



## ROLE OF CLIMATE-SMART AGRICULTURE IN ENHANCING SUSTAINABLE AGRICULTURAL PRODUCTION

Otitoju, M. A., \*Obeten, W. O., Ojile, D. O. and Ya'u, H.

Department of Agricultural Economics, Faculty of Agriculture, University of Abuja,  
Abuja, Nigeria. Postcode: 900001.

**Corresponding Author email: wobet337@gmail.com, Phone: 08028437321.**

### ABSTRACT

With the challenge of global food insecurity increasingly getting more severe, and the problem made worse by the extreme vulnerability of agriculture to climate change, climate-smart agriculture has emerged as an appropriate response aimed at minimising the harmful effect of climate change to agricultural production. This paper seeks to review the role of climate-smart agriculture in enhancing sustainable agricultural production towards attaining global food security. The paper majorly looks at the applications and benefits of climate-smart agriculture, and the constraints and limitations of climate-smart agriculture. This review sees the major strategies for mitigating the constraints in climate-smart agriculture to include, strengthening financial support mechanisms, promoting technological innovations and adoption, enhancing knowledge sharing and capacity building, promoting policy reforms and institutional support and addressing socio-cultural factors. Addressing the constraints and limitations of climate-smart agriculture and promoting its adoption at the global and local levels, are essential for achieving sustainable agricultural production, enhancing resilience, and mitigating climate change impacts.

**Keywords:** Climate-Smart Agriculture, sustainable agriculture, climate change, food security.

### INTRODUCTION

World Bank (2020) report found that about 690 million people (8.9 %) of the global population were hungry, an increase of about 60 million in five years. The report projects the food security challenge to become more severe, as about 70 percent more food would be required by year 2050 to feed about 9 billion people of the world. These problems are made worse by the extreme vulnerability of agriculture to climate change. Climate change is seen to be among the greatest threats to agricultural productivity worldwide (Niang *et al.*, 2014). Climate change is regarded as a variation in the form of the climate which can be observed by changes in the variability of its properties, persisting for prolonged periods, usually decades (IPCC, 2007). According to Mesfin (2019), these changes in climate is marked with increased intensity and frequency of climate shocks like flood, drought and extreme temperatures, in addition to changing timing and distribution of rainfall, as major factors adversely affecting sustainable crop production.

Many developing countries, particularly the ones within the tropics, are highly susceptible to climate change due to high temperatures which affects agricultural production (Kurukulasuriya and Mendelsohn, 2007), and limited human and physical resources to stem the assault of climate change (Di Falco, 2014). Cooper *et al.* (2013) consider most African countries as prone to being severely affected by the effects of worsening climate change, especially due to the high dependence of these African countries on rain-fed agriculture.

Climate-smart agriculture (CSA) has emerged as an agricultural approach aimed at minimising the harmful effect of climate change to agricultural production. According to Food and Agriculture Organization (FAO, 2021), "climate-smart agriculture is an approach that



helps guide actions to transform agri-food systems towards green and climate resilient practices,” and further depicts CSA as an approach which follows the triple objectives of increasing agricultural productivity in a sustainable way; building and adapting resilience to climate change and removing and/or reducing greenhouse gases (GHG) emissions relative to conventional practices. Climate-smart agriculture looks at ways to minimize the use of farm inputs, such as pesticides, fuels, energy, mineral fertilisers, for more resource-efficient inputs and to keep carbon in the soil, as well as making farming systems more resilient to climate change, by making them more diverse (Sjelin, 2021). It is therefore the objective of this paper to review the role of climate-smart agriculture in enhancing sustainable agricultural production towards attaining global food security.

### **APPLICATIONS AND BENEFITS OF CLIMATE-SMART AGRICULTURE**

In Africa, climate-smart agriculture research focused on conservation agriculture, sustainable land development, sustainable agricultural development, chemical control and animal breeding, which build on top of CSA practices. A major aspect of climate-smart agriculture technology which has witnessed rapid growth is precision farming involving the integration of global positioning system (GPS), earth observation satellites and geographical information system (GIS) technologies, which provide the expanded scope of precision agriculture practices vital for fine-scale (at the field) monitoring and mapping of crop phenology parameters and yield (Zakaria *et al.*, 2020).

#### **Climate-smart Soil Management**

In most African countries, crop production systems are based on intensive and continuous soil tillage which have led to excessively high soil erosion rates. Lal (2001) defines soil erosion as a multi-stage process involving the detachment, redistribution, and deposition of soil in depressions and finally in aquatic ecosystems. Poor nutrient supply in arable lands, especially among smallholder farmers is a critical factor limiting crop yields (Mandiringana *et al.*, 2005). The poor nutrient supply is attributed to nutrient mining because of continuous cropping without appropriate nutrient replenishment.

A review of possible soil fertility management strategies revealed that the use of mineral fertilizers as a source of nutrients for plant growth is still critical for increasing productivity (Stewart and Roberts, 2012). However, chemical fertilizers adversely affect soil health (Stapper, 2006) and their use should to be progressively replaced with integrated soil fertility management (ISFM) approaches that combine optimally applied fertilizers with organic resources. Conversion to organic farming, where possible, is recommended, as it has superior soil regeneration potential while adapting to and mitigating climate change.

In many African farming communities, conservation agriculture is a common practice to promote water and soil conservation properties. Also, in addition to slash and burn farming systems, CSA approaches include: minimum tillage, sustenance of soil cover with mulching or cover cropping, and crop rotation (Giller *et al.*, 2009). With respect to adaptation and productivity, CSA is confirmed by empirical evidence to increase the yield of major food crops such as sorghum, millet and maize, and offer much benefits from broadened crop rotation systems (Giller *et al.*, 2009). Good nutrient management practices are based on the principles of 4R nutrient Stewardship reported by Fairhurst (2012) and Zingore *et al.* (2014). This approach ensures that the Right fertilizer source is used at the Right rate, at the Right time and in the Right place. The correct application of these 4R management practices will result in increased crop yields, as well as mitigate the depletion of soil nutrients.

Also, addition of organic manures can be used to improve soil aggregate stability necessary for improve soil nourishment through decomposition and nitrogen mineralization. Using integrated soil fertility management practices markedly reduce the need of large



quantities of synthetic fertilizers which, apart from their high costs contribute to GHG emissions (Wouterse, 2017).

### **Climate-smart Agricultural Water Management**

The biggest potential increases in crop yield are in rain-fed areas wherein many of the world's poor live and where managing water is the key to such increases (Molden, 2007). Rainwater harvesting (RWH) practices have been demonstrated to increase agricultural production and sustainability. Rainwater harvesting is based on the rule of depriving (naturally or artificially) section of the land of its share of rainfall (which is usually not used productively) and adding it to another section, where it can be used beneficially. Therefore, rainwater harvesting is the practice of concentrating rainfall as runoff from larger areas for its beneficial use in smaller target areas (Oweis *et al.*, 2001).

In the Sahel areas of Nigeria and other African countries, farmers use planting pits called "Zai," to retain water for millet and sorghum production, as water harvesting techniques (Wouterse, 2017, Sawadogo, 2011). The techniques developed from indigenous knowledge, are being advanced as water conservation and climate-smart soil technologies (Lahmar *et al.*, 2012; Masse, 2011). Zai involves digging pits to collect water before planting, which may be with/without the application of organic resources like plant residues, compost and animal manure (Sawadogo, 2011).

### **Climate-smart Intercropping/Crop Diversification**

Intercropping or crop diversification involves growing of two or more crops in the same field. In intercropping, alternative crops or non-crop plants are planted with cash crops. Intercropping has been seen to build up and make agroecosystems better under climate change by enhancing soil water holding capacity, improving resource use efficiency, and increasing the quality and diversity of habitat for beneficial insects that provide natural pest control and pollination services (Huss *et al.*, 2022). Crop diversification, according to Lin (2011), improves soil fertility, controls for pests and diseases, and brings about yield stability as it buffers crop production from the effects of greater climate variability and extreme events. Cropping systems are more resilient with intercropping even under conditions of low soil fertility and moisture.

### **Climate-smart Range Livestock Production/Management**

Properly managed livestock are key to restoring the rangeland soils that have the potential to store greater than 10% of terrestrial biomass carbon and 10 to 30% of global soil organic carbon (Derner and Schuman, 2007), and to minimizing the most damaging impacts on humans and the natural world. Continuous grazing has given rise to the replacement of natural perennial grasses, which dominate in good rangelands, by annuals and forbs that have less forage and ecological values (Nordborg, 2016). Holistic management of grasslands has resulted to regeneration of soils, increased productivity and biological diversity, as well as economic and social well-being. Holistic management can therefore, be considered climate smart agriculture, as it maintains or restores rangelands leading to maintaining and increasing carbon sequestration, food security, drought resilience and financially viable communities (Nordborg, 2016).

## **CONSTRAINTS AND LIMITATIONS OF CLIMATE-SMART AGRICULTURE**

Climate-smart agriculture implementation faces various constraints and limitations that hinder its effectiveness in promoting sustainable agricultural production. According to FAO (2013), these constraints can be financial, technological, knowledge-related, policy-related, and influenced by socio-cultural factors. Understanding these barriers is crucial for developing strategies to overcome them and maximizing the benefits of CSA.

To gain a comprehensive perspective, comparison will be made of the constraints and limitations of CSA in the international context with a specific focus on Nigeria. Nigeria



provides an interesting case study as a developing country in the tropical region, highly susceptible to climate change impacts, yet it has made efforts to adopt CSA practices. We shall look at the constraints:

1. **Financial Constraints:** One of the primary constraints in implementing climate-smart agriculture practices is the lack of financial resources. Many CSA techniques require upfront investments in infrastructure, technologies, and training, which may be beyond the means of small-scale farmers and resource-constrained regions. Limited access to credit and high transaction costs further exacerbate the financial challenges.
2. **Technological Constraints:** Effective implementation of CSA relies on the availability and accessibility of appropriate technologies. However, certain regions, particularly in developing countries, may lack access to advanced agricultural technologies such as precision farming tools, climate-resilient seeds, and efficient irrigation systems. Limited technological infrastructure and low levels of technological literacy can hinder the adoption of CSA practices.
3. **Knowledge and Information Gaps:** A key constraint in adopting climate-smart agriculture is the lack of knowledge and information among farmers, extension agents, and policymakers. Insufficient understanding of CSA principles, practices, and their potential benefits hinders the widespread adoption of these techniques. Inadequate access to reliable climate data, information on CSA best practices, and training programs further limit the dissemination of the required knowledge.
4. **Policy and Institutional Barriers:** Inconsistent policies and inadequate institutional support can impede the mainstreaming of climate-smart agriculture. Policy frameworks that do not make climate change adaptation and mitigation a priority, weak enforcement mechanisms, and conflicting policies across different sectors can create barriers to the adoption of CSA practices. Insufficient institutional capacities, coordination gaps, and limited extension services can also hinder the implementation of CSA at scale.
5. **Socio-cultural factors:** Social and cultural factors play a significant role in the adoption and success of climate-smart agriculture. Traditional farming practices, cultural beliefs, and social norms may hinder the acceptance and adoption of new agricultural techniques. Gender inequalities limited social cohesion, and lack of community participation can further limit the effectiveness of CSA interventions.

### **Strategies for Mitigating Constraints in Climate-smart Agriculture**

According to FAO (2013), strategies for mitigating constraints in climate-smart agriculture include:

1. **Strengthening financial support mechanisms:**
  - Increase public and private investments in agricultural research and development, with a specific focus on Climate-Smart Agriculture.
  - Develop financial instruments such as low-interest loans, grants, and insurance schemes targeted at small-scale farmers to facilitate their access to finance for CSA adoption.
  - Foster partnerships between financial institutions, development agencies, and agricultural stakeholders to create innovative financing models for CSA projects.
2. **Technological innovations and adoption:**
  - Promote research and development of climate-smart technologies tailored to local contexts and farming systems.
  - Facilitate technology transfer programs and capacity-building initiatives to enhance farmers' knowledge and skills in adopting and effectively utilizing CSA technologies.





- Establish demonstration farms and field trials to showcase the benefits and feasibility of climate-smart technologies.
3. Enhancing knowledge sharing and capacity building:
- Strengthen extension services to provide training and technical support on CSA practices, including climate risk management, soil health, water management, and sustainable pest and disease control.
  - Develop farmer-to-farmer learning networks and participatory approaches to exchange experiences and knowledge on CSA implementation.
  - Establish digital platforms, mobile applications, and online resources to disseminate information and best practices related to Climate-Smart Agriculture.
4. Policy reforms and institutional support:
- Develop and implement supportive policies that incentivize and prioritize Climate-Smart Agriculture, including climate change mitigation and adaptation measures.
  - Enhance coordination and collaboration among relevant government ministries, departments, and agencies to ensure policy coherence and effective implementation of CSA programs.
  - Strengthen institutional capacities at national, regional, and local levels to provide regulatory support, monitoring, and evaluation of CSA initiatives.
5. Addressing socio-cultural factors:
- Conduct gender-responsive approaches to ensure the active participation and engagement of women in CSA initiatives.
  - Raise awareness and promote behavior change through targeted campaigns, farmer field schools, and community-based approaches.
  - Engage with local communities and traditional leaders to understand and integrate indigenous knowledge and practices that align with CSA principles.

By implementing climate-smart agriculture practices at scale, countries can make significant contributions to mitigating climate change while promoting sustainable agricultural production and enhancing resilience to climate impacts.

## CONCLUSION AND RECOMMENDATION

Climate-smart agriculture has emerged as a promising approach to enhance sustainable agricultural production while addressing the challenges posed by climate change. However, several constraints and limitations hinder the widespread adoption and effectiveness of CSA practices. These constraints include financial limitations, technological barriers, knowledge and information gaps, policy and institutional challenges, and socio-cultural factors.

In conclusion, addressing the constraints and limitations of climate-smart agriculture and promoting its adoption at the global and local levels are essential for achieving sustainable agricultural production, enhancing resilience, and mitigating climate change impacts. Continued research, collaboration, and investment in CSA are crucial for advancing knowledge, improving practices, and maximizing the potential of climate-smart agriculture in contributing to a sustainable and resilient future. To mitigate these constraints, various strategies can be employed and these include, strengthening financial support mechanisms, promoting technological innovations and adoption, enhancing knowledge sharing and capacity building, implementing policy reforms, and addressing socio-cultural factors are key strategies for promoting the successful implementation of CSA.



### **Declaration of Conflict of Interests**

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

### **REFERENCES**

- Cooper, P. J. M., Cappiello, S., Vermeulen, S. J., Campbell, B. M., Zougmore, R. & Kinyangi, J. (2013). Large-scale implementation of adaptation and mitigation actions in agriculture. CCAFS Working Paper No. 50. Copenhagen, Denmark. Retrieved from <https://hdl.handle.net/10568/33279>
- Derner J. D. & Schuman G. E. (2007). Carbon sequestration and rangelands: A synthesis of land management and precipitation effects. *Journal of Soil and Water Conservation*, **62**: 77–85. Retrieved from [https://www.ars.usda.gov/ARSEUserFiles/30180000/DernerPDF/32.JSWC62\(2\)Derner.pdf](https://www.ars.usda.gov/ARSEUserFiles/30180000/DernerPDF/32.JSWC62(2)Derner.pdf)
- Di-Falco, S. (2014). Adaptation to climate change in Sub-Saharan Agriculture: Assessing the evidence and rethinking the drivers. *European Review of Agricultural Economics*, **41**(3): 405-430. <https://doi.org/10.1093/erae/jbu014>
- Fairhurst, T. (2012). Handbook for integrated soil fertility management. Africa Soil Health Consortium, Nairobi. Retrieved from [https://publications.cta.int/media/publications/downloads/1853\\_PDF.pdf](https://publications.cta.int/media/publications/downloads/1853_PDF.pdf)
- Food and Agriculture Organization (2013). Climate-Smart Agriculture Sourcebook. Food and Agriculture Organization of the United Nations. Retrieved from <http://www.fao.org/3/i3325e/i3325e.pdf>
- Food and Agriculture Organization (2021). Climate-smart agriculture case studies 2021: Projects from around the world. Rome. <https://doi.org/10.4060/cb5359en>
- Giller, K. E., Witter, E., Corbeels, M. & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: the heretics' view. *Field crops research*, **114**(1): 23-34.
- Huss CP, Holmes KD, Blubaugh CK. (2022). Benefits and Risks of Intercropping for Crop Resilience and Pest Management. *J Econ Entomol*, **115**(5): 1350-1362. <http://doi.org/10.1093/jee/toac045>
- IPCC (2007). Climate change 2007: Mitigation of climate change. Contribution of Working Group III to the Fourth Assessment Report of the IPCC. Cambridge, United Kingdom and New York. Retrieved from <https://www.ipcc.ch/report/ar4/wg3/>
- Kurukulasuriya, P. & Mendelsohn, R. (2007). A Ricardian Analysis of the Impact of Climate Change on African Cropland. Policy Research Working Paper; No. 4305. World Bank, Washington, DC. Retrieved from <http://hdl.handle.net/10986/7508>
- Lahmar, R., Bationo, B. A., Lamso, N. D., Guéro, Y. & Tittonell, P. (2012). Tailoring conservation agriculture technologies to West Africa semi-arid zones: building on traditional local practices for soil restoration. *Field crops research*, **132**: 158-167. <https://doi.org/10.1016/J.FCR.2011.09.013>
- Lal, R. (2001). Soil Degradation by Erosion. *Land Degradation and Development*, **12**(6): 519-539. <http://doi.org/10.1002/ldr.472>
- Lin, B. B. (2011). Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change, *BioScience*, **61**(3): 183-193. <https://doi.org/10.1525/bio.2011.61.3.4>
- Mandiringana, O. T., Mnkeni, P. N. S., Mkile, Z., van Averbeke, W., Van Ranst, E. & Verplancke, H. (2005). Mineralogy and Fertility Status of Selected Soils of the Eastern Cape Province, South Africa. *Communications in Soil Science and Plant Analysis*, **36**: 2431-2446. <https://doi.org/10.1080/00103620500253514>



- Masse, M. (2011). REST API Design Rulebook: Designing Consistent RESTful Web Service Interfaces. "O'Reilly Media, Inc."
- Mesfin, S. G. (2019). A review on the role of climate smart agriculture for sustainable crop production. *Journal of Biology, Agriculture and Healthcare*, **9**(12): 21-29. <https://doi.org/10.7176/jbah>
- Molden, D. (2007). Water for food, water for life: a comprehensive assessment of water management in agriculture. IWMI Books, Reports H040193, International Water Management Institute. London. Retrieved from <https://www.iwmi.cgiar.org/assessment/Publications/books.htm>
- Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, C., Lennard, C., Padgham, J., Urquhart, P. & Descheemaeker, K (2014). African climate change: Impacts, adaptation, and vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment; Cambridge University Press: Cambridge, UK; New York, NY, USA, pp. 1199–1265. <https://doi.org/10.2134/agronj2010.0303>
- Nordborg, M. (2016). *Holistic management – a critical review of Allan Savory's grazing method*. Uppsala: SLU/EPOK – Centre for Organic Food & Farming & Chalmers. Retrieved from [https://www.slu.se/globalassets/ew/org/centrb/epok/dokument/holisticmanagement\\_review.pdf](https://www.slu.se/globalassets/ew/org/centrb/epok/dokument/holisticmanagement_review.pdf)
- Oweis, T.Y., Prinz, D. & Hachum, A.Y. (2012). Rainwater Harvesting for Agriculture in Dry Areas. CRC Press/Balkema, Taylor & Francis Group, London, 262 p. <http://doi.org/10.1201/b12351>
- Sawadogo, H. (2011). Using soil and water conservation techniques to rehabilitate degraded lands in North-Western Burkina Faso. *International journal of agricultural sustainability*, **9**(1): 120-128. <https://doi.org/10.3763/ijas.2010.0552>
- Sjelin, K., Smith, J. & Söderlund, S. (2021). Climate-smart agriculture: Solutions for resilient farming and forestry. EIP-AGRI Service Point publication. Retrieved from <https://ec.europa.eu/eip/agriculture/en/publications/eip-agri-brochure-climate-smart-agriculture.html>
- Stapper, M. (2006). Soil Fertility Management - Towards Sustainable Farming Systems and Landscapes. Retrieved from <https://api.semanticscholar.org/CorpusID:54950617>
- Stewart, W. M., Roberts, T. L. (2012). Food Security and the Role of Fertilizer in Supporting it. *Procedia Engineering*, **46**(2012): 76 – 82. <http://doi.org/10.1016/j.proeng.2012.09.448>
- World Bank (2020). Climate-smart agriculture. Retrieved from <https://www.worldbank.org/en/topic/climate-smart-agriculture>.
- Wouterse, F. (2017). Empowerment, climate change adaptation, and agricultural production: evidence from Niger. *Climatic Change*, **145**: 367. <https://doi.org/10.1007/s10584-017-2096-8>
- Zakaria, A., Azumah, S., Appiah-Twumasi, M., & Dagunga, G. (2020). Adoption of climate smart agricultural practices among farm households in Ghana: The role of farmer participation in training programmes. *Technol. Soc.*, **63**: 101338. <https://doi.org/10.1016/j.techsoc.2020.101338>
- Zingore, S, Njoroge, S, Chikowo, R, Kihara, R, Nziguheba, G. & Nyamangara, J. (2014). 4R Plant nutrient management in African agriculture: An extension handbook for fertilizer management in smallholder farming systems. Nairobi, Kenya: International Plant Nutrition Institute (IPNI). Retrieved from <https://hdl.handle.net/10568/66635>