to-farmer interactions and other forms of social networking and institutional engagement. From the study, farmers identified four main information channels through which agronomic practices are adopted and spread. These included farmer-to-farmer interactions, social and kinship networks, non-governmental organizations (NGOs), and Agriculture Extension Agents (AEAs).

Table 3: Information sources and social learning channels for agronomic practice adoption

Source	Supporting quotes
Farmer to farmer	*A colleague farmer from Jirapa introduced me to weedicides that helped in killing grasses and easing farming* (A farmer from Bulenga, 10th July 2022). *I went to a funeral at Dorimon and during a discussion with a farmer from Nator (in Nadowli District) he informed me about how the use of pesticides saved his maize from destruction in the previous season and advised me to always apply it on my maize* (A male farmer from Bayiri, 17th July 2022).
Social kinship network	*A brother of mine who works with an agrochemical company educated me on how the application of weedicides and pesticides could help me with my farming and since then I have been using them. The harvest I get from my farm is far better than before* (Female farmer from Chagu, 10th August 2022).
NGOs	*An NGO working in this community and those around first introduced us to the use of weedicides and a particular kind of fertiliser that help our crops to do well. Since then, I have been using them on my farm, and the harvest has been good* (A farmer from Kundugu, 8th August 2022).
Agric Extension Agents	*I got the information and knowledge about all these things (fertiliser, weedicides, and pesticides) from the Agriculture Officer who works with us in the community. The agent teaches us all the new ideas and chemicals for farming, and they have been helpful to us over the years* (A farmer from Bulenga, 12th July 2022).

From the analysis, farmers cited farmer-to-farmer interactions as the primary channel through which agronomic practices spread and are contextually adopted within communities. The farmers explained that when they meet at markets, community gatherings, and through farming networks they discuss and share experiences about crop varieties, input use, and ploughing methods that have worked well under the changing rainfall conditions. This peer-based social learning is significant not because it constitutes the creation of new knowledge per se, but because it represents the mechanism through which externally introduced practices (such as early maturing maize and herbicide use) become embedded in local farming systems and adapted to community-specific conditions. This point is illustrated by a male farmer during an interview on how he learned about weedicides application in Bayiri.

> *I got to know about weedicides from another farmer. I went to the market a few years ago to buy farm inputs and met a long-time friend. As we discussed farming difficulties due to the climate change, he suggested that I use weedicides to eliminate grasses and cultivate large parcels of land. He said that if the chemicals are used, the crops could be sowed anytime the rains start. So, when I tried it, it worked, and since then, I have been spraying the farm with weedicides (Interview with Male farmer from Bayiri, 15th July 2022).*

The excerpt illuminates how information about agronomic practices flows through farmer-to-farmer interactions. Through these channels, local farmers learn about practices that have helped others manage climate variability, and selectively adopt those suited to their own conditions thereby improving adaptive capacity and harvest outcomes.

Secondly, the farmers cited social and kinship networks as important channels for learning about agronomic practices. The results showed that social and kinship networks play a significant role in transmitting information about farming practices across communities. The farmers explained that they have relatives who reside in other parts of Ghana who shared information about agronomic practices that have proved useful in adapting to the shortened, unpredictable rainfall pattern and frequent droughts experienced in the region. These networks illustrate how agricultural practices are diffused through relational ties rather than formal extension channels, underscoring the socially embedded nature of agricultural change within these communities. For instance, FGD discussants revealed that migrant relatives in the Bono Region are a major source of information on agronomic practices. One of the discussants narrating how he learnt about insecticides from migrant relatives stated that:

> *I have two brothers who are also farmers in a village near Techiman in the Bono East Region. When they come home, they share with me whatever knowledge they had gathered. Such knowledge has been useful to me* (Male discussant, Bulenga community, 20th July 2022).

