

# Climate Smart Agriculture for Improving Crop Production and Biodiversity Conservation: Opportunities and Challenges in the 21<sup>st</sup> Century - A Narrative Review

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## To cite this article:

Wycliffe Tumwesigye, Abebe Aschalew, Wambi Wilber, Doreen Atwongyire, Goretty Mary Nagawa, Daniel Ndizihiwe. Climate Smart Agriculture for Improving Crop Production and Biodiversity Conservation: Opportunities and Challenges in the 21st Century - A Narrative Review. *Journal of Water Resources and Ocean Science*. Vol. 8, No. 5, 2019, pp. 56-62. doi: 10.11648/j.wros.20190805.11

**Received:** February 5, 2019; **Accepted:** April 8, 2019; **Published:** October 17, 2019

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**Abstract:** Climate change and agriculture are interlinked and affect each other globally. The global population continues to rise while food and nutritional insecurity remain main global challenges facing humanity. Traditional agriculture methods need transformation to climate smart agriculture (CSA) approaches that have potential to improve food production amidst climate change realities. The review aimed at evaluation of published literature on CSA, establishment of CSA linkages with national development plans for Uganda and Ethiopia, African Union Agenda 2063, UN Sustainable Development Goals and CSA contribution to biodiversity conservation across the globe. Additionally, the review aimed at identifying opportunities and challenges of CSA in the 21<sup>st</sup> Century and recommend possible options for all stakeholders for improved income, environmental conservation, and food and nutritional security. Literature search from 2000-2019 was carried out using key words and key phrases in relevant journals and authentic websites. It was found out that CSA supports three pillars: 1) Sustainably increasing agricultural productivity and incomes, 2) Adapting and building resilience to climate change, 3) Climate change mitigation and contributes to Biodiversity Conservation and management. CSA approach has potential to improve food security and farmers' income. CSA has a vast number of opportunities that include availability of crop genetic diversity, availability of interested CSA researchers, gene banks for genome resources for CSA crop enhancement; enhanced technology for CSA practices that can be accessed by farmers and vibrant research organizations and donor agencies interested in promoting CSA approaches. CSA challenges were identified to include: limited technical and financial capacity and negative attitude from smallholder farmers. It was concluded that CSA approach is a better option for the present and centuries to come farmers across the globe for the attainment of the United Nations (UN) Sustainable Development Goals (SDGs) 2015-2030, UN Agenda 2063 and national development plans of most African countries including Uganda and Ethiopia. The review recommended that capacity building for farmers and researchers need to be done and governments and donor agencies should provide soft CSA loans to farmers to supporting CSA practices and technologies in all developing countries and the approach should be adopted by all the farmers and be promoted by all stakeholders at all levels in both the present and future centuries.

**Keywords:** Climate Smart Agriculture, Mitigation, Adaptation, Resilience, Food Security, Biodiversity Conservation

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## 1. Introduction

Food insecurity and biodiversity loss are global in scope and cannot be viewed independently. Population pressure, poverty and climate change are major drivers of food insecurity and biodiversity loss in the present century [1]. Research and knowledge dissemination from local to global has potential to address the status quo [2]. Small-holder farming systems form the backbone of global food security [3]. Knowledge from agriculture research, climate change and food insecurity in Sub-Saharan Africa (SSA) is pertinent in the current century to inform policy makers and scientists on the appropriate actions to be taken [4]. This is essential for all stakeholders in agriculture sector including both local and national governments in the region? which region specify. Traditional and inappropriate methods of agriculture concomitant with climate change have exacerbated the current situation. Slash and burn, heavy tillage, limited agriculture inputs and over cultivation are some of the traditional inappropriate agricultural methods used in SSA countries. Such methods contribute to soil degradation, biodiversity loss and reduced crop yield on degraded soils in the region. Previous studies have noted that time is running out and we have perhaps 40 years to radically transform agriculture [5], and find solutions to grow more food without exacerbating environmental problems, and simultaneously cope with climate change [6]. Currently, it is estimated that worldwide 1 billion people are hungry and another 1 billion people are malnourished [7]. Food insecurity and malnutrition in the region is equally pronounced and need stakeholders' attention. To address this challenge, food production needs to increase by 60% between now and 2050 or even by 70–100%, especially in developing countries [8]. Due to land shortage and fragile soils, increasing food production in most developing countries is usually accompanied by land degradation, forest cover reduction and biodiversity loss [9]. This is because many agricultural practices damage ecosystems and are not sustainable. Climate smart agriculture practices that conserve water and soil for sustainable agriculture can be a solution to meet the 21<sup>st</sup> Century demands [10]. The concept of CSA, its contribution to biodiversity conservation, its benefits to stakeholders, its opportunities, challenges and way forward for the current century are poorly documented. Hence the narrative review aimed at answering the following questions: What is climate smart agriculture? Why climate smart agriculture? Who benefits from CSA? Does CSA promote biodiversity conservation? When should we embrace CSA? What are the challenges and opportunities of CSA in the 21<sup>st</sup> Century?

