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Sustainable Agriculture and Climate Resilience in Sub- Saharan Africa

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Abstract
Sustainable Agriculture is a farming approach that in the long run and it improves the quality of the environment and the foundational resources that agriculture & livestock rely on. It fulfils fundamental human needs for food and fiber ensuring economic viability while also promoting the welfare of farmers and society as a whole (ASA, 1989). Sustainable agriculture operates within the limitations of both physical and biological resources as well as the socio-economic aspects and overall quality on the other. Sustainable agriculture is not only a method of farming but also a philosophy. Based on a set of principles, it reflects an understanding of ecological and social realities, coupled with a commitment to respond effectively to this understanding. It places significant emphasis on establishing and sustaining farming techniques that are compatible with the environment's natural processes to conserve all resources, minimize waste, and reduce environmental harm, all while sustaining and enhancing farm productivity (Mac Rae et al., 1990). Sustainable Agriculture faces the huge challenge of meeting increasing food demands while simultaneously reducing its environmental footprint and meeting sustainability goals. Climate change is a major risk to sub-Saharan Africa and the southern Africa region in particular. This study explores the critical intersection of agriculture, climate change, and sustainable development in Africa. It emphasizes the urgent need to strengthen agricultural sectors to ensure food security, alleviate poverty, and address climate change's looming threat. The research involves a literature review methodology, analyzing climate change trends and their impact on

food security through both qualitative and statistical analysis. It also includes the creation of a customized climate change adaptation framework for Africa. Sustainable agriculture emerges as a key solution to address challenges such as soil degradation in Africa's diverse agricultural landscape. Climate change is driven by greenhouse gas emissions, significantly affects the continent's agriculture & livestock production. Strategies like diversification, ecosystem-based adaptation and technology adoption are recommended. Government policies, climate advisories, and sustainable agriculture initiatives play significant roles. The study concludes by pin-pointing the significance of collaboration, innovation and investment to dynamize Africa's agriculture against climate change and its effects leading to a more secure and prosperous future.

***Keywords**: Climate Change, Climate Resilient, Sustainable Agriculture, Diversification, Ecosystem-Based Adaptation, Sub- Saharan Africa.*

Introduction

Sub- Saharan African nations with their rich natural resources and vibrant viable cultures stand at a crossroads of an astronomical opportunity and profound constraints. At the heart of this segment lies agriculture which is an indispensable cornerstone of Africa's past, present, and future. These nations envisage an urgent imperative to fortify their agricultural sectors, not only to ensure food security for burgeoning populations, but also to address poverty and to confront the formidable specter of Climate change and Climate change poses a significant threat to Africa's development and economic growth, with significantly devastating consequences across all sectors of the economy (Erezi and Ehi, 2023). This looming risk is particularly evident in the context of food security, as Africa's limited capacity to adapt to climate-related challenges leaves it much more vulnerable. Despite the rapid growth of the population in sub-Saharan Africa, which is expected to more than double to 2.0 billion by 2050 (Bongaarts 2009), the positive aspects of this demographic shift, driven by advancements in healthcare technology, are countered by increased pressure on agricultural land and forest resources (Brandt et al. 2017). To mitigate these environmental risks and ensure food security, a concerted effort is needed to align technology and policies accordingly and appropriately.

Additionally, it is significant that the majority of hungry individuals who are mainly in abject poverty are concentrated in developing nations especially within Africa (Abegunde et al. 2019). The United Nations Framework Convention on Climate Change (UNFCC 2006) recognizes that the poorest communities in developing countries, are reliant on natural resources and rain-fed agriculture for their livelihoods, are the most vulnerable to climate change impacts. It is important to acknowledge that agriculture remains the primary source of employment for rural residents in Africa, as evidenced by various studies (e.g., Kalungu and Leal Filho 2018; Belay et al. 2017; Mutunga et al. 2017; Lembani 2020; Cobbinah and Anane 2016). The interconnectedness of these issues is undeniable. Food security defined as the consistent access to sufficient, safe, and nutritious food for all individuals, is a fundamental human right. Yet, across Africa, millions still grapple with hunger and malnutrition. Simultaneously, poverty's stubborn grip persists, exacerbated by the vulnerability of many African economies to global market fluctuations. In this intricate web of challenges, agriculture emerges as a potent agent of change for the people.

Globally, smallholder farmers are considered to be especially susceptible to the effects of climate change. This susceptibility arises from the fact that alterations in temperature, rainfall patterns, and the occurrence of extreme weather events directly impact their agricultural and livestock yields (Vignola et al. 2015). The vulnerability of these smallholder farmers is a pressing concern due to their substantial representation, accounting for 85% of farmers worldwide and supplying over 80% of the food consumed in developing regions. Consequently, the fate of smallholder farmers holds significant social, economic, and environmental implications on a global scale (Vignola et al. 2015). If empowered and operating at peak efficiency, their sheer numbers have the potential to substantially combat food insecurity (Abegunde et al. 2019). However, their vulnerability, particularly in the face of climate variability in Africa persists due to limited resources, inadequate skills, and a lack of supportive government policies. To mitigate the impacts of extreme weather events, especially on rural smallholder farmers who depend heavily on climate-sensitive agriculture (rain fed), climate change adaptation measures have become imperative (Cobbinah and Anane 2016).