Although the other sources of knowledge, NGOs and AEAs were the least cited, we examined these because of their roles in transmitting agricultural innovations. NGOs operating in the area emerged as significant information channels: farmers explained that an NGO (Masara N'Dera) had introduced improved early maturing maize varieties to the communities. According to the farmers, one of the early maturing varieties takes 75 days to mature and the other takes 90 days to mature. These varieties are not novel to northern Ghana broadly, but their structured introduction through NGO supply chains and demonstration plots made them accessible to farmers in these specific communities. During an interview with a women's leader in Chagu, she revealed how an NGO introduced the maize varieties and supported their uptake. A female farmer narrating how she adopted early maturing maize through an NGO, had this to say about how they learned about the new maize varieties:

> *The changes in rainfall and the prolonged drought had made it impossible for us to farm in the past. We suffered a lot because we used the traditional maize variety that we inherited from our great grandparents which takes a longer time to mature. So, planting the new maize variety is appropriate* (Women's leader from Chagu, 12th August 2022).

The quotation illustrates that NGOs working in the agricultural sector serve as key institutional intermediaries, introducing new crop varieties and farming inputs to local farmers and providing the supply chain and credit arrangements that make adoption feasible. The significance of this lies not in the novelty of the inputs themselves fertilizer, weedicides, and improved maize varieties have been present in northern Ghana for decades but not in the structured, community-level channels through which access and uptake have been organised. These institutional pathways, combined with peer learning networks, represent the social infrastructure through which agronomic practice change occurs, with important implications for how climate change adaptation support should be designed and delivered.

5. Discussion

This study explored how smallholder farmers in northern Ghana are adapting their agronomic practices in response to increasing climatic variability. The findings demonstrate that climate change is influencing not only farm-level decision-making but also broader transformations in agricultural production systems, knowledge networks, and technological adoption. Importantly, the results both corroborate and extend existing research on climate change adaptation in smallholder farming systems.

First, the findings highlight the growing importance of mechanisation, particularly tractor ploughing, as an adaptive response to changing rainfall patterns. Farmers reported that mechanised land preparation allows them to cultivate larger areas and plant crops quickly once rainfall begins. This finding corroborates previous studies that emphasise the role of mechanisation in improving farmers' capacity to cope with labour shortages and climatic variability (Houssou et al., 2018; Diao et al., 2014). These studies argue that mechanisation enhances agricultural productivity by enabling timely land preparation and improving labour efficiency, which is particularly critical in rain-fed farming systems where planting windows are increasingly narrow due to climate variability. However, the findings also reveal unequal access to mechanised services, which may reinforce existing socio-economic disparities among farmers. Wealthier farmers were more able to hire tractor services, while poorer farmers relied on traditional tools such as hoes. This observation supports earlier work by Yaro (2013) and Belay et al. (2017), who found that access to financial resources and institutional support strongly influence farmers' adaptive capacity. At the same time, the results extend this literature by illustrating how mechanisation can contribute to agrarian differentiation, whereby wealthier farmers are better positioned to benefit from technological innovations while poorer farmers face structural barriers to adoption.

Second, the increasing adoption of early-maturing maize varieties reflects farmers' efforts to cope with shortened and unpredictable rainfall seasons. This finding is consistent with studies across Sub-Saharan Africa that identify improved crop varieties as a key climate adaptation strategy among smallholder farmers (Cairns et al., 2013; Cacho et al., 2020). Early-maturing varieties allow crops to complete their growth cycle before the onset of drought conditions, thereby reducing the risk of crop failure under erratic rainfall regimes. Nevertheless, the present study also reveals an important dimension that has received less attention in the literature: the close linkage between improved seed adoption and increasing reliance on chemical fertilizers and agrochemicals. While previous studies acknowledge that improved varieties often require complementary inputs (Burney et al., 2014), farmers in this study reported using fertilizers and herbicides more intensively to sustain yields under changing climatic conditions. This finding suggests that climate adaptation may be driving a transition toward more input-intensive farming systems, which could create new economic and environmental challenges. Heavy dependence on purchased inputs may expose farmers to market fluctuations and financial constraints, a concern raised by several scholars studying sustainable agricultural intensification (Bisht & Chauhan, 2020).

Third, the findings emphasise the importance of social learning and farmer-to-farmer knowledge exchange in facilitating the adoption of new agronomic practices. Farmers consistently reported that they learned about improved seeds, fertilizers, and pesticides primarily through interactions with other farmers rather than through formal extension services. This finding supports existing literature on socially embedded innovation systems, which emphasises the role of local knowledge networks in the diffusion of agricultural technologies (Ensor & Harvey, 2015; Sadoulet, 2016). These studies highlight that farmers often rely on trusted peers when evaluating the risks and benefits of new agricultural practices. The prominence of informal knowledge networks observed in this study also aligns with findings from northern Ghana by Derbile and Laube (2014), who showed that farmer-to-farmer learning plays a critical role in shaping adaptation decisions in rural communities. However, the present study extends this literature by demonstrating that informal learning processes often operate alongside institutional interventions from NGOs and agricultural extension services. This suggests that climate adaptation is most effectively understood as a hybrid knowledge process, in which external innovations are filtered, interpreted, and adapted through locally embedded social networks.

Taken together, the findings suggest that climate change adaptation among smallholder farmers is occurring within broader processes of agrarian transformation and technological intensification. While mechanisation, improved seeds, and agrochemical inputs offer opportunities to enhance agricultural productivity and resilience, these strategies also introduce new risks related to inequality, environmental sustainability, and dependency on external inputs. These findings resonate with broader debates in rural development literature, which caution that technology-driven adaptation strategies may produce uneven outcomes if issues of access, affordability, and sustainability are not addressed. From a policy perspective, these findings highlight the importance of adaptation strategies that integrate technological innovation with local knowledge systems and social learning structures. Approaches such as Endogenous Development, which emphasise the co-production of knowledge between local communities and external actors, may offer a promising pathway for strengthening climate resilience in smallholder farming systems (Derbile et al., 2016). Building on farmers' existing knowledge networks while improving access to appropriate technologies and institutional support, such approaches can promote more inclusive and sustainable adaptation pathways.

6. Conclusions

This study explored the agronomic practices of smallholder farmers in northern Ghana and examined the information flow and social learning pathways that drive the adoption of these practices, highlighting their implications for climate change adaptation. The findings document that farmers are engaged in a range of agronomic practices including mechanised ploughing, adoption of early-maturing maize varieties, and increased use of chemical inputs that are closely tied to perceived shifts in rainfall patterns, particularly the shortening of the rainy season. While these practices were not always conceived or designed explicitly as "climate change adaptation strategies," they carry significant adaptive value: they enable farmers to plant and harvest within a narrower rainfall window, reduce labour bottlenecks, and sustain yields under more erratic conditions. The study further reveals that the spread of these practices occurs largely through farmer-to-farmer interactions, kinship networks, and NGO-facilitated supply chains, highlighting the primacy of informal and institutional learning systems in shaping practice change. Three key implications for climate change adaptation planning emerge from these findings. First, adaptation support must address the socio-economic constraints particularly credit access and input affordability that prevent farmers from fully implementing practices they already know to be beneficial. Second, NGOs and extension services serve as critical intermediaries in the adoption pathway; adaptation planning should formalise and strengthen these roles. Third, the Endogenous Development approach to Climate Change Adaptation Planning, which centres local knowledge systems and farmer networks, offers a promising framework for building adaptive capacity in smallholder farming communities. Strengthening farmer-to-farmer learning networks, improving access to mechanization services through cooperative arrangements, and promoting sustainable soil management practices can collectively enhance adaptation outcomes. Future research should examine how these practice adoption dynamics vary across different agro-ecological regions and assess the long-term environmental and socio-economic implications of increasing reliance on mechanization and chemical inputs.

Disclosure of interest
The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of funding
No funding was received.

Data availability
Data will be made freely available on request.