## 2. Explanation of CSA Approach

Climate Smart agriculture (CSA) is defined as agricultural practices that sustainably increase productivity and resilience (adaptation), and reduce greenhouse gas emissions (GHG) (mitigation) while enhancing the achievement of national

food security and Millennium Development Goals [11]. Integrating CSA approach has potential to enhance both food security and biodiversity conservation [12]. The CSA approach involves practices such as mulching, conservation agriculture, intercropping, crop rotation, integrated crop-livestock management, agroforestry, improved grazing, improved water management, better weather forecasting, use of more resilient food crops and risk insurance [14, 15, 4]. Other researchers argue that climate smart agriculture is actually similar to sustainable agriculture that reduces GHG emissions [4]. Ashish *et al* (2017) pointed out the three pillars of climate smart agriculture. These include the following:

- i Productivity: CSA aims to sustainably increase agricultural productivity and incomes from crops, livestock and fish, without having a negative impact on the environment. This, in turn, will raise food and nutritional security. Increasing productivity makes CSA an approach that promotes crop yields. This is important for agriculture-dependent communities that derive much of their livelihood from agriculture and agribusiness. For example, agriculture in Uganda contributes to 20.9% of the National Gross Domestic Product and 80% export earnings but the output has been declining for some decades [15]. The decline is partly attributed to climate change and unsustainable methods of agriculture used in many parts of the country [16].
- ii Adaptation: CSA aims to reduce the exposure of farmers to short-term risks, while also strengthening their resilience by building their capacity to adapt and prosper in the face of shocks and longer-term stresses. Particular attention is given to protecting the ecosystem services which ecosystems provide to farmers and others. These services are essential for maintaining productivity and our ability to adapt to climate changes. The practices applied in CSA should enable farming systems survive in both short- and long-term risks.
- iii Mitigation: Wherever and whenever possible, CSA should help to reduce and/or remove greenhouse gas (GHG) emissions. This implies that we reduce emissions for each calorie or kilo of food, fiber and fuel that we produce. That we avoid deforestation from agriculture. And that we manage soils and trees in ways that maximizes their potential to acts as carbon sinks and absorb CO<sub>2</sub> from the atmosphere” [8]. CSA should therefore, aim at Carbon sequestration enhancement in farming systems hence mitigating effects of global climate change.

Additionally, World Bank (2013), points out that climate-smart agriculture includes proven practical techniques — such as mulching, intercropping, conservation agriculture, crop rotation, integrated crop-livestock management, agroforestry, improved grazing, and improved water management — but also innovative practices such as better weather forecasting, early warning systems and risk insurance [1]. To achieve this, farmers should adopt practices

that are feasible to their own farming systems because what works well for one may not be applicable to another.

### 2.1. CSA and GHG Emissions Reduction

The various practices used in CSA aim at reduction of GHG emissions and enhancement of soil carbon sequestration. Such practices also promote soil and water conservation that is essential for keep soil health and increase productivity [10]. Deforestation is usually avoided and agroforestry is encouraged during farming. Cover crops and fallowing enhance soil and water conservation, and at the same time promotes nutrient retention in farming system. These practices are opposed to slash and burn that enhance soil degradation, nutrient loss hence promoting soil erosion in farming systems.

### 2.2. CSA and Food Security

Previous studies show that CSA promotes crop yields and increase productivity [17]. Increased crop yield and productivity provides nutrition and income security to smallholder farmers that practice CSA approaches. This boosts household food supply for both domestic consumption and commercial purposes. Increased food production consequently increases family income hence reducing poverty among the farming communities [18]. CSA reduces malnutrition and associated diseases thus promoting human health especially among children and teenagers. This is particularly important in developing countries where limited technology and financial capital are major challenges faced agrarian communities.

### 2.3. Linkage of CSA, Sustainable Development Goals with African Union Agenda 2063

CSA is an approach that contributes to the attainment of the United Nations (UN) Sustainable Development Goals (SDGs), those that are interconnected with food security, biodiversity and climate change [19]. The following are the goals to which CSA substantially contribute:

**Table 1.** SDGS associated with CSA (Source: UN 2015).

Goal 1. End poverty in all its forms everywhere
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 6. Ensure availability and sustainable management of water and sanitation for all
Goal 13. Take urgent action to combat climate change and its impacts*
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 1: Due to the potential of CSA for crop yield enhancement, the approach boosts crop production hence household income for the agriculture-dependent communities, especially in developing countries.