The continent of Africa especially the Sub- Saharan African nationals are on the brink of a significant food security crisis in the coming decade due to its limited ability to cope with the increasingly severe climatic conditions brought about by climate change including droughts, floods and high temperatures (Abegunde et al. 2019). According to a special report from the IPCC, a 2 °C temperature increase could worsen food shortages, causing a 50% drop in rain-fed crop yields in certain African countries by 2020 (IPCC 2018). This growing concern over the present and future impacts of climate change has led to a surge in scholarly research on climate change adaptation (Cobbinah and Anane 2016; Burnham and Ma 2016; Lasco et al. 2014) and its integration into national policies and international discussions (IPCC 2007, 2013).

Addressing the challenges posed by climate change necessitates a continual development of new adaptive strategies and the enhancement of existing ones, with a focus on encouraging their widespread adoption by smallholder farmers (Kalungu and Leal Filho 2018). Therefore, it is crucial to align adaptation initiatives with the unique realities of Africa. Recent studies have emphasized the positive connection between public response and smallholder farmers' capacity to adapt to climate change in sub-Saharan Africa (Abegunde et al. 2019). Nonetheless, there remains a gap in critically assessing the role of existing climate change adaptation policies in facilitating the adoption of these initiatives. This chapter's objective is to examine the spatial and temporal trends of the food crisis in Africa and the adaptive measures in place, with the aim of devising a framework for a climate change adaptation pathway tailored to the continent's specific needs.

Research Methodology

The research adopted a literature review approach drawing from a wide range of sources such as; government reports, academic journals, and climate datasets. The primary focus was on investigating climate change trends and food security indicators in the Sub- Saharan Africa. The collected data underwent both statistical and qualitative analysis enabling the identification of how climate change affects food security. Additionally, the study encompassed a thorough enquiry of existing research related to climate change adaptation in Sub- Saharan Africa. Using the insights

gained from this data and literature, a custom-tailored climate change adaptation framework was formulated for Sub- Saharan Africa considering the region's ecological and socio-economic variations.

Literature Review; Sustainable Agriculture in Sub- Saharan Africa

Sub- Saharan Africa's agricultural landscape stands out for its remarkable diversity, encompassing a wide range of ecosystems, varying climate zones, and a multitude of smallholder farming systems (Jones, 2018). Within this complex environment, sustainable agricultural practices have emerged as a promising solution to tackle pressing challenges that threaten food security and livelihoods across the continent. One significant issue that sustainable agriculture addresses is soil degradation. Prolonged and intensive agricultural practices can deplete soil nutrients and reduce its fertility, jeopardizing long-term productivity. Sustainable farming methods, such as crop rotation, cover cropping, and reduced tillage, help combat soil degradation by maintaining soil health and structure (FAO, 2015). Water scarcity is another critical concern in many African regions due to erratic rainfall patterns and increasing water demand. Sustainable agricultural practices emphasize efficient water management techniques like drip irrigation, rainwater harvesting, and the cultivation of drought-resistant crops. These strategies enable farmers to optimize water use and adapt to changing climate conditions (Mbilinyi et al., 2013). The overuse of chemical inputs, such as synthetic fertilizers and pesticides, has detrimental effects on both the environment and human health. Sustainable agriculture promotes organic and integrated pest management approaches that minimize chemical reliance. This reduces the pollution of water bodies and promotes safer food production practices (Pretty et al., 2018).

Recent studies have provided empirical evidence of the advantages of sustainable farming methods. These benefits include:

Improved soil health is a cornerstone of sustainable agriculture, offering a range of benefits that can significantly enhance agricultural productivity and environmental sustainability. Sustainable farming practices have been shown to promote soil health by increasing organic matter content, enhancing soil fertility, and improving its physical structure. These improvements have a direct impact on crop yields and the overall resilience of agricultural systems. One of the fundamental aspects of sustainable agriculture is the incorporation of organic matter into the soil. This is typically achieved through practices such as cover cropping, the use of organic amendments (e.g., compost and manure), and reduced tillage. These practices introduce organic materials rich in carbon into the soil. As these materials decompose, they become a source of stable organic matter, increasing the soil's organic carbon content (Lal, 2004). Agriculture is not just about growing crops; it can also be a tool for promoting biodiversity and supporting ecosystems. Sustainable farming practices often emphasize the importance of planting a variety of crop species and preserving natural habitats within and around agricultural landscapes. This approach brings several ecological benefits. Sustainable farming systems tend to be more robust in the face of climate-related challenges. Crop diversity and improved soil health provide a buffer against extreme weather events and changing precipitation patterns (Vermeulen et al., 2012).

Efforts to Acclimatize to Climate Change in Sub- Saharan Africa

It is imperative to state that scientific findings indicate that the Earth's climate is swiftly evolving, primarily due to elevated levels of greenhouse gas emissions. This phenomenon is resulting in higher average temperatures worldwide and significant shifts in the patterns and amounts of rainfall on a global scale (Dasgupta et al. 2014). There is an expanding body of evidence suggesting that the impacts of climate change are anticipated to be more pronounced in sub-Saharan Africa compared to the global average. This heightened vulnerability is attributed to projected trends of increased warming, marked by frequent occurrences of extreme heat events under a 4 °C warming scenario (Serdeczny et al. 2016), heightened aridity, and diminished rainfall (Belay et al. 2017). Sub-Saharan Africa is particularly sensitive to these climatic transformations.

Even so, recent years have witnessed an escalation in reports regarding heightened risks of drought, extreme weather events such as floods, the proliferation of pests, elevated temperatures, and diseases affecting farmers (Lembani, 2020). These factors have compounded the food crisis in Africa (Mutunga et al. 2017; IPCC 2018). It is evident from existing literature that the adverse effects are particularly pronounced within rural and smallholder farming communities, especially in the African context (Cobbinah and Anane 2016). This underscores the notion that an adaptation initiative can be considered effective only if it successfully achieves its objectives of enhancing food security, bolstering resilience, and proving adaptable for smallholder farmers (Descheemaeker et al. 2016). Consequently, within the African context, prioritizing adaptation measures over mitigation measures is deemed more pertinent (Descheemaeker et al. 2016). There is an urgent requirement to fortify adaptive strategies to safeguard food security in Africa.

Expansion of Investments in Sub Saharan Africa

In Sub Saharan Africa, various forms of diversification strategies are being employed to adapt to the challenges posed by climate change. These strategies encompass different sectors, including agriculture product diversification, crop diversification, tree-based diversification, and livelihood diversification serves as a means to provide smallholder farmers with a wider range of dietary options while simultaneously enhancing their income and nutrition security. This is particularly crucial in sub-Saharan Africa, where rainfed agriculture is prevalent. For instance, Mauritius has embraced agricultural diversification by rapidly expanding industrialization for textile exports and promoting tourism to diversify sectors and crops. The government has also facilitated access to land for small planters specifically interested in diversifying agricultural products (Luximon and Nowbuth, 2010).

In Kenya, diversification initiatives are primarily driven by smallholder farmers. They engage in off-farm employment, lease land for cultivation (Kalungu and Leal Filho, 2018), practice mixed cropping and livestock farming (Mutunga et al., 2017), and introduce new drought-resistant crops or switch to different crop varieties (Crick et al., 2018). Morocco's farmers focus on crop diversification, including intercropping vegetables and tree-based diversification by cultivating high-value crop trees like drought-tolerant fig, almond, pomegranate, and olive varieties (Kmoch et al., 2018). In Ethiopia, smallholder farmers practice crop diversification, integrate crops with

livestock, and engage in tree planting. However, they sometimes reduce the number of meals as part of livelihood diversification strategies to adapt to limited food supply (Belay et al., 2017).

Even so, for instance, Tanzanian smallholder farmers diversify their agricultural products by growing vegetables in the off-season and selling livestock during drought periods. In the Republic of South Africa, livelihood diversification is common, with a focus on livestock in cases of crop failure. Mozambican smallholder farmers diversify their food sources to meet dietary needs and shift their focus beyond agriculture for alternative livelihoods. Similarly, Ghanaian farmers diversify to improve food security and adapt to changing conditions.

Ecosystem-Based Naturalization

Ecosystem-Based Adaptation refers to the utilization of biodiversity and ecosystem services as a fundamental component of an overarching strategy to assist farmers in adapting to the adverse impacts of climate change (Vignola et al., 2015). There is a rapidly growing interest in ecosystem-based adaptation due to its potential advantages in social, environmental, and economic dimensions (e.g., Cerdán et al., 2012; Namirembe et al., 2014; Vignola et al., 2015). Agroforestry practices offer both environmental and social benefits as integral elements of farming livelihoods. In most documented cases where agroforestry has been successfully implemented, systems incorporating trees are found to be more productive, sustainable, and better aligned with the cultural or material needs of communities compared to treeless alternatives (Mbow et al., 2014). The cultivation of trees or shrubs within farming landscapes and the integration of forests with agriculture are increasingly preferred approaches among African farmers. Despite the productivity potential of agroforestry systems, they have not been universally adopted in many African countries. For instance, Kenya's goal of achieving a 10% target of tree cover on farmers' land remains unrealized (Oloo, 2013). Consequently, there is a pressing need for deeper insights into the productivity and environmental performance of agroforestry systems across Africa (Mbow et al., 2014). Agroforestry systems involving leguminous fodder plants to support livestock during extreme weather events are gaining traction among farmers in sub-Saharan Africa (Cobbinah and Anane, 2016). In Tanzania, smallholder farmers are prioritizing the planting of trees as hedgerows, while in Zambia, on-farm trees are used to provide shade for crops and animals (Burnham and Ma, 2016). Tree-based agroforestry practices are also prominent in Morocco, where smallholder farmers utilize bi- or triennial trees like olives to augment tree cover on their farms (Kmoch et al., 2018).

Advancement of improved tree fallows, featuring leguminous trees is exhorted in maize fields in Zambia, Zimbabwe, Malawi as cost-effective agroforestry methods to rehabilitate soil fertility (Keil et al., 2005). Research conducted in semi-arid regions of Tanzania has demonstrated that agroforestry tree species, known for producing high-quality litter, can enhance post-fallow soil nutrient availability and crop yields by facilitating the mineralization of soil organic matter and acting as green manure (Kimaro et al., 2008). In Mauritius, farmers advocate for the adoption of organic farming practices, emphasizing the use of organic manure that exhibits greater resilience to drought and reduces the risk of floods (Luximon and Nowbuth, 2010). Similarly, in Kenya, farmers prepare organic manure using locally available organic materials (Oloo, 2013). Moroccan

farmers adapt to climate change effects such as floods by promoting conservation agriculture practices that involve minimal tillage and increased soil coverage (Kmoch et al., 2018). Minimum tillage and crop rotation have been observed to boost maize productivity on farms, with a notable increase of approximately 26-38% for minimum tillage and 21-24% for crop rotation in Zambia (Kuntashula et al., 2014).

Across sub-Saharan Africa's rangelands, smallholder farmers engage in grazing and rangeland management techniques to improve the collection, storage, and application of manure (Descheemaeker et al., 2016). Smallholder farmers in Tanzania, Kenya, and Ethiopia commonly employ strategies such as planting cover crops and utilizing manure to conserve soil, prevent erosion, and enhance soil fertility (Mutunga et al., 2017; Belay et al., 2017; Burnham and Ma, 2016). In Ethiopia, farmers are observed practicing both soil and water conservation methods (Belay et al., 2017). In Burkina Faso, smallholder farmers implement on-farm and in-field stone lines to capture surface runoff for micro-water harvesting and prevent soil erosion caused by sudden floods. In South Africa, smallholder farmers construct bunds along contour lines to slow down water runoff (Burnham and Ma, 2016).

Sensitivity of Sub- Saharan Africa agriculture: *Agriculture in Sub- Saharan Africa heavily relies on the unpredictability of the rainfall patterns which remains highly sensitive to climate variations and precipitations. Fluctuations in temperature and rainfall patterns have adverse effects on crop production and livestock posing a threat to food security in the continent (Lembani, 2020).*

Climate Resilience Strategies

In Sub Saharan Africa smallholder farmers are currently facing significant challenges due to the rising frequency of climate related disasters such as droughts, floods, and unpredictable weather patterns. These events pose substantial risks to agricultural production and livelihoods threatening food security and economic stability (Lembani, 2020). However, climate-resilient agriculture strategies have gained prominence as effective measures to mitigate the adverse impacts of climate change on African farmers. This section aims to explore the various strategies employed including crop diversification, drought tolerant crop varieties and efficient water management, using case studies from different regions to exemplify their effectiveness.

- **Heterogeneity of Crop Variegation**

Crop diversification is an essential climate-resilient agriculture strategy that involves growing various types of crops instead of relying on a single species. This approach helps farmers manage the risks associated with climate variability by reducing the vulnerability of their farm systems to specific climate-related shocks. For example, in regions prone to drought, farmers can include drought-tolerant crops like millets and sorghum alongside staple crops such as maize and rice. A case study conducted by Frelat et al. (2018) in Tanzania examined the impact of crop diversification on smallholder farmers' resilience to climate change in two districts. The study found that diversifying crop production enhanced farmers' ability to cope with climate-induced shocks while improving overall productivity and income stability. Furthermore, the diversification

approach helped mitigate the negative effects of drought as the combination of drought-tolerant crops and staple crops reduced the risk of complete crop failure.

- **Drought-Tolerant Crop Varieties**

  The development and adoption of drought-tolerant crop varieties play a crucial role in enhancing agricultural resilience to climate change. These crop varieties are bred to withstand water scarcity, increasing the probability of a successful harvest even during drought periods. For instance, improved maize varieties with enhanced drought tolerance have been successfully introduced in many African countries. A case study by Abate et al. (2018) investigated the impacts of drought-tolerant maize varieties in Ethiopia. The study revealed that farmers adopting these varieties experienced significant yield improvements compared to those using traditional varieties. Moreover, drought-tolerant maize helped farmers cope with prolonged dry spells and reduced water availability, ensuring food security and minimizing vulnerability to climate-related shocks. The findings demonstrate that the adoption of drought-tolerant crop varieties can contribute to increased resilience and adaptive capacity among Sub Saharan African farmers.

- **Efficient Water Management**

  Efficient water management is another vital climate-resilient agriculture strategy that helps farmers combat the impacts of changing rainfall patterns and water scarcity. Implementing water-saving techniques like drip irrigation and rainwater harvesting enables farmers to optimize water use, especially during dry periods (Lembani, 2020). Additionally, proper soil water management techniques such as mulching and soil conservation practices underpin retain moisture in the soil, reducing water loss and increasing crop yields. A case study conducted in Zimbabwe by Mafongoya et al. (2019) assessed the impacts of improved water management practices among smallholder farmers. The study revealed that farmers utilizing drip irrigation and soil conservation techniques achieved higher crop yields, mitigating the negative effects of drought. Furthermore, efficient water management contributed to income diversification through off-season vegetable production, thus reducing dependence on rain-fed agriculture. The study highlights the potential of efficient water management as an effective strategy to enhance climate resilience and agricultural productivity.

- **Arrogation of Technology & Innovation**

  Embracing suitable technologies in small-scale agriculture serves as a crucial response to address the impacts of climate change and variability, particularly in Africa (Kalungu and Leal Filho 2018). Smallholder farmers commonly employ integrated pest management for pest control (Luximon and Nowbuth 2010). Existing literature highlights the extensive use of technology to enhance dairy farming adaptation in Tunisia. For instance, Tunisian farmers establish fodder reserves during favorable years, increase concentrate distribution, manage nutritional needs, and encourage ad libitum water access (Hajer et al. 2018). They also prioritize breed selection and optimize the utilization of agricultural byproducts as animal feed. To boost productivity, Tunisian farmers improve irrigation capabilities at the farm level and strategically adjust calving schedules to align with favorable feeding periods (Belay et al. 2017). The practice of creating fodder reserves for livestock is also observed in Burkina Faso (Burnham and Ma 2016). In Burkina Faso, farmers

combat drought shocks by cultivating dry-season vegetables through irrigation and using improved seeds.

In myriad African Nations, small holder farmers employ a range of technological interventions to adapt to dry seasons and changing climate conditions. These practices include:

a. **Improved Seeds**: Farmers are using hybrid crop varieties and drought-tolerant crops to match prevailing weather conditions. This is seen in countries like Angola, Benin, Kenya, Nigeria, Mozambique and others.
b. **Irrigation**: Irrigation techniques, such as well irrigation, are widely adopted in countries like Ethiopia, Tanzania, South Africa, and Morocco to ensure water availability for crops during dry seasons.
c. **Crop Variety Selection**: Farmers change their crop varieties based on climate variability. This adaptive strategy is prevalent in Kenya, where there is high awareness of using different crop varieties.
d. **Short-Season Crops**: Planting short-season crops and drought-resistant varieties is a common practice in Kenya. This helps farmers cope with the challenges of dry seasons.
e. **Crop Rotation and Intercropping**: Rotation cropping of cereals and legumes as well as mixed intercropping are practiced in some countries to improve soil fertility and crop yields. This is observed in Malawi, Zambia, and Zimbabwe.
f. **Agro-Silviculture**: In Morocco, the practice of agro-silviculture, which involves growing trees and agricultural crops together is predominant in irrigated farms.
g. **Post-Harvest Storage**: Technologies like metal silo storage are used in Kenya to protect stored grains from pests, reducing post-harvest losses and ensuring food security.
h. **Livestock Farming**: Farmers are considering breeds and types of animals that are better adapted to heat stress and dry conditions.
i. **Water Efficiency:** The Water-Energy-Food nexus is promoting the use of drip irrigation among smallholder farmers in Morocco to enhance water allocation efficiency.

These technological interventions aim to enhance farm-level productivity, improve food security, and mitigate the adverse effects of climate change on agricultural ecosystems in various African countries.

Policy and Governance

Government policies and international organizations play a crucial role in shaping the development and progress of agriculture in African nations. Numerous studies have highlighted the importance of supportive policies in fostering sustainable agricultural practices and the significance of investments in research and extension services. Supportive government policies are essential for the growth and sustainability of agriculture in African countries. For instance, a study by Scoones et al. (2019) emphasizes the role of subsidies in promoting sustainable practices such as organic farming or agroecology. These subsidies can incentivize farmers to adopt environmentally friendly methods, reduce reliance on chemical inputs, promote soil health, and enhance biodiversity. Investments in research and extension services are also vital for agricultural development.

Research helps in the development of new technologies, crop varieties, and farming techniques that are better suited to local conditions. Extension services provide farmers with the necessary knowledge and skills to implement these innovations effectively. A study by Spielman et al. (2010) highlights the positive impact of agricultural research and extension services on productivity and efficiency in African agriculture.

International Non- Governmental Organizations (INGOs) have been instrumental in supporting agricultural development in African nations. The Food and Agriculture Organization (FAO), the World Bank, and the African Development Bank are some of the key organizations providing financial and technical assistance. They assist governments and local organizations in formulating and implementing policies, funding infrastructure development, and supporting capacity building initiatives. International agreements and partnerships have also played a significant role in promoting climate-smart agriculture in Africa. The Paris Agreement, for example, emphasizes the need for countries to adopt climate-resilient agricultural practices while reducing greenhouse gas emissions. These agreements have led to increased support for climate-smart agriculture initiatives in African countries. International organizations have supported African nations in implementing climate-smart agriculture through various initiatives. They provide funding for climate adaptation projects, support the development and dissemination of climate-resilient farming practices, and facilitate knowledge sharing and capacity building among farmers and policymakers. A study by Lipper et al. (2014) highlights the importance of international partnerships in promoting climate-smart agriculture in Africa.

Supportive government policies play a crucial role in promoting the growth and sustainability of agriculture in African countries. By providing subsidies for sustainable practices, such as organic farming or agroecology, governments can incentivize farmers to adopt environmentally friendly methods. These subsidies can have several positive impacts on agriculture, including reducing the reliance on chemical inputs, promoting soil health, and enhancing biodiversity. One of the key benefits of government subsidies for sustainable practices is the reduction in the use of chemical inputs. Chemical fertilizers and pesticides are commonly used in conventional farming methods, but they can have detrimental effects on the environment, including soil degradation, water pollution, and harm to beneficial organisms. By providing subsidies for organic farming or agroecology, governments can encourage farmers to adopt practices that minimize or eliminate the use of chemical inputs, leading to a more sustainable and environmentally friendly agricultural system (Scoones et al., 2019).

In addition to reducing chemical inputs, government subsidies for sustainable practices can also promote soil health. Organic farming practices, for example, focus on building and maintaining healthy soils through the use of organic matter, crop rotation, and biological pest control. These practices can improve soil structure, enhance nutrient cycling, and increase soil fertility over time. A study conducted by Scoones et al. (2019) in Zimbabwe found that government subsidies for organic farming practices led to increased adoption rates and improved soil fertility. This demonstrates the positive impact that supportive government policies can have on soil health in agriculture. Furthermore, government subsidies for sustainable practices can contribute to

enhancing biodiversity. Conventional farming methods often rely on monocultures and the use of chemical inputs, which can lead to a loss of biodiversity and the disruption of natural ecosystems. In contrast, sustainable practices such as agroecology emphasize the importance of biodiversity in agricultural systems. By providing subsidies for agroecological practices, governments can encourage farmers to adopt methods that promote biodiversity, such as intercropping, crop diversification, and the creation of habitat for beneficial organisms. This can help restore and maintain biodiversity in agricultural landscapes, which is crucial for ecosystem resilience and long-term sustainability (Scoones et al., 2019).

Additionally, investments in agricultural research and extension services are vital for the advancement of agriculture in Sub-Saharan Africa. Research institutions and extension services play a crucial role in providing farmers with the necessary knowledge, technologies, and best practices to enhance productivity and adapt to changing climatic conditions. These investments can lead to the development of improved crop varieties, effective pest and disease management strategies, and efficient water management techniques.

Agricultural research institutions are responsible for conducting scientific studies and experiments to develop new technologies and innovations that can benefit farmers. Through research, scientists can develop improved crop varieties that are more resistant to pests, diseases, and environmental stresses. These improved varieties can significantly enhance crop yields and contribute to food security. Additionally, research institutions can develop innovative farming techniques and practices that optimize resource use, such as water-efficient irrigation systems or precision agriculture technologies (Lowder et al., 2016). Extension services, on the other hand, are responsible for disseminating the knowledge and technologies developed by research institutions to farmers on the ground. Extension agents work closely with farmers, providing them with training, advice, and technical support. They help farmers adopt new technologies and best practices, ensuring that they are implemented correctly and effectively. Extension services also play a crucial role in facilitating knowledge exchange among farmers, enabling them to learn from each other's experiences and successes (Lowder et al., 2016).

Even so, a study conducted by Lowder et al. (2016) in Ethiopia highlights the positive impact of agricultural research and extension services. The study found that increased investments in these areas resulted in higher crop yields and improved food security. The introduction of improved crop varieties and pest management strategies, coupled with the dissemination of knowledge and training through extension services, led to significant improvements in agricultural productivity. This demonstrates the importance of investing in agricultural research and extension services to drive agricultural development and improve livelihoods in Africa. International agreements and partnerships have played a significant role in promoting climate-smart agriculture in African nations. Climate-smart agriculture aims to increase agricultural productivity, enhance resilience to climate change, and reduce greenhouse gas emissions. International organizations, such as the Food and Agriculture Organization (FAO) and the World Bank, have collaborated with African governments to develop and implement climate-smart agriculture initiatives.

These initiatives focus on the adoption of climate-resilient crop varieties, conservation agriculture practices, and improved water management techniques. Climate-resilient crop varieties are developed through research and breeding programs to withstand the challenges posed by climate change, such as drought, heat stress, and new pest and disease pressures. Conservation agriculture practices, including minimum tillage, crop rotation, and cover cropping, help to improve soil health, reduce erosion, and enhance water retention. Improved water management techniques, such as rainwater harvesting and efficient irrigation systems, contribute to water conservation and sustainable water use in agriculture (FAO, 2013).

The influence of international agreements and partnerships in promoting climate-smart agriculture is evident in the increased adoption of these practices across the continent. African governments, with the support of international organizations, have implemented policies and programs to incentivize farmers to adopt climate-smart agriculture practices. For example, the African Union's Comprehensive Africa Agriculture Development Programme (CAADP) has prioritized climate-smart agriculture as a key component of agricultural development strategies in African countries. This has led to increased investments in research, extension services, and infrastructure to support the adoption of climate-smart practices (FAO, 2013). Furthermore, international partnerships have facilitated knowledge exchange and capacity building in climate smart agriculture. Through these partnerships, African farmers and agricultural stakeholders have gained access to training, technical assistance, and best practices from other countries and regions. This has helped to build local expertise and strengthen the implementation of climate smart agriculture initiatives (FAO, 2013).

Climate Advisory and Extension

Climate advisories and information serve as valuable tools for educating smallholder farmers about climate related risks in Sub- Saharan Africa. For instance, programs like the agro-meteorological advisory program and weather and climate bulletins in Mali play a crucial role in providing guidance to farmers regarding decisions such as crop variety selection, planting schedules, and input timing (Carr and Onzere 2018). In Kenya, it is encouraged to provide access to climate change information and extension services, although there is still a significant 76% gap in access to agricultural extension services (Kalungu and Leal Filho 2018). These extension services play a pivotal role in disseminating information about new agricultural technologies and innovations. In Ghana, there is ample evidence of farmers effectively utilizing weather information (Belay et al. 2017). The use of early warning signs, weather forecasts, and agricultural extension services is highlighted as crucial for helping farmers adapt to climate variability in sub-Saharan Africa (Descheemaeker et al. 2016; Mbow et al. 2014). However, smallholder farmers in East Africa face challenges with limited access to climate advisory and extension services, leading to reduced capacity to utilize climate data and climate-related knowledge gaps (Atela et al. 2018; Singh et al. 2016).

Nonetheless, there is growing interest in harnessing Information and Communication Technologies (ICTs) to expand climate information services (CIS). For instance, Zambia and Uganda has initiated a community worker program that delivers short-term climate information

including 10-day, monthly, and seasonal weather forecasts, directly to farmers via SMS on their mobile phones (Singh et al. 2016). Access to weather information has been shown to significantly impact farmers' decisions, including adopting improved crop varieties, adjusting agricultural activities, implementing better land management practices, and increasing fertilizer usage in West Africa (Wood et al. 2014). Initiatives that create and disseminate agro-advisory services and weather information are vital for risk management and adaptive strategies in Africa (Nyasimi et al. 2014).

Socio-economic Impact

The adoption of sustainable agriculture practices and climate resilience measures has been shown to have significant socio-economic implications, particularly in African nations. Numerous studies have highlighted the positive outcomes of these initiatives, including poverty reduction, improved food security, and enhanced livelihoods for smallholder farmers. By prioritizing agricultural sustainability, African countries can effectively address both economic and environmental challenges.

- **Poverty Reduction:**

  Sustainable agriculture practices have the potential to alleviate poverty by increasing agricultural productivity and income for smallholder farmers. A study conducted in Kenya found that farmers who adopted sustainable practices, such as agroforestry and organic farming, experienced a significant increase in income, leading to poverty reduction in rural communities (Muriuki et al., 2019). Similarly, a study in Ethiopia revealed that the adoption of sustainable land management practices resulted in increased crop yields and improved household income, contributing to poverty reduction (Mekonnen et al., 2018).
- **Improved Food Security:**
  Sustainable agriculture practices play a crucial role in ensuring food security by enhancing agricultural productivity and resilience to climate change impacts. A study conducted in Malawi demonstrated that the adoption of sustainable agricultural practices such as conservation agriculture and agroforestry, led to increased crop yields and improved food security for smallholder farmers (Makate et al., 2016). Additionally, a study in Uganda and Kenya found that the implementation of climate-smart agriculture practices improved food security by increasing crop production and reducing vulnerability to climate-related shocks (Nkonya et al., 2016).
- **Enhanced Livelihoods:**
  The adoption of sustainable agriculture practices can significantly improve the livelihoods of smallholder farmers by diversifying income sources and reducing vulnerability to climate change. A study conducted in Tanzania showed that the adoption of sustainable land management practices, such as terracing and agroforestry, led to increased income and improved livelihoods for farmers (Mowo et al., 2019). Similarly, a study in Ghana found that the adoption of sustainable farming practices, such as organic farming and crop rotation, resulted in increased income and improved livelihoods for smallholder farmers (Kwasi et al., 2018). By fostering agricultural sustainability, African nations can simultaneously address economic and environmental

challenges. Sustainable agriculture practices not only contribute to poverty reduction, improved food security, and enhanced livelihoods but also help mitigate the negative impacts of climate change on agriculture. These practices promote the efficient use of resources, reduce greenhouse gas emissions, and enhance ecosystem services, leading to long-term environmental sustainability (FAO, 2019).

Possible Future Direction

Even so, there is a need for research to identify and promote appropriate technologies and practices that can enhance productivity and resilience in African agriculture. This includes exploring the use of climate-smart agriculture techniques, such as conservation agriculture, agroforestry and precision farming.

Another significant area of research should be on the socio-economic aspects of sustainable agriculture and climate resilience. This includes understanding the impact of climate change on smallholder farmers and vulnerable communities, and identifying strategies to enhance their adaptive capacity and livelihoods. Furthermore, research should also focus on policy and governance issues related to sustainable agriculture and climate resilience. This includes analyzing the effectiveness of existing policies and institutions in promoting sustainable agriculture, and identifying opportunities for policy reform and institutional strengthening.

Alternative Adaptation Measures

Expanding agricultural land to boost productivity is a strategy employed in certain African nations. For instance, Mauritius dedicates approximately 46.4% of its landmass to agriculture in order to increase crop and livestock yields (Luximon and Nowbuth 2010). The primary objective of enlarging farms is to augment food crop production, mitigating the problem of low productivity while maintaining sustainable output. Nonetheless, this approach faces sustainability challenges. For instance, in Ghana, continual expansion of farmlands and forest clearance may lead to deforestation, exacerbating climate change (Cobbinah and Anane 2016). To address these concerns, local farmers are adopting collective measures, such as collaboration. Examples include the community-centered approach to livestock management in Morocco (Kmoch et al. 2018), cooperatives and community-based development projects in South Africa (Belay et al. 2017), and social production and natural resource management-related groups in West Africa (Wood et al. 2014). These efforts aim to reduce risks and enhance the ability to adapt to climate change.

Various adaptive strategies are being considered by farmers in different regions. These include altering planting times to coincide with the start of rains and relocating animals. For instance, in Kenya and Ghana, farmers are adjusting their planting schedules, sometimes planting near rivers (Belay et al. 2017; Mutunga et al. 2017; Descheemaeker et al. 2016). In Ethiopia, Kenya, and Nigeria, planting as early as possible after the first rain is practiced (Belay et al. 2017; Oloo 2013). South African farmers are moving livestock to different areas, storing fodder, and selling animals as part of their adaptation efforts (Belay et al. 2017). Seasonal herd migration is observed in sub-Saharan Africa (Descheemaeker et al. 2016), and temporary migration occurs in Tanzania (Belay

et al. 2017). Capacity building for climate change adaptation is recognized as a way to empower farmers to adopt various technological and diversification initiatives. This is evident in Mauritius (Luximon and Nowbuth 2010), where farmers are trained, and in Mali, where a farmer observer program enhances the capacity of southern Mali's farmers (Carr and Onzere 2018). In Morocco, capacity building for water user associations, combined with local knowledge and scientific expertise, is common (Kmoch et al. 2018). Zambia enhances farmer capacity through traditional agricultural extension systems and participatory farmer interactions (Kuntashula et al. 2014).

Climate change adaptation through insurance is being trialed in sub-Saharan Africa (SSA) to address climate-related risks faced by farmers (Descheemaeker et al. 2016). Mali is experimenting with weather-based index insurance (Carr and Onzere 2018). In Kenya and Senegal, adaptation planning in the form of insurance is being explored, with or without external support (Crick et al. 2018). However, these insurance products face low adoption rates across SSA due to regulatory weaknesses, financial limitations, basis risk, weather data quality and availability, capacity building needs, and the lack of innovative approaches for local adaptation and scalability (Ntukamazina et al. 2017). Furthermore, the use of credit facilities for adaptation has been documented in countries like Kenya and Mauritius (Mutunga et al. 2017; Luximon and Nowbuth 2010). A study in Nigeria found that commercial bank credits had a positive impact on food security, improving it by up to 8% (Osabohien et al. 2018). However, it's important to note that traditional credit usage among smallholder farmers in SSA is quite low, indicating the need for policy improvements in many countries (Adjognon et al. 2017).

Discussion of findings

The research underscores the severe threat of climate change to African nations. Elevated temperatures, shifting rainfall patterns, and increased climate-related disasters are disrupting traditional agricultural practices and endangering food security. Sustainable agriculture emerges as a critical approach to address these challenges. It not only helps combat soil degradation but also promotes the efficient use of resources and ecosystem-based strategies to enhance resilience.

The adoption of diversification strategies, including crop and livelihood diversification, is crucial. These approaches provide smallholder farmers with a more varied income and dietary options, reducing vulnerability to climate-related shocks. Ecosystem-based adaptation is an important aspect of climate resilience. By harnessing biodiversity and ecosystem services, it offers a nature-centric solution to help farmers cope with climate impacts.

The research highlights the importance of technology adoption in agriculture. Integrated pest management and other innovations can help farmers adapt to changing conditions and increase productivity.

Recommendation

1. **Invest in Climate-Resilient Agriculture**: Governments and international Non- Governmental Organizations (INGOs) should prioritize investments in climate-resilient agriculture. This includes funding research into drought-resistant crops, flood-tolerant varieties, and climate-smart farming practices tailored to different regions and ecosystems within Africa.
2. **Promote Sustainable Practices:** Encourage the adoption of sustainable farming practices, such as organic farming, agroforestry, and conservation agriculture. Provide training, incentives, and access to resources for smallholder farmers to implement these practices.
3. **Strengthen Policy Frameworks:** Develop and enforce policies that support sustainable agriculture and climate adaptation. This includes creating incentives for farmers to adopt climate-resilient practices, providing subsidies for eco-friendly technologies, and ensuring land tenure security.
4. **Enhance Climate Information Services**: Expand climate advisory and extension services across the continent. This involves improving weather forecasting, providing timely climate related information to farmers, and training agricultural extension workers in climate-smart practices.
5. **Facilitate Technology Transfer**: Promote the transfer of appropriate agricultural technologies to smallholder farmers. Collaborate with research institutions, NGOs, and the private sector to make climate-resilient technologies accessible and affordable.
6. **Encourage Ecosystem-Based Adaptation**: Foster initiatives that focus on ecosystem-based adaptation. Protect and restore biodiversity and ecosystems that are vital for agriculture, such as wetlands, forests, and natural water sources.
7. **Infrastructure Investment:** Develop rural infrastructure such as; irrigation systems, roads, and storage facilities. Improved infrastructure can help farmers mitigate the impacts of extreme weather events and access markets more efficiently.
8. **Support Farmer Cooperatives**: Exhort the formation of farmer cooperatives, clubs and business associations. These groups can facilitate collective action, joint resource management and access to credit facilities and markets as regards crop and livestock value chains.
9. **Research and Knowledge Dissemination**: Continue research into climate adaptation strategies and promote knowledge sharing among African nations. Facilitate regional cooperation and partnerships to exchange successful practices and lessons learned.
10. **Monitoring and Evaluation:** Establish robust monitoring and evaluation systems to track the impact of climate resilience initiatives on food security, livelihoods, and environmental sustainability. Use these findings to refine and improve future interventions.
11. **International Collaboration:** Collaborate with international partners, including donor agencies and research institutions, to access funding, expertise, and technical assistance for climate adaptation programs in African agriculture.
12. **Public Awareness and Education:** Raise public awareness about the importance of climate resilient agriculture and sustainable food systems. Education campaigns can promote the adoption of eco-friendly practices and foster a sense of responsibility towards the environment. By implementing these recommendations, African nations can work towards building a more climate-resilient and sustainable agricultural sector. This, in turn, will contribute to improved food security, poverty reduction, and overall economic development across the continent.

Conclusion

This study disclosed the critical importance of addressing the challenges posed by climate change in Sub- Saharan African agriculture production. It emphasizes sustainable agriculture as a key solution to combat soil degradation, resource inefficiency, and biodiversity loss. Diversification strategies, ecosystem-based adaptation, technology adoption, and supportive policies are all essential components of building climate resilience in the agricultural sector. Furthermore, climate advisory services and education play a vital role in empowering farmers to make informed decisions. The socioeconomic impact of sustainable agriculture is positive, contributing to poverty reduction and improved food security. To move forward, collaboration among governments, international organizations, researchers, and stakeholders is crucial. By implementing the recommended actions and fostering international cooperation, African nations can strengthen their agricultural sectors, enhance food security, and mitigate the adverse impacts of climate change. This approach holds the promise of a prosperous future for the continent, even in the face of climate changechallenges.

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