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Climate-smart cropping systems for resilient food production in Sub-Saharan Africa in the face of changing climate: a review

Eric Owusu Danquah[1*], Felix Frimpong[1,2], Abigail Addo-Danso[1], Patricia Amankwaa-Yeboah[1], Stephen Yeboah[1,2], Frank Osei Danquah[3], Kwame Obeng Dankwa[1], Kwesi Atta Senior Aidoo[1], Agbesi Kwadzo Keteku[1], Mary Otiwaa Osei Asante[1,3], Erasmus Narteh Tetteh[1,3], Richard Dormatey[1], Allen Oppong[1] and Benedicta Essel Ayamba[4]

[1] *CSIR – Crops Research Institute, Kumasi, Ghana*
[2] *CSIR – College of Science and Technology (CCST), Fumesua, Kumasi, Ghana*
[3] *Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana*
[4] *CSIR – Soil Research Institute, Kwadaso, Kumasi, Ghana*
* Corresponding author, E-mail: ericdany7@gmail.com or e.owusudanquah@cropsresearch.org

Abstract

As the global population is projected to reach 9.6 billion by 2050, the urgency for effective water management strategies that can support both ecosystems and food production is paramount. This article utilizes a systematic review to underscore the importance of water-efficient cropping systems in aiding small-scale farmers in navigating the intricate challenges of climate change. Sub-Saharan Africa is especially susceptible to climate change, with forecasts predicting a significant rise in average daily temperatures (1.5–2.5 °C) and increasingly unpredictable rainfall patterns by the end of the century. These factors threaten food security and the livelihoods of millions of farmers who are heavily dependent on rain-fed agriculture. Water-efficient cropping systems present a viable solution to these issues. Key strategies identified include crop diversification, the use of appropriate crop varieties, conservation (minimum/zero) tillage, traditional water harvesting techniques (Zai and Half-moon pits), and agroforestry. Crop diversification and the utilization of adapted crop varieties empower farmers to overcome the constraints of regions with brief rainy seasons and growing periods. These tactics bolster resilience to drought and boost overall crop performance. Conservation tillage practices aid in preserving soil health while retaining crucial soil moisture. Indigenous water harvesting techniques keep soil water and nutrients near crop roots, markedly enhancing crop production in difficult environments. Agroforestry, the practice of integrating trees into farming landscapes, provides numerous advantages, including shading, erosion prevention, and improved moisture conservation. These approaches contribute to both sustainable crop production and environmental sustainability, addressing Sustainable Development Goals (SDGs) of 1 (no poverty), 2 (zero hunger), and 13 (climate action).

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Introduction

Agriculture, a critical human activity for survival, is significantly impacted by climate change. The global hydrological cycle and water resources are affected by factors such as population growth, urbanization, and increased food demand and consumption, making the sustainable management of water resources a formidable challenge[1,2]. Although 25% of the world's arable land is in sub-Saharan Africa (SSA), with about 85% of Africa's water withdrawn for agriculture, SSA contributes only 10% to the global agricultural output[3]. Therefore, efficient water management and utilization are essential for maintaining ecosystems and food production to feed the anticipated 9.6 billion global population by 2050[4].

General Circulation Models (GCMs) used for climate change predictions have indicated a substantial increase in regional and global average daily temperatures and a decrease in precipitation by the end of the 21st century, which is expected to affect freshwater resources and agricultural productivity[5]. Africa, particularly its rural population, has been observed to be especially vulnerable to climate change[6,7]. By mid-century (2050), rainfall is projected to decrease by 10%, resulting in reduced crop productivity. Meanwhile, over 70% of the workforce in SSA is employed in the agricultural sector, contributing about 15%–20% of the Gross Domestic Product (GDP). Approximately 93% of land cultivated by smallholder farmers in SSA for food relies on rain-fed agriculture. This supports the strong correlation between agricultural productivity, food security, and rainfall in SSA[8,9]. Although recent food production in Africa has seen considerable growth, and rapid population growth in the same region has offset all the gains, leading to poverty, food insecurity, and malnutrition[10]. To adequately feed Africa's population by 2050, when the global population is expected to peak, the current food production must increase fivefold[11,12]. Therefore, Africa's future hinges on improving and sustaining food production, which also depends on water resources mainly from rainfall. Using multi-ensemble GCMs and the Soil and Water Assessment Tool (SWAT) hydrological model, an increase in rainfall uncertainty and drought events in Africa was observed[13]. Sub-Saharan Africa has been observed to have the lowest water use efficiency, with a current and projected water use efficiency of 22% and 25% respectively[14]. It is projected that about 40% of the world's population will live in areas of severe water stress due to a 55% increase in global water demand[15]. This indicates severe implications for sustainable water resources management, food production, and security.

Addressing the future's highly variable and uncertain rainfall patterns requires smallholder farmers to adopt agricultural technologies that allow them to adapt to climate change, ensuring sustained ecosystem services while enhancing food productivity. This article examines water-efficient cropping technologies that facilitate the effective use of available rainwater in the soil for better adaptation to climate change. Thus, water-efficient technologies ensure optimum conversion of the available soil water to crop productivity. Approaches to cropping systems such as minimum/zero tillage, crop diversification, the planting of adapted crops and varieties, agroforestry, and traditional water harvesting practices are explored. The importance of a supportive policy and environment to facilitate the adoption of these technologies is also emphasized. Since climate change and water resources management are global issues, in line with the SDGs, this paper adds guidelines for the facilitation of local and international collaboration and knowledge sharing to address global water resource challenges.

Search methodology and quality appraisal

The methodology of the review utilized in this manuscript corresponds with that of Khan et al.[16]. The approach to searching for climate-resilient crop production technologies was not strictly delineated. The research inquiries raised were as follows: What are the patterns in crop production and their ramifications on food security in Sub-Saharan Africa? Are there novel climate-resilient crop production technologies accessible? How might these technologies contribute to climate change mitigation, adoption, and food security? What impact does a conducive policy environment have on the adoption of these technologies (see Fig. 1)?

The Population, Intervention, Comparison, Outcomes, and Study (PICOS) framework was employed to establish eligibility criteria in the systematic review. The search concentrated on English-language, current (2011−2023) peer-reviewed articles, book chapters, books, and reputable websites focusing on climate change and food production, climate-resilient cropping systems, soil fertility management, crop physiology, and sustainable soil water management in agriculture. The key themes utilized in the search encompassed crop production in SSA, water-efficient/resilient and climate-resilient crop production, strategies for mitigating climate change, and food security. The evaluation of the quality of the retrieved papers adhered to the standards established by the Center for Internet Security (CIS)[17].

The literature exploration assessed original research articles on erratic precipitation (abrupt droughts and floods) and their influence on crop production and food security. Works authored by experts for professional purposes on effective soil moisture management for sustainable crop yield were also consulted. A total of 76 scholarly articles constituted the foundation of this review. These were gathered from traditional search engines and research repositories such as Google, Google Scholar, Web of Science, ResearchGate, etc. The search terms encompassed water-resilient cropping systems; crop yield and drought; crop yield and flood; climate change and food security; approaches to soil conservation, drought, and traditional water preservation methods; food security and climate change, among others. Additionally, personal collections and literature relevant to the review subject at the CSIR – Crops Research Institute library repository were utilized.

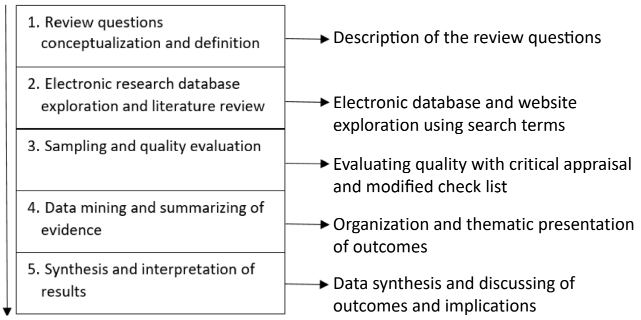

Fig. 1 Steps used in literature search for the current review paper.

Results

Climate change and future food production in Sub-Saharan Africa

Climate change-induced variability is expected to result in inconsistent and diminished rainfall, leading to a decline in food production under rain-fed crop production systems, which are characteristic of smallholder farmers in Africa. An escalation in pests and diseases would further exacerbate the situation by reducing crop productivity and farmers' income[18−20].

Maize, a globally significant cereal crop that serves as a staple food for over 4.5 million people, is projected to decrease by 45% by the end of the century due to climate change[21]. The reduction in maize productivity would be more severe in SSA. A decline in yield resulting from climate change is anticipated, as 58% of the area currently under maize cultivation would be lost in SSA[10]. Despite maize being primarily produced on a small scale and predominantly under rain-fed conditions, it is a principal staple food crop, providing about 45% of the food calories for the population in SSA. However, despite maize's crucial role, its yield is the lowest and continues to stagnate[22,23]. Sorghum and millet, other essential staple cereals for food security, particularly in the Sahelian region (Mali, Niger, Burkina Faso, and northern parts of Senegal), are also under serious threat. Crop simulation models have predicted a yield decline of more than 41% for both crops due to increased daily temperatures and reduced erratic rainfall[12,24]. A 27%–48% decline in yam yields due to rising temperature and variable rainfall in West Africa has been projected[25]. Climate change provides a conducive environment for virulent pathogens such as nematodes, bacteria, and fungi on crops, especially yam, leading to losses in the stagnating yield[26,27]. Thus, climate change would hinder yam production along the West African yam belt[28,29]. Similarly, cassava, another important staple root and tuber crop of the SSA region is projected to decline in productivity with decreasing rainfall and increasing daily temperature resulting from climate change[30]. Vegetables, which most smallholder farmers rely on for readily available cash and household nutrition (vitamins such as A, C & E, and micronutrients such as zinc, iron, folic acid, boron, etc), are also dwindling as a result of climate change. The increasing temperature and reduced soil water variability, salinity, and flooding are the major factors impeding sustainable vegetable production[31]. In addition to the high risk of crop failure, the changing climate presents a favorable environment for pests and diseases, resulting in reduced vegetable quality and farmers' profit[32,33].

Therefore, there is a need to employ crop and soil management approaches such as conservation (minimum/zero) tillage, crop diversification, agroforestry, and Indigenous water harvesting practices to enhance adaptation to climate change, as shown in Table 1.

Conservation tillage and soil moisture conservation

Conservation tillage is a practice that involves tilling or planting in a way that retains at least 30% of plant biomass cover on the soil surface. This includes forms such as zero tillage, no-tillage, mulch tillage, and ridge tillage[12,34]. Recently, minimum/zero tillage, a cultivation method involving little to no soil disturbance from one season to the next has garnered significant attention[35]. The goal of conservation tillage is to preserve soil and moisture by minimizing losses from the soil, thereby enhancing crop productivity. Implementing minimum tillage and maintaining straw on the soil surface led to a 49.78% increase in wheat grain yield compared to

Table 1. Selected list of climate-smart research with major findings.

Climate-smart practice	Study area	Major findings	Ref.
Conservation tillage and soil moisture	Agronomy and soil	No-till with organic biomass on the soil surface improved soil moisture retention, carbon sequestration potential and better enhanced soil productivity	[36,38,39]
Crop diversification	Cropping systems	Crop diversification improves suppression to weeds, pest and diseases in cropping systems. It improves the overall productivity of the system and improves resilience to climate change	[46,48,50]
Adapted crops and varieties	Breeding and crop improvement	Breeding for fast yielding varieties and as such harsh climate escaping varieties or climate change tolerate varieties would improve resilience and productivity	[55,53,57]
Agroforestry and soil moisture conservation	Tree-Crop interaction	Integration of agroforestry trees into cropping systems improves soil moisture retention and nutrition. This improves the systems productivity and adaptation to climate change	[65,66,67]
Indigenous water harvesting approaches	Sociology	Traditional ecological knowledge practiced by smallholder farmers and handed over to their generations such as planting in pits (Zai and half-moon), intentional residue on the field etc improved soil moisture availability for crop productivity	[69,72]

traditional tillage methods[36]. This improvement was attributed to the retention of field residue, which boosted soil moisture, decreased bulk density, and enriched soil nutrition[37,38], fostering a conducive environment for root growth and nutrient absorption, and consequently, improved crop productivity.

Severe droughts caused by increased soil temperatures are projected impacts of climate change on crop production in SSA. Conservation tillage, specifically minimum/zero tillage that retains residue on the soil, is a climate-smart strategy for enhancing resilience to climate change[39,40]. It was observed that soil moisture retention was better with conservation farming than with conventional farming[40]. Soil moisture retention further improved when residues were retained on the soil in the form of biochar. Additionally, the soil temperature remained lower for a longer duration under conservation farming with biochar residue, followed by conservation farming and conventional farming. On highly weathered soils of West Africa, conservation tillage combined with residue incorporation promoted soil moisture retention, leading to enhanced soil nutrition properties and nitrogen (N) use efficiency in crops, particularly cereals[41]. Under rain-fed conditions, conservation tillage is the preferred option for enhancing soil moisture for improved maize productivity in semi-arid Zimbabwe compared to conventional tillage[42]. When comparing conservation tillage (no-till) and conventional tillage, a greater yield response was observed with conventional tillage than no-till under certain conditions[43]. However, the authors also indicated that the use of conservation tillage (no-till) with residue retention and crop rotation compensates for the negative impact of no-till, resulting in high long-term crop productivity. Thus, no-till with residue retention and crop rotation is suggested to be the best option for soil moisture conservation for rain-fed cropping systems, serving as a crucial adaptation strategy in the face of changing climate. In addition, the trade-off of using crop residue as livestock feed versus use, as mulch, is another challenge that needs to be addressed. The suggestion is that an intensive system that ensures high biomass production and efficient recycling of biomass between livestock and crop production would promote residue retention in the field and enough to feed livestock[44]. Therefore, tillage practices that encourage residue retention on the field reduce moisture loss through evaporation and runoff, resulting in moisture conservation for the benefit of the crops.

Crop diversification

Crop diversification is the practice of integrating novel crops or cropping systems into the agricultural production of a particular farm, considering various root systems for resource utilization and the benefits from value-added crops with supplementary marketing prospects[45]. This approach enriches the diversity of a simplified cropping system across time and space by integrating extra crops[46]. Strategies for diversifying crops encompass crop rotation, multiple cropping, bee crops, nurse crops, variety mixtures, and intercropping. Various factors like increasing income on small farm plots, alleviating the impacts of climate change, balancing food requirements, reducing environmental contamination, and improving community food security all contribute to the acceptance of crop diversification[44].

The diversification of crops can be accomplished by incorporating new crops into an existing cropping system either through temporal diversification, like prolonging continuous cultivation of a single crop or crop rotation, or through spatial diversification, for instance, intercropping, mixed cropping, or companion cropping[46]. Common crops utilized in crop diversification encompass cereals, pulses, fodder legumes, grasses, field vegetables, and flowers, either individually or in combination[46].

Farmers employ various strategies for crop diversification, which are correlated with the attributes of their agricultural households, such as farm size, and the age, gender, and educational background of the farm household heads[47]. For instance, larger farms are more likely to have a greater diversity of crops, younger farmers plant more crops, and female-headed households plant more crops, while farmers with higher educational levels have less diversified crops. Very poor households have limited diversification due to barriers such as market availability and extension support for non-staple foods and perceived higher risk levels of diverting scarce land away from staple foods, although the financial rewards of crop diversification are typically most significant for the most impoverished farmers[48]. High-capital farmers also diversify less because the economic returns of specialized farming systems may be higher for such households. However, crop diversification offers immense benefits, to most deprived farmers and their households, who are particularly susceptible to climate variabilities and extreme weather events. Moreover, poor farm households have limited capital for investment in costly adaptation strategies, increasing their vulnerability to changing environments[49].

Crop diversification offers several strengths, such as providing farmers with alternative income-generating sources, so they do not have to rely on a single crop. It enhances pest and disease suppression through weed suppression, reduction in pathogen transmission, and their operations[50−52]. It also diversifies production, reduces production costs and improves the resilience of crop production to climate change. There is increased natural biodiversity for an improved and resilient agroecosystem. Diversified crop production enhances the overall productivity of the system and encourages the harvest of new products such as medicine from associated crops. This results in improved farmers' income and livelihoods[45,48,49,52,53]. Despite these merits, crop diversification has the limitation of difficulties in obtaining high yields per crop, especially at the initial stages of the system. There is even the possibility of risk of poor economic returns in situations where crops are selected without market assessment[46,51].

Adapted crops and varieties

The process of transitioning to crop species or varieties that can withstand climatic stress is referred to as the use of adapted crops and varieties, or crop adaptation[54]. One approach to dealing with drought is to breed for drought tolerance, which aids in the provision of adapted genotypes[55]. As compared to susceptible varieties, adapted crops, and varieties can result in reasonable yields even under adverse conditions[56]. The European Environment Agency (EEA) states that the costs associated with the use of adapted crops and varieties depend on the prices of the seeds used and whether significant structural changes to the farm's production would necessitate large investments by farmers[53]. In stress environments, such as drought situations, the use of adapted crops and varieties may involve the use of traditionally diverse and adapted varieties, as well as drought-tolerant, drought-escaping, and drought-avoidance strategies[55,57]. To some extent, crops have developed drought-tolerant, escape, and avoidance strategies over time as adaptation methods that help them mitigate the adverse effects[57]. Drought-tolerant crops can withstand water shortages either by becoming dormant and resuming growth and development when water is available or by having deep rooting systems that can absorb water from deeper soil depths. Drought-escaping crops have short growth cycles and mature quickly before all the soil's water is used up, or they have rapid development, which aids them in completing their life cycles before drought stress. This strategy is used by plants in conditions where there is likely to be water limitation late in the growing season. Drought avoidance crops enter a phase of slow growth associated with small or closed stomata with reduced photosynthesis and low cell metabolism[58,59].

The use of adapted crops and varieties presents significant benefits to farm productivity and adaptation to stressed environments, but it may not be easily adopted by smallholder farmers (especially those genetically bred) due to its capital intensity. The lengthy periods involved in their release also present a disincentive challenge. Therefore, more innovative and faster strategies are needed to ensure they are bred, tested, delivered, and adopted quickly, most importantly, by poor farmers who seem to be at the highest level of the vulnerability curve. For instance, backing policies can be used to provide infrastructure and incentives for adoption.

Adopted varieties have the strengths of increasing yields, enhancing drought resilience, and contributing to food and nutrition security. It enhances farmer resilience to climate change and improves income generation sources, which is key to SDGs 1 (no poverty), and 13 (climate action). It serves as an opportunity for increasing plant genetic diversity to enhance ecosystem diversity. It provides an avenue for the storage of carbon in the trees and soil, thus serving as a climate change mitigation measure. However, it comes with the demerit of involving a longer period of breeding, testing, delivery, and adoption processes. In addition, huge financial resources are required[53,54,56,60,61]. The use of adapted crops, crop diversification, and varieties helps agricultural systems cope with or reduce the negative effects of climate change and extreme climate events such as droughts and ensure stable agricultural production[53]. The European Environment Agency (EEA) also notes that crop diversification and the use of adapted crops are among farm-level adaptation strategies used to cope with extreme climate events, with some of the other strategies being precision farming, use of cover crops, no-tillage, improved animal rearing, and the installation of greenhouses.

A simulation study suggested that stress-tolerant crop varieties could offer benefits to farmers in the face of changing climates. However, it cautioned that these benefits can vary depending on the current climate, soil properties of the production environment, and the extent and nature of future climate change[57]. This implies that stress-tolerant crops and varieties should not be adopted indiscriminately; the prevailing climate and soil conditions should always be evaluated in conjunction with their use. Farmers, learning from past experiences with extreme weather events, adopt crop diversification in subsequent years to mitigate risks[47]. Utilizing crop diversification to cope with droughts can be viewed as a risk-spreading strategy to prevent the loss of an entire farm's production, given the varied responses of different crops to weather and climate[53]. The selection of crop varieties resistant to harsh climates enables agricultural activities to persist, even in extreme climate scenarios that are unexpected due to severe climate variability resulting from climate change or expected according to seasonality[45]. For instance, simulation studies on SAMMAZ-16 and SAMMAZ-26, non-drought and drought-tolerant varieties in Nigeria, showed that even under the worst conditions, SAMMAZ-26, the drought-tolerant variety, would retain about 1%–6% of its yields compared to the non-drought tolerant (SAMMAZ-16)[62]. The most effective strategy to cope with climate change is the use of species and varieties bred to withstand conditions imposed by climate limiting factors[53]. For example, crops with drought-escaping traits are used to ensure that crops can complete their life cycles quickly under favorable conditions[59]. However, caution is needed when replacing diverse and adapted traditional crop varieties with genetically narrow base genotypes, as these have significantly affected agricultural production systems[63]. Instead, a wide range of genetic resources is recommended as useful in developing drought-adapted varieties. The authors also note that the wild relatives of crops are excellent sources of genes for developing drought-adapted crops. For the effective use of crop diversification and adapted crop environments, it should be accompanied by a comprehensive package of complementary technologies such as nutrients, water, and locally appropriate carbon management[61]. The implementation of supporting policies and procedures, such as the Common Agricultural Policy of the European Union and the National and Regional Rural Programmes is recommended.

Agroforestry and soil moisture conservation

Agroforestry encompasses all land-use practices that integrate the cultivation of trees and shrubs with food crops and/or livestock, fostering interactions that enhance and boost productivity[64]. The management of interactions between food crops, trees/shrubs, and livestock is crucial in facilitating resource use within the agroforestry system. Agroforestry presents a cost-effective technological solution for mitigating and adapting to climate change[65]. This is because, in the context of climate change, the integrated trees/shrubs serve a dual purpose by conserving moisture through shading and providing food and income to smallholder farmers. A study conducted on rubber-plantain intercropping systems in two locations (Ellembelle and Jomoro) in the Western region of Ghana demonstrated that increasing plantain density enhanced the total soil moisture in the topsoil (0–30 cm) of the rubber-plantain cropping system (Fig. 2)[66]. This improvement is attributed to the microclimate shade conditions created by the rubber and plantain leaves, which reduced soil moisture loss from the system. Additionally, weed suppression facilitated resource use, benefiting both plants.

An assessment was also conducted on the impact of shade and pruned biomass on moisture retention in the ridges of yam in a pigeon pea-yam cropping system in Ghana[67]. The findings

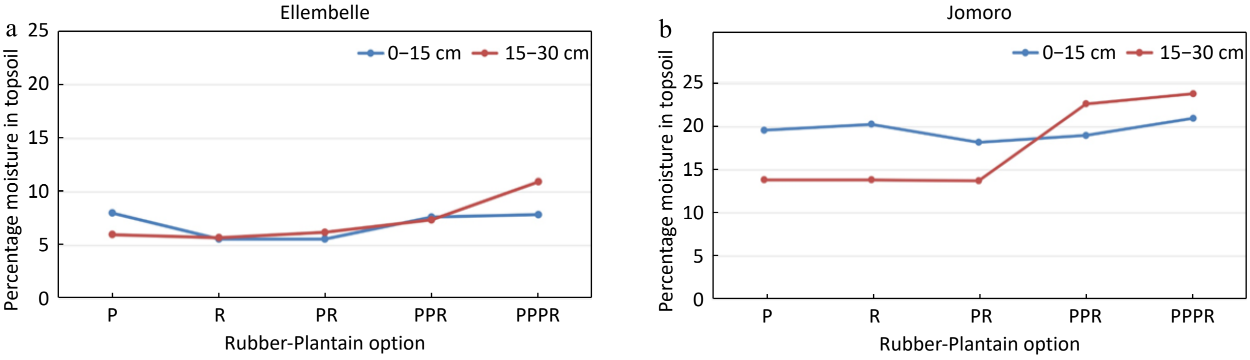

Fig. 2 Soil water (moisture) percentage in the topsoil as influenced by the Rubber-Plantain intercropping system options. (a) Ellembelle, (b) Jomoro, (P, R, PR, PPR, and PPPP are sole plantain, sole rubber, low-density plantain, medium density plantain, and high-density plantain respectively in the Rubber-Plantain intercropping system) Adapted from Tetteh et al.[66].

suggested that incorporating the pigeon pea and its biomass into yam production enhanced moisture retention on the ridges, benefiting the yam. The shade and pruned biomass from the pigeon pea on the yam ridges reduced water loss and increased moisture retention on the ridges (0–30 cm), leading to improved yam productivity (Fig. 3). Therefore, the arrangement of trees/shrubs in cropping systems can be managed to ensure moisture availability for crop growth, thereby enhancing productivity.

Indigenous water harvesting approaches

Smallholder farmers possess Indigenous knowledge and experience, cultivated through oral traditions and experiential learning passed down through generations, enabling them to adapt to their societal and environmental contexts. Due to the uncertainties in rainfall patterns brought about by climate change, communities in semi-arid and arid regions employ Indigenous rainwater harvesting techniques for food production[7,68]. In the Sahel regions of West Africa (Mali, Niger, and Burkina Faso), the practice of planting in pits (Zai and half-moon) is commonly used as a climate-smart strategy for water and soil conservation for cereal such as Sorghum and millet production[69,70]. The Zai and half-moon pit planting methods involve digging pits for water collection before planting. In the case of Zai pits, a pit of about 20–40 cm in diameter and 10–15 cm in depth is used, while the half-moon method involves a semi-circle pit with about 2 m in diameter. Organic manure such as compost, farmyard manure from plant residue after harvest, animal manure, etc., are added to the pits to enhance soil fertility[7,71]. This approach not only conserves soil moisture but also promotes soil conservation by preventing soil erosion. A study conducted in the Bhai district of Tanzania, where rainfall is relatively low and unpredictable, revealed that farmers utilized the Indigenous water harvesting approach of hanging pieces of cloth at the edges of the roof to collect and direct water into buckets for domestic and agricultural use[72]. Additionally, water is collected from open spaces that gather water after rains, as well as from shallow wells dug at riverbanks for water collection during dry seasons. This approach has been enhanced with the use of plastic covering material or by cementing the rooftop for the harvesting of rain into cisterns. This represents an Indigenous climate-smart strategy to ensure water availability for domestic and agricultural use in the face of climate change.

Enabling policy environments for smart-water production

To motivate smallholder farmers to adopt water and soil conservation technologies that facilitate adaptation to climate change, it is essential to establish an enabling policy environment. Assessment and ownership of land are crucial in the implementation of soil and water conservation technologies. Security of land tenure and full rights to land resources are among the main factors identified as vital for the adoption of soil and water conservation practices[73,74]. The integration of trees/shrubs into cropland to provide mulch to cover the soil and serve as shade requires years to mature and necessitates long-term land ownership to realize these benefits. Land renting by migrating households is a significant characteristic of smallholder farming in most countries of SSA, making farmers hesitant to make long-term investments that would enable soil and water conservation[75]. Policies that promote land ownership by smallholder farmers would enhance the adoption of long-term measures that would improve soil moisture conservation. Encouraging crop diversification among smallholders while simultaneously promoting crop specialization for medium to large-scale farmers would require policy support. A preliminary feasibility study noted

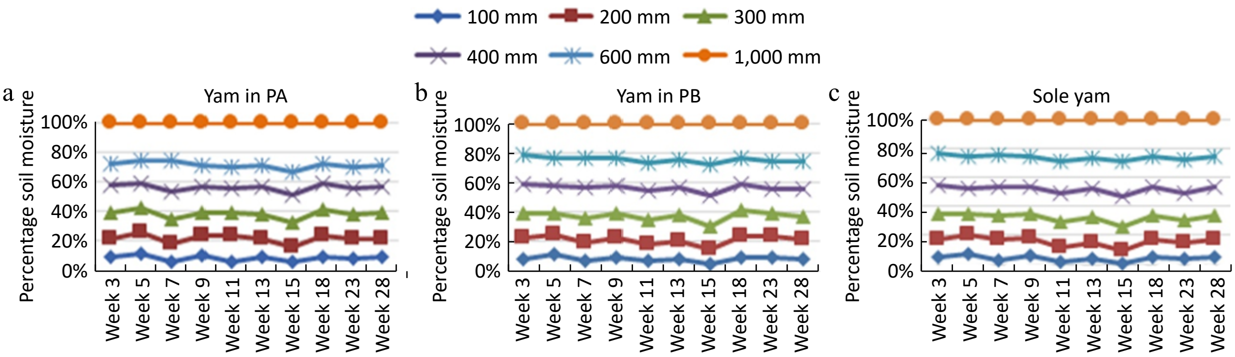

Fig. 3 Soil moisture over time through the soil profile as influenced by pigeon pea-yam cropping system. Adapted from Owusu Danquah[67]. (a) PA-yam in alley of pigeon pea; (b) PB-yam with pigeon pea as border; (c) Sole yam.

that robust market research is crucial to guide policy direction on the practice of crop diversification to avoid overproduction or market unavailability[45]. Smallholder farmers who adopt soil and moisture conservation technologies but have to sacrifice their production, especially at the initial stages, should be compensated to serve as an incentive for adoption[76,77]. The adoption of these climate-smart technologies by smallholder farmers would enable farmers to adapt to climate change for sustained food production.

Conclusion

Crop production and food security in Sub-Saharan Africa rely heavily on weather patterns, given that a significant portion of smallholder agriculture is dependent on precipitation, the impact of climate change results in a continuous decline in crop yields, intensifying the issue of food insecurity. Hence, there is a pressing requirement for the implementation of water-efficient technologies to address and adjust to climate change. Essential soil and water conservation methods like cover cropping, conservation tillage, and agroforestry play a vital role in this context. The enhancement of traditional water retention practices, such as Zai and half-moon pits, aids in preserving soil moisture and nutrients in proximity to crop roots, thereby enhancing the efficiency and productivity of crop cultivation. Recognizing and remunerating farmers for their ecological contributions to sustainable food production would be advantageous. Thus, payment to farmers for environmental services or ecological contributions is provided by the adoption of climate-smart technologies and practices. Collaborative actions by governmental and non-governmental entities in advancing these initiatives will significantly support climate change adaptation and agriculture/farmer resilience efforts. Consequently, establishing supportive policies and frameworks for the adoption of these water-efficient technologies holds paramount importance. The policy and framework can be a standard for quantifying farmer climate-smart technologies and practices to serve as a basis for payment of compensation to farmers. Climate change is a global issue, therefore collaborations among local (farmers, communities, farmer-based organizations, agriculture extension officers, etc.), and international (CGIAR institutions, FAO, donors organizations, etc.) stakeholders would ensure a participatory and holistic approach towards improving agriculture's resilience to climate change. The Climate-Smart cropping system is a step towards sustainable intensification of food production by smallholder farmers amidst changing climate. This would enhance food security in line with the Sustainable Development Goals 13 (climate action), 2 (zero hunger), and 1 (no poverty) to foster global progress.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design, draft manuscript preparation: Owusu Danquah E, Frimpong F, Addo-Danso A, Amankwaa-Yeboah P, Yeboah S; manuscript revision: Danquah FO, Dankwa KO, Aidoo KAS, Keteku AK; manuscript editing: Asante MOO, Tetteh EN, Dormatey R, Oppong A, Ayamba BE. All authors contributed with literature review, read, editing, and approved the final manuscript.

Data availability

The data that support the findings of this study are available in the [NAME] repository. These data were derived from the following resources available in the public domain: [list resources and URLs].

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Conflict of interest

The authors declare that they have no conflict of interest.

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