Goal 2: Increased crop production, avails essential nutrients to households and reduces malnutrition from populations of all age groups and gender.

Goal 6: Conservation of soil and water are the major outcomes of CSA approach this is achieved by employing conservation agriculture.

Goal 13: CSA addresses climate change impacts by reducing GHG emissions, mitigation and adaptation hence contributing to UN 2030 SDGs.

Goal 15: CSA approach aims at soil fertility restoration, protection of terrestrial ecosystems, reduction of land degradation and promotion of biodiversity conservation. The approach contributes to conservation of soil biodiversity and enhances species diversity in all soil types [20, 21]. It is therefore paramount for the farming communities to embrace CSA for the contribution it has towards attaining SDGs for 2030.

Likewise, the African Union Agenda 2063 targets at poverty eradication, increased agriculture productivity and climate change mitigation [22]. This aims at improving food security and environmental protection in the region both of which can be attained through CSA approach.

#### 2.3.1. Linkage of CSA with Uganda Vision 2040

Furthermore, many African countries like Uganda have CSA program 2015-2025 whose target is to increase nutritional and income security for farming communities, and consequently boost the country's GDP [15]. The vision and objectives are tabulated below (Table 2):

**Table 2.** Uganda Climate Smart Agriculture Program 2015-2025 (Source: GoU, 2015).

Vision
The Vision of the CSA Program is a "Climate resilient and low carbon agricultural and food systems contributing to increased food security, wealth creation and sustainable economic growth in line with the National Vision 2040."
Objectives
The five core objectives of the Country CSA Program are:
1. Increase agricultural productivity through climate smart agriculture practices and approaches that consider gender.
2. Increase the resilience of agricultural landscapes and communities to the impacts of climate change.
3. Increase the contribution of the agricultural sector to low carbon development pathways through transformation of agricultural practices.
4. Strengthen the enabling environment for efficient and effective scaling up of climate smart agriculture.
5. Increase partnerships and resource mobilization initiatives to support implementation of climate smart agriculture.

CSA is among the 10-year priorities for improving peoples' wellbeing and promote sustainable development for the human capital.

Furthermore, the world's population is increasing at a high rate and so should be the food production. FAO 2013 [15] projects that the population of the world will increase by one-third and 2 billion will live in developing countries. In order to meet the nutritional demands of all the people, food production should increase by 60% hence the need for CSA application across the globe.

#### 2.3.2. Linkage of CSA with Ethiopia Growth

##### Transformation Plan 2015/2016-2019/2020

The Ethiopian Government Growth and Transformation

Plan II (GTP II) objectives include:

- i To bring about accelerated and sustained growth of agriculture within the framework of the Climate Resilient Green Economy Strategy that equitably benefits people at all levels and that realizes structural transformation of the sector and the overall economy
- ii To bring about a significant shift in agricultural productivity, build productive capacity and thereby enhance the contribution of the sector to the economy and stabilizing the macro economy [23].

The two objectives for the transformation of Ethiopia are closely linked with CSA because they advocate for green economy, climate resilient and improved income. At the same time, Ethiopia's vision is becoming a lower middle-income country by 2025. Embracing CSA will contribute the country's vision and transform peoples' livelihood.

### 3. Beneficiaries of CSA Approach

CSA is a win-win approach for all stakeholders [7, 24, 25]. Governments, legislature, conservation NGOs, Farmers, Private sector, all people along agriculture value chain are beneficiaries of CSA. Improved agriculture production enhances government revenues that enables governance to offer appropriate services to people. The legal framework benefits from reduced crimes accruing from environmental degradation; conservation NGOs benefit because their actions are support by CSA that advocates for reduction of deforestation and biodiversity conservation; Farmers benefit by improved agriculture and increased production that generates more income; Private sectors benefit by doing better businesses related with agriculture value chain from producers to sellers.

#### 3.1. Contribution of CSA to Biodiversity Conservation

Previous studies show that biodiversity benefits from CSA approaches because the practices enhance ecosystems management across various landscapes [26, 27]. Both soil and terrestrial biodiversity benefits from CSA practices. Organic farming benefits mammals, birds, invertebrates and flora species abundance and richness [28]. About 75% of poor farmers in developing countries depend on agriculture biodiversity for food production [21]. On-farm biodiversity depends on farming practices at farm and landscape scales [29]. Species diversity (macro and micro) is enhanced by CSA approaches for different regions across the globe. For instance, mulching and conservation agriculture both conserve soil and water thus supporting soil invertebrates by providing them with a suitable environment for survival. Similarly, agroