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Agroecological farming: An adaptation and mitigation strategies in the light of climate change

Dossa KF* and Miassi YE
Action-Research for Sustainable Development NGO,
Department of Research Project, Cotonou 03296, Benin
Corresponding author: fabdossa@gmail.com

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ABSTRACT

The aim of the study was to explore different agroecological strategies employed by farmers around the world to adapt to varying climatic conditions and to ensure sustainable food production. Following PRISMA guidelines for systematic review, it was conducted a comprehensive literature search using PubMed, ProQuest, and Elsevier databases. It was included studies published in the last ten years that focused on the agroecological adaptation strategies adopted by farmers around the world in response to climatic conditions. Of the studies identified, only 31 were in accordance with the inclusion criteria and were included in the systematic review. Among many agroecological practices, the use of diverse and climate-specific crops, conservation tillage, changes in plantation dates, mixed farming, and water conservation strategies were mostly utilized by farmers around the world. Included studies showed that although farmers are adapting the agroecological practices yet many factors including access to knowledge, training and resources as well as the lack of policies and support from the governing bodies impact their full potential. The results of the systematic review highlighted the importance of agroecological farming as a sustainable approach to buildingfarmers' resilience to climate change. However, more work needs to be done to comprehend the effectiveness of these strategies and to tackle the challenges faced by farmers in the implementation of these practices.

Keywords: Adaptation; Agroecology; Climate Change; Mitigation.

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Introduction

Change in climate due to global warming stands as one of the most urgent and pressing issues faced by world today. The agricultural industries are being significantly impacted by this climate change, which poses a danger to global food security (Dogondaji, 2013). Global temperature rise has been attributed to greenhouse gas emissions, including carbon dioxide, nitrous oxide and methane (Malhi et al., 2021). The agriculture sector is experiencing challenges with regards to sustainability and production due to changes in rainfall patterns and temperature rise. This calls for a shift towards more sustainable strategies which are tailored to needs of climate change and can help in mitigating its effects on agriculture. Agroecology is an approach of agricultural practices that involves integration of ecological processes and ecosystem elements to develop sustainable agricultural system (Wezel et al., 2013).

Traditional agricultural practices and technological innovations alone are not sufficient to combat the impacts of change in climate on agriculture. With its emphasis on creating climate resilience, agroecological farming has come to light as a viable way to address issues of sustainability and food security under changing climatic conditions.It focuses on reducing effects of these changes on agriculture in addition to adapting agricultural methods to demands of climate change.

The unpredictable weather patterns and changes in rainfallpatterns and distributionhave negatively affected agriculture and global food security. Reduction in crop yield, lesser forage production, poor productivity of livestock and soil infertility have resulted from changes in rainfall patterns (Sinore & Wang, 2024). Although the extent and intensity of the effect of climate change is different in different agroecological zones yet the overall point of concern is food security. To address the potential of agroecological farming in mitigating climate change effects on agriculture, more research needs to be directed toward understanding how farmers respond to these changes and which strategies, or combination of strategies would work best.

Materials and Methods

The review evaluates influence of climate shift on agroecology and adaptations practiced by farmers across the world. The prior data available on subject was based on general agroecological farming. There were no specifications on underlying practices and adaptation strategies against climate change. This choice to do a systematic review on this topic was made to findthe most adopted mitigation practices across regions and effectiveness of each against climatic resistance.

The key difference between agroecology and conventional agriculture is that conventional farming is based on inorganic or synthetic fertilizers, pesticides, and plant growth catalysts, such as antibiotics and hormones, while agroecology is based on natural inputs. (*Epule, 2022*).

Literature Review Methodology: To reviewrecords on agroecology farming practices in light of climate change, we applied a comprehensive review methodology through databases and online repositories. The review followed PRISMA-RR guidelines and protocol consisting of the following phases: the literature finding phase, title-basedscreening, abstract and full-textscreening, eligibility phase, and the evidence retrieval phase.

Identification phase: To identify the literature sources for this systematic review, it was used a search string including terms relevant to agroecological farming and practices, and mitigation and adaptation strategies against climate change. Mesh terms were used and asterisk (*), were inserted at end of the base word to retrieve a greater number of relatedrecords. For the identification of available literature, we screened PubMed™(65 articles retrieved), ProQuest (1513 articles retrieved),and the Elsevier™ (n =346 articles retrieved) databases. Toidentify and retrieve other published documents, we hand-searched the online repositories of several well-established institutes.

Screening phase: After screening, the abstracts of the identified records were either retained for the evaluation stage or removed from further research (Table 1). We prepared a set of inclusion and exclusion criteria for this procedure that considered agroecological practices and publication dates, the influence of climate changeand adaptations used and article quality, language and accessibility. After title-based screening, 135 abstracts were hand-screened by two reviewers independently and simultaneously. Titles and abstracts-based screening was done by two independent reviewers after duplicates were eliminated manually using Mendeley. When two reviewers could not agree on what should be included, a third reviewer made the final decision.

Following this title screening stage, 48 abstracts were selected for full-text screening.

Table 1: Search strings and sources of literature used for the review

Search string	**Literature databases and online repositories searched.**
(agroecology* OR agro-ecology* OR 'diversified farming system'OR 'ecological agriculture' OR 'agroforestry' OR 'organic agriculture'OR 'crop diversification 'OR 'mixed farming' OR 'mixed cropping' OR 'agricultural ecology') AND ('adaptation OR adoption* OR mitigation* OR management* OR 'mitigation strategies) AND ('climate change OR climate conditions* OR climate resistance* OR change in climate* OR 'climate-change)	• PubMed® NCBI • Elsevier™ • ProQuest • Online repositories (websites), for example: - FAO - Agroecology Fund - SOCLA - Agroecology Europe - IDDRI

Eligibility phase

After studying the full texts of the selected articles, therecords were further screened using an inclusion criterion on (i) thetypeof agro-ecological practices used, (ii) specific climate change conditions (iii) relevance of the methodological approach, (iv) adaptation practices and mitigation strategies employed by subjects against the climatic conditions and (v) quality evaluation of the article (Table 2).

I. *Specification of agro-ecological practice:* Sources of literature that did not mention agroecological methods (such as intercropping systems including genetically modified crops or heavy application of herbicides and insecticides) have not been included. Furthermore, records mentioning agroecological production techniques that lacked specific practice identification—that is, papers discussing conservation agriculture,
II. biodynamic farming, or organic farming without providing specific practice details—were also disqualified from additional examination. Literature that mentioned the use of specific agroecological practices such as intercropping, mixed farming, conservation tillage, changes in plantation dates, and soil and water conservation strategies were kept.
III. *Specific climate change conditions:* The review includes a number of research articles and case studies that were conducted across different regions of the world. Climate change is a global concern, but its implication varies across different regions. Literature that clearly identified and mentioned the climatic concern in the region was included. As the adaptation strategies were subjective to the type of climatic condition, only records that mentioned both were included.
IV. *Relevance of the methodology in use:* Here, we considered the methodology that was being used to determine the adaptation practices in agroecology in light of climate change. We considered articles that provided specific adaptation strategies against specific climatic concerns such as practices adopted by farmers in case of irregular rainfalls or strategies used in case of soil erosion. We included articles with proven on-farm implementation and on-farm intervention studies since they are more like real farming situations as the farmer participates on his or her farm.
V. *Adaptation/ mitigation strategies:* Literature that included the adaptation strategies applied by farmers in different regions of the world to alleviate the climate change impacton crops were kept. Strategies such as using alternate planting dates, switching of crop varieties, planting drought-resistant crops and additional irrigation and crop rotation. Although the strategies vary across regions, we will provide a compiled list of strategies used as countermeasures for adapting to climate change.
VI. *Article quality evaluation:*Data from the last 10 years that was published in quality journals was included. Records were gathered from databases and other online repositories for the purpose of screening and reviewing the literature. Following the ultimate assessment, the most recent information from reliable databases was included.

Table 2: Inclusion and exclusion criteriaused for the abstract-based screening

Inclusion criteria	**Exclusion criteria**
Published between 2014 and April 2024	Not published between2014 and April 2024
Includes agro-ecological strategy and practices	Does not include agroecological practices
Refers to climate change and adaptation strategies.	Does not refer to climate change and adaptation strategies.
Peer-reviewed research paper, academic book, report, PhD dissertation, thesis from a university with national or international recognition (gray literature): (a) Institution which has a track record of research (b) Institution having expertise in the subject area (c) Institution having no track record of falsified or dishonest research	The study is not a Peer-reviewed research paper, academic book, report, PhD dissertation, or thesis from a university with national or international recognition (gray literature): (a) Institution that has no track record of research (b) The institution does not have expertise in the subject area (c) Institution havinga track record of falsified or dishonest research
Full text accessibility	Full text inaccessible
Text in English language only.	Text not in English language.

Evidence retrieval phase

The objective of the phase was to gather pertinent data regarding the mitigation and adaptation practices adopted by farmers in response to extreme climatic conditions. The first step involved compiling all the chosen articles into a synoptic table in an Excel database. This table contained the following details: references, context, and scope of the articles (such as the country, region, and crops used), the agroecological practices employed, the adaptation strategies used, and the climate conditions. The farmer serving as a key player, we concentrated on farm-level analysis while incorporating findings from other levels that were discovered throughout the assessment.The type of agroecological practice implementation (on-farm real implementation vs. on-farm intervention research) and the data collecting method (survey vs. observations vs. statistical data) were established by the methodological approach.

Studies that use surveys as their major data-gathering method often interview farmers using semi-structured questions. Research studies that rely on observations are ones in which the informationwas obtained directly from researchers on the farm through their own measurements and/or less formal interactions (such as focus groups).

In addition to the data gathered through surveys, this approachcan also benefit from observations and secondary data is frequently used to supplement these approaches. These additional strategies are common in much of the research, but they were not specifically used during the evidence retrieval phase; we concentrated on highlighting the primary strategy of data collecting.

Second, the adaptation practices adopted by farmers in response to specific climatic conditions experienced in their region were included (Fig 1). Various socioeconomic and demographic factors influenced farmers' decisions about which adaptation strategies to use. Agroecology, age, education level, active labor, TLU, farm income, off-farm income, frequency of extension contacts, financing availability, and market access were among the variables that affected the adaptation measures. Thus, these factors were taken into consideration when implementing the adaptation approach at the farm level.

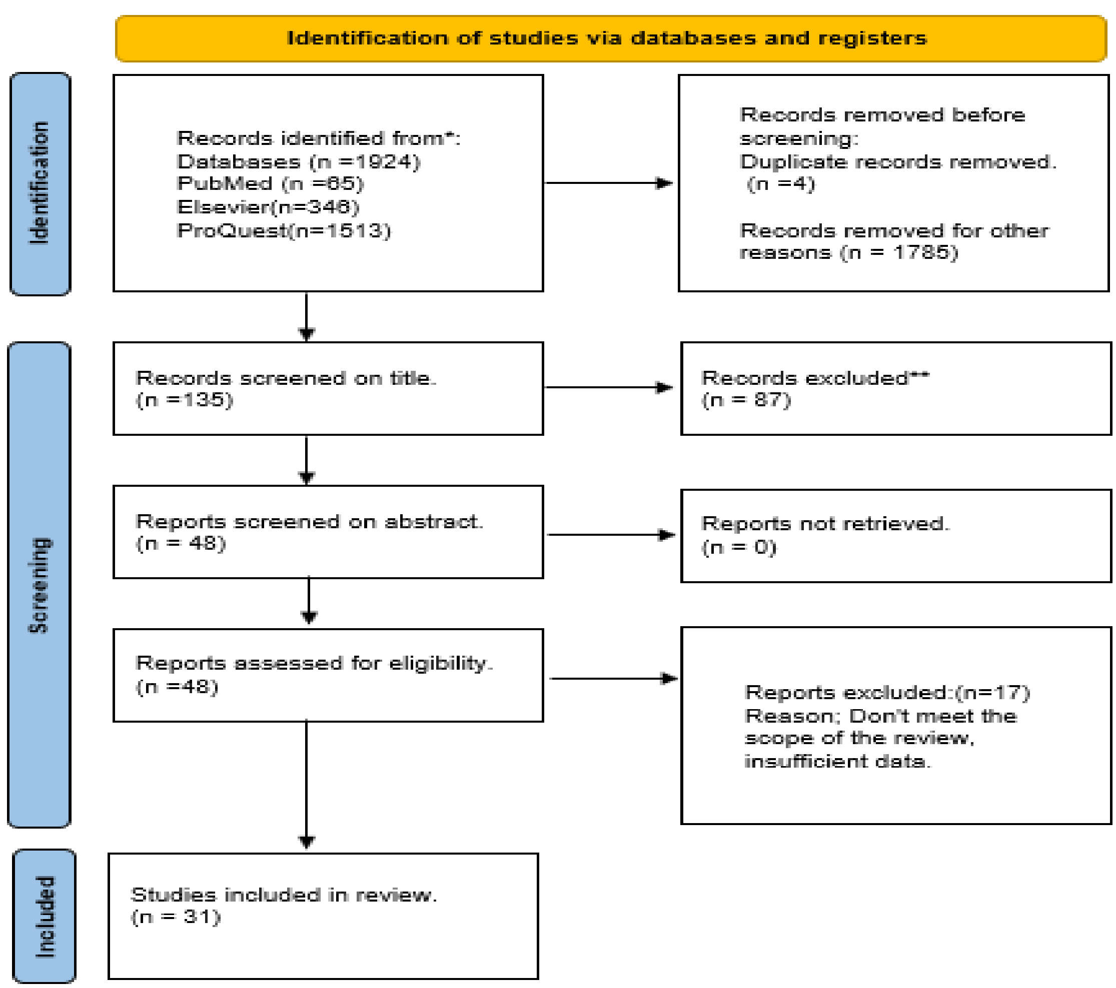

Fig 2: PRISMA methodology used in the study

Results and Discussion

The result of the systematic review summarizes the key findings from the research studies on agroecological adaptation practices used by farmers around the world to deal with climate change impacts in their local agroecosystems. A total of 31 case studies were identified covering different regions across the world. The studies described the climate-related challenges currently being experienced by farmers in each location and the agroecology-based solutions that were being practiced to increase climate resilience. The results provide insights into the context-specific agroecological adaptation strategies used by smallholder farmers to tackle changing rainfall patterns, increased temperatures, and frequency of other extreme weather events in their agricultural production systems.

The region column lists the geographic locations where the case studies were conducted, including the Lowlands of Ethiopia, Ghana, Bangladesh, Kenya, Hungary, France, and Africa. This shows that studies were drawn from diverse agroecological zones around the world.

The main climate issue column describes the primary effect of climateinstabilitychallenging farmers in each region. The issues faced included droughts, floods, shifting rainfall patterns and distribution, carbon removal, greenhouse gases, extreme temperature variations, and water scarcity. This demonstrates that climate change is already affecting agricultural production through a range of climatic stresses.

The adaptation strategies employed column outlines the agroecological practices that farmers in the different regions have adopted to cope with the climate impacts. Popular approaches included landscape and farm diversification, intercropping, mixed farming, using climate tolerant and early maturing varieties of crop, mulching, use of transitional agroecological zones crop, pasture rotation, adding organic fertilizers, using cover crops, reducing or eliminating synthetic inputs and applying climate-smart practices.

It provided a consolidated view of the agroecological adaptation strategies being implemented by farmers across climatic contexts to manage climate change impacts documented in the literature (Table 3).

Table 3: Consolidated view of the agroecological adaptation strategies being implemented by farmers across climatic contexts

Place of study	*Climatic concern*	*Adaptation strategy*
Tigray regional state, Ethiopia	▪ Drought (78.8%) and flood (11.7%) ▪ Low precipitation ▪ Short rainfall duration	▪ 85.3% shifted the species type to a new adaptive Type. ▪ (80.1%) change their previous crop variety to those introduced by agricultural extension/research systems. ▪ (13.3%) change their livestock species. ▪ (6.6%) changed their tree species. to another species they perceive as adaptive. ▪ Agroforestry (ranked by respond- ▪ ents as a third adaptation choice) as their adaptation ▪ and coping mechanisms for climate change.
Dinajpur district, Bangladesh	▪ Shifting pattern of rainfall and its fluctuation ▪ Temperature ▪ flooding risk ▪ Humidity ▪ Sunshine hour variation.	▪ Modification of irrigation dates and ▪ amount of water for wheat. ▪ Advancement of sowing date by one week to avoid terminal. ▪ heat stress for wheat. ▪ Improved fertilizer management and soil test-based application in ▪ both rice and wheat. ▪ Use of short-duration rice varieties so that advanced wheat planting can be accommodated.
Saesietsaeda Emba	▪ Irregular	**Agricultural water additions and land management such as**

district, Ethiopia	▪ Rainfall/ unimodal rainfall ▪ Low vegetation cover ▪ Poor quality of soil fertility ▪ Severe degradation ▪ Drought	▪ implementation of soiland water conservation ▪ change in the quantity of land under cultivation. ▪ moving to different farm site ▪ deep tillage ▪ pond-making, ▪ irrigation usage ▪ water harvesting ▪ compost preparation and usage. ▪ digging water wells ▪ managing floods and droughts ▪ run-off harvestingadaptation measures. **adjustment of farm and crop-livestock management such as** ▪ New high yielding crop variety ▪ Short maturing crop varieties ▪ Crop rotation. ▪ Change in planting, weeding, and harvesting dates. ▪ Apply inorganic fertilizer. ▪ Apply farmyard manure/organic fertilizer. ▪ Fallowing ▪ Drought resistant crops ▪ Managing pest and disease prevalence ▪ Proper usage of pesticides and herbicides ▪ Mixed cropping ▪ Planting trees ▪ Use mixed crop-livestock farming system. ▪ Changing from livestock to crop production. ▪ Changing from crop production to livestock ▪ Reducing the number of livestock **Diversificationto non-farm adaptation strategies** ▪ Salaried/professional employment ▪ Resource rent income ▪ Migration to urban areas-temporary/seasonal migration ▪ Wage work/daily laborer ▪ Remittance income ▪ Crop insurance. ▪ Handcraft ▪ Petty trading ▪ Preparation and selling of local beverages e.g. 'siwa', 'mess' ▪ Natural resources (wood, charcoal, minerals)
Masaba South Sub-County, Kisii County, Kenya	▪ Decrease in rainfall. ▪ Poor rainfall ▪ distribution ▪ Late onset of rainfall ▪ Increase in temperature.	▪ Crop Diversification ▪ Change of planting time ▪ Crop rotation and mixed cropping. ▪ Use of manure ▪ Change of crop varieties ▪ Soil conservation/mulching/terraces ▪ Livelihood diversification ▪ Enhancing animal rearing practice ▪ Increase land under farming/cultivation. ▪ Use of Integrated Pest Management ▪ Change to Irrigation/Water harvesting. ▪ Reducing the land under cultivation ▪ Switch from crop farming to livestock.
Sub-Saharan Africa	Changing rainfall and temperature	▪ Improved ground/vegetation cover ▪ Cross-slope measure ▪ Integrated soil fertility management ▪ Water harvesting

		▪ Pastoralism and grazing land management ▪ Agroforestry
Hungary	▪ Carbon removal ▪ Greenhouse gases.	▪ Planting a given area of windbreaks in between agricultural fields. can have similar climate change mitigation effects as planting forests in the same given area. ▪ Carbon sequestration at the farm level
Central Ethiopia	▪ Onset rainfall ▪ problem (51.18%) ▪ Rained after the perceived time (42.06%) ▪ Cessation rainfall problem ▪ (71.18%) ▪ Rain ends up before the perceived time (61.18%) ▪ Drought ▪ Flooding ▪ Temperature change	▪ Crop-diversification (51.47%) ▪ Improved crop varieties and input use ▪ intensity (62.65%) ▪ Adjusting planting date (45.59%) ▪ Soil and water conservation (49.12%) ▪ Changing of the crop type (50.59%)
Upper West Region of Ghana	▪ Unpredictable rainfall patterns ▪ Flooding ▪ Drought ▪ Rising temperatures ▪ Insect infestations	▪ Agricultural Ecological Intensification (AEI) ▪ Integrated cropping, soil, water, and nutrient management (ICSWNM) ▪ Incorporation of organic compounds like manure and crop residue ▪ Use of inorganic fertilizers ▪ Establishment of ▪ drainage channels and sunken beds in gardens ▪ Adoption of cover cropping for moisture conservation ▪ Ridges formation ▪ Crop rotation. ▪ Cover cropping.
Choke Mountain, Ethiopia	▪ Drought ▪ Floods ▪ Hailstorms ▪ Erratic ▪ Rainfall	▪ Climate smart agriculture approach ▪ Management of crop residue ▪ Compost ▪ Row planting. ▪ Agroforestry
Occitanie region in southwestern France	▪ Water scarcity ▪ Temperature increase	▪ Diversity in water sources ▪ Improve water storage. ▪ Irrigate winter crops. ▪ Use variety resistant to hydric stress. ▪ Return harvest residues to the soil. ▪ Increase irrigation efficiency. ▪ Plant cover crops.
Mecha areas in northwestern Ethiopia	▪ Temperature Variability ▪ Mean annual temperature exhibited a warming trend of 0.12 to 0.54°C per decade ▪ Rainfall decreased by 38 to 67mm per decade. ▪ Droughts happen every one to three years.	▪ Maize varieties with a low water requirement and high- temperature tolerance be planted. ▪ Optimal plant density and nitrogen fertilizer doses would be applied to shorten the maturity. time
Lowland farms, southern Ethiopia	▪ Increased floods ▪ Droughts	▪ Changing planting dates ▪ Crop diversification.

	▪ Erosion ▪ Increase in long-term temperature. ▪ Declining ▪ rainfall	▪ Drought-tolerant crops ▪ Tree planting alongside crops ▪ Practice crop rotation. ▪ Constructing soil and water conservation (SWC) structure ▪ Water harvesting for irrigation. ▪ Migrate to another area.
Wolaita Zone Ethiopia	▪ Maize vulnerability to climate change ▪ Reduced Soil Moisture ▪ Change in Rainfall patterns resulting in water stress. ▪ Drought and reduced productivity of Maize	▪ Conservation tillage ▪ Crop diversification. ▪ Drought-resistant maize variety ▪ Soil and Water Conservation (SWC) practices ▪ Mineral Fertilizers ▪ A combination of agroecological and technological practices
Bono East Region Ghana	▪ Rainfed agriculture is impacted by changes in rainfall patterns. ▪ Lack of timely access to weather forecast ▪ 16% increase in rainfall ▪ Reduced yield and destruction of crops	▪ Implemented a variety of Climate Smart Practices (CSA) ▪ Mixed farming systems ▪ Crop diversification. ▪ Use of transitional agroecological zones
Forest-Savana Ghana	▪ Variability in pattern and intensity of rainfall ▪ Increase in temperature. ▪ Increased number of droughts due to deforestation in the area ▪ Windstorms destroying crops	▪ Agro-chemical Adaptation ▪ Mulching (Using locally dried plant parts) ▪ Agroforestry approach ▪ Use of drought-resistant crops by 78% of the farmers ▪ 81% relied on mixed cropping of local and modern crop varieties.
Bangladesh	Drought	▪ Change in plantation dates. ▪ Use of short-duration wheat varieties ▪ Irrigation
Khumasi, Ghana	▪ Increase in average temperature over time. ▪ Change in pattern of rainfall (85mm decrease in rainfall)	▪ Mixed farming ▪ Plantation of trees, zero tillage, and contour ploughing ▪ Mulching and intercropping
Southern Ethiopia	▪ Reduced precipitation ▪ Increase in temperature. ▪ Frequent droughts, floods and storms	▪ 69.3% used improved seed variety. ▪ 19% used climate-specific varieties. ▪ Adjustment of plantation dates and row planting ▪ Low percentage of farmers employed agroforestry
Dire Dawa Eastern Ethiopia	▪ 18.3% variability in annual rainfall ▪ Overall change in the pattern of seasonal, monthly, and annual rainfall ▪ An average increase of 0.21 degrees in the last decade	▪ Soil and water conservation practices (100% of the farmers) ▪ 50% relied on planting drought-tolerant varieties while 45% changed their planting dates. ▪ Off-farm activities are also a common substitute used by farmers.

Central Region Ghana	▪ 19% variability in rainfall ▪ 1% variability in temperature	▪ Change in plantation dates. ▪ Use of drought-tolerant cocoa varieties ▪ Mulching, cover cropping and migration
Upper East Region Ghana	21.9% variability in rainfall and 1.4% increase in temperature from 2010-2020.	▪ Used various climate specific adoption strategies. ▪ Use of diversified crops (63%) ▪ Crop rotation (78%) ▪ Mulching, seed banking and change in plantation dates
Upper East Region Ghana	▪ Rise in annual rainfall (16% variation) ▪ Increased temperature with a variability of 1.2%	▪ 82% of farmers employed traditional agroecological practices including crop diversification and mixed farming. ▪ A small percentage relied on other practices like migration and off-farm strategies

While climate change and the threats it poses have affected many parts of the world, socioeconomically vulnerable groups—especially underprivileged and marginalized communities—are most affected. Several studies show that people living in rural areas of developing countries are especially vulnerable since their economic sustenance is based on climate-dependent natural sources. Forecasts of changes in rainfall patterns and temperatures suggest an escalation in extreme weather events, posing a threat to global efforts aimed at reducing poverty by undermining small-scale agricultural practices.

This systematic review was conducted to assess the agroecological practices and other adaptation strategies against climate change mitigation in agricultural systems. We screened 135 research articles, involving agroecological case studies as well. As an adaptation technique, we found that agroecological farming was often linked to improvements in crop yield, agricultural diversification, profitability, and the management of water and nutrients (Figure 3).Most of the evidence was relatedto the yield of primary crops. Secondary crop yields were often not reported or were aggregated. The focus on primary crop yield is consistent with a review of sustainable intensification studies on smallholder farms (Edouardo, 2020).

A successful adaptation strategy against climate change has been demonstrated by agroecological techniques, as evidenced by the patterns seen in this review. Landscape and farm diversification, intercropping, mixed farming, using drought-resistant and early maturing varieties of crop, mulching, use of transitional agroecological zones crop, pasture rotation, adding organic fertilizers, using cover crops, reducing or eliminating synthetic inputs and applying climate-smart practices were examples of agroecological approaches(Kerr, 2023).

There is evidence (IPCC, 2022) supporting adaptation to climate change as well as several co-benefits linked to systems and practices that follow agroecological principles; nevertheless, advantages and trade-offs may differ depending on social, economic and ecological situations.

In order to better comprehendthe global climate crisis and risks and the co-benefits of climate change mitigation and resilience, long-term quality research on farms andlandscapes is required, with agroecology being compared to its alternatives. This is because the analysis only provides modest evidence for mitigation and adaptation. Evidence like this can raise awareness about agroecology as a possible climate policy choice. Extensive studies utilizing inventive methodologies like participatory modeling, on-farm benchmark studies, and community-based research are imperative to comprehend the consequences of climate shift at various levels and enhance the ability to implement novel techniques. To accomplish environmental services and other climate change objectives on a wide scale without sacrificing useful services, policy research is also required.

Conclusions

This review explored the various adaptation strategies employed by farmers at different agroecological levels in the light of climate change. The findings showed that farmers around the globe have adopted several agroecological practices, such as crop rotation, conservation tillage, intercropping, and agroforestry, to deal with the effects of climate change, which include increased temperatures, droughts, floods, and unpredictable rainfall patterns. These techniques enhance adaptation at the farm level and help to diversify crops and sowing dates, protect against erosion, retain moisture, and increase soil organic matter.

By utilizing compost and manure, mulching, covering crops that fix nitrogen, and integrated livestock-crop systems, agroecology can be used to minimize emissions on farms. It was found that agroecological farming reduces emissions more economically than conventional farming practices.

The review did, however, also highlight some of the present barriers that have prevented agroecology from being adopted more widely. These barriers include a lack of legislative support for diversified agroecosystems, high upfront costs, unstable tenure, and a lack of farmer education. The research indicates that more training programs, incentives, financial support schemes, and the promotion of local agroecology-based value chains are needed to improve uptake among smallholder farmers who are most vulnerable to climate change.The findings highlight the need for supportive policies and laws in order to fully realize the benefits of agroecology's mitigation and adaptation on a global scale, especially with regard to smallholder agriculture's adjustment to the new climate reality. The results also support agroecology's potential as a climate-resilient farming strategy. Future research should evaluate approaches to integrate agroecology into the whole solution package for climate change-adaptive agriculture.

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