References

Akinyi, P. M., Dror, I., Franzel, S., & Kindt, R. (2021). The role of smallholder farmers in adaptation to climate change and variability: insights from semi-arid regions of Kenya. *Climate Research,* 83, 103–118. doi.org/10.3354/cr01638

Awazi, N. P. (2022). Adaptation and mitigation of climate change through agroforestry in Cameroon: constraints and prospects. *Agricultural Research,* 11(4), 677–694. doi.org/10.1007/s40003-022-00590-w

Awazi, N. P., Ngone, M. A., & Tematio, P. (2024). Gender differentiation in climate change adaptation through agroforestry in Cameroon. *Agroforestry Systems,* 98(2), 341–358. doi.org/10.1007/s10457-023-00912-z

Batung, E., Mohammed, K., Kansanga, M. M., Nyantakyi-Frimpong, H., & Luginaah, I. (2021). Intra-household decision-making and perceived climate change resilience among smallholder farmers in semi-arid northern Ghana. *SN Social Sciences*, 1(12), 290.

Belay, A., Recha, J. W., Woldeamanuel, T., & Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture & Food Security*, *6*(1), 24. doi.org/10.1186/s40066-017-0100-1

Bisht, N., & Chauhan, P. S. (2020). Excessive and disproportionate use of chemicals cause soil contamination and nutritional stress. In *Soil contamination*. IntechOpen.

Boafo, Y. A., Saito, O., Jasaw, G. S., Otsuki, K., & Takeuchi, K. (2016). Provisioning ecosystem services-sharing as a coping and adaptation strategy among rural communities in Ghana's semi-arid ecosystem. *Ecosystem Services,* 19, 92–102. doi.org/10.1016/j.ecoser.2016.04.003

Burney, J., Cesano, D., Russell, J., La Rovere, E. L., Corral, T., Coelho, N. S., & Santos, L. (2014). Climate change adaptation strategies for smallholder farmers in the Brazilian Sertão. *Climatic Change*, *126*(1-2), 45-59. doi.org/10.1007/s10584-014-1186-0

Cacho, O. J., Moss, J., Thornton, P. K., Herrero, M., Henderson, B., Bodirsky, B. L., ... & Lipper, L. (2020). The value of climate-resilient seeds for smallholder adaptation in sub- Saharan Africa. *Climatic Change*, *162*(3), 1213-1229. doi.org/10.1007/s10584-02002817-z

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting maize production to climate change in Sub-Saharan Africa. *Food Security,* 5(3), 345–360. doi.org/10.1007/s12571-013-0256-x

Callo-Concha, D., Gaiser, T., & Ewert, F. (2012). Farming and cropping systems in the West African Sudanian savanna. WASCAL research area: northern Ghana, southwest Burkina Faso and northern Benin. *ZEF working paper series* (No. 100) .

Cooper, P. J. M., Stern, R. D., Noguer, M. and Gathenya, J. M. (2013) Climate change adaptation strategies in SubSaharan Africa: foundations for the future. In: Singh, B. R. (ed.) Realities, Impacts Over Ice Cap, Sea Level and Risks. InTech Open, pp. 327-356

Dazé, A. and Echeverría, D. (2016). Review of current and planned adaptation action in Ghana. CARIAA Working Paper no. 9. International Development Research Centre, Ottawa, Canada and UK Aid, London, United Kingdom. Available online at: www.idrc.ca/cariaa.

Derbile, E. K., & Laube, W. (2014). Farmer-to-farmer learning and agricultural adaptation to climate change in northern Ghana. *GeoJournal,* 79(6), 743–758. doi.org/10.1007/s10708-014-9543-x

Derbile, E.K., Adams, A. & Yakubu, I. (2016). Local Knowledge and Community–Based Assessment of Environmental Change in Ghana. Journal of Geography. 8(2), 59-83

Derbile, E.K., Jarawura, F.X. & Dombo, M.Y. (2016). Climate Change, Local Knowledge and Climate Change Adaptation in Ghana. In: J.A. Yaro and J. Hesselberg (eds.), Adaptation to Climate Change and Variability in Rural West Africa, Springer International Publishing Switzerland. doi.org/10.1007/978-3-319-31499-0_6

Diao, X., Hazell, P., & Thurlow, J. (2014). The role of agriculture in African development. *World Development,* 38(10), 1375–1383. doi.org/10.1016/j.worlddev.2010.06.001

Ensor, J. E., & Harvey, B. (2015). Social learning and climate change adaptation: evidence for international development practice. *Wiley Interdisciplinary Reviews: Climate Change,* 6(5), 509–522. doi.org/10.1002/wcc.348

Fagariba, C. J., Song, S., & Soule Baoro, S. K. G. (2018). Climate change adaptation strategies and constraints in Northern Ghana: Evidence of farmers in Sissala West District. Sustainability, 10(5), 1484. doi.org/10.3390/su10051484

Fang, D., Chen, J., Wang, S., & Chen, B. (2024). Can agricultural mechanization enhance the climate resilience of food production? Evidence from China. *Applied Energy*, *373*, 123928.

Food and Agriculture Organisation (2010). Climate change and food security: Risks and responses. Food and Agriculture Organisation. New York, United States of America. Retrieved from http://www.fao.org/3/i5188e/i5188e.pdf. Accessed 20 June 2021

Food and Agriculture Organisation (2023). *The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems*. FAO, Rome. doi.org/10.4060/cc7724en

Ghana Statistical Service (2018). Ghana living standard survey round 7: Poverty trends in Ghana 2005-2017. Accra, Ghana: Ghana Statistical Service.

Ghana Statistical Service (2020). Multi-dimensional poverty - Ghana. Accra, Ghana. Ghana Statistical Service.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., & Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 2973-2989. doi.org/10.1098/rstb.2010.0158

Houssou, N., Johnson, M., Kolavalli, S., & Asante-Addo, C. (2018). Changes in Ghanaian farming systems: stagnation or a quiet transformation? *Agriculture and human values*, *35*(1), 41-66.

Ibe, G. O., & Amikuzuno, J. (2022). Climate change in Sub-Saharan Africa: A menace to agricultural productivity and ecological protection. Journal of Applied Sciences and Environmental Management, 23(2), 329-335. doi.org/10.4314/23i2.20

IPCC (2014) In: Core Writing Team, Pachauri RK, Meyer LA (eds) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, pp 151

IPCC (2021). Supplementary Material. *IPCC WGII Sixth Assessment Report*, 1–225

IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. doi.org/10.1017/9781009325844

Kesby, M. (2000). Participatory diagramming as a means to improve communication about sex in rural Zimbabwe: a pilot study. *Social Science & Medicine*, *50*(12), 1723-1741.

Kombat, R., Napari, P., Owusu, V., & Asante-Poku, G. (2021). Climate change vulnerability and adaptive capacity of smallholder farmers in northern Ghana. *Climate and Development*, 13(8), 689–702. doi.org/10.1080/17565529.2020.1870966

Makate, C. (2019). Local institutions and indigenous knowledge in adoption and scaling of climate-smart agricultural innovations among sub-Saharan smallholder farmers. *International Journal of Climate*

Change Strategies and Management, 11(2), 301–320. doi.org/10.1108/IJCCSM-07-2017-0144

Mapfumo, P., Mtambanengwe, F., & Chikowo, R. (2013). Soil fertility management as a driver of food production under contrasting socioeconomic and biophysical conditions in Zimbabwe. *Field Crops Research,* 140, 55–66. doi.org/10.1016/j.fcr.2012.10.014

Maziya, M., Pillay, K., & Mudhara, M. (2024). Psychological capital and climate change adaptation among smallholder farmers in southern Africa. *Climate Risk Management,* 43, 100581. doi.org/10.1016/j.crm.2024.100581

Mendelsohn, R. (2014). The impact of climate change on agriculture in Asia. Journal of Integrative Agriculture, 13(4), 660-665. doi.org/10.1080/19390450802495882

Mensah, A. K. (2025). Smallholder agronomic adaptation and social learning in northern Ghana: Evidence from the Wa East District. *African Geographical Review*, 44(1), 45–62. doi.org/10.1080/19376812.2024.2389140

Nyahunda, L., & Louis, W. R. (2024). Marginalisation of indigenous knowledge in formal climate change policy: evidence from South Africa and Zimbabwe. *Local Environment,* 29(3), 312–329. doi.org/10.1080/13549839.2023.2278461

Nyoni, B., Mthembu, N., & Phiri, D. (2024). Rainfed agriculture and climate adaptation in sub-Saharan Africa: Trends, constraints, and pathways for resilience. *Agricultural Systems*, 215, 103875. doi.org/10.1016/j.agsy.2024.103875

Onyango, E. A., & Nzengya, D. M. (2023). Systematic review of smallholder farmers' adaptation to climate variability and change in sub-Saharan Africa: Evidence and gaps. *Journal of Arid Environments*, 209, 104897. doi.org/10.1016/j.jaridenv.2023.104897

Opoku Mensah, P., Asamoah, O., & Darko, R. (2025). Mechanisation, improved seeds, and input intensification among smallholder farmers in northern Ghana: A climate adaptation perspective. *Sustainability*, 17(3), 1124. doi.org/10.3390/su17031124

Sadoulet, E. (2016). Review of Theories of Learning for Adopting. Working Paper 163.

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., ... & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. Regional Environmental Change, 17(6), 1585-1600.

Shackleton, S., Ziervogel, G., Sallu, S., Gill, T., & Tschakert, P. (2015). Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. Wiley Interdisciplinary Reviews: Climate Change, 6(3), 321-344. doi.org/10.1002/wcc.335

Shorten, A., & Smith, J. (2017). Mixed methods research: expanding the evidence base. *Evidence-Based Nursing,* 20(3), 74–75. doi.org/10.1136/eb-2017-102699

Siatwiinda, S. M., Recha, J. W., & Thierfelder, C. (2025). Integration of indigenous ecological knowledge into climate change adaptation in Zambia's Agroecological Region I. *Environmental Science & Policy,* 153, 103691. doi.org/10.1016/j.envsci.2024.103691

Slootman, M. (2018). A Mixed-Methods Approach. In Slootman, M (ed). Ethnic Identity, Social Mobility and the Role of Soulmates, Springer, Cham. pp. 41-57. doi.org/10.1007/978-3- 319-99596-0

Stacey, N., Lenaiyasa, L., & Robinson, E. J. Z. (2025). Social navigation and climate adaptation among pastoralists in Kenya's drylands: mobility, negotiation, and everyday resilience. *World Development,* 177, 106541. doi.org/10.1016/j.worlddev.2024.106541

Terrell, S. R. (2012). Mixed-methods research methodologies. Qualitative report, 17(1), 254- 280.

Tume, S. J. P., Kimengsi, J. N., & Fogwe, Z. N. (2022). Indigenous Knowledge and Farmer Perceptions of Climate and Ecological Changes in the Bamenda Highlands of Cameroon: Insights from the Bui Plateau. Climate, 7(12), 138. doi.org/10.3390/cli7120138

Umoquit, M. J., Dobrow, M. J., Lemieux-Charles, L., Ritvo, P. G., Urbach, D. R., & Wodchis, W. P. (2008). The efficiency and effectiveness of utilizing diagrams in interviews: an assessment of participatory diagramming and graphic elicitation. *BMC Medical Research Methodology*, *8*, 1-12.

Yaro, J. A. (2013). The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers. Regional Environmental Change, 13(6), 1259-1272. doi.org/10.1007/s10113-013-0443-5

Zvobgo, L., Johnston, P., & Wilson, D. (2023). Indigenous knowledge and hybrid seasonal forecasting systems: farmer adaptation practices in Chiredzi, Zimbabwe. *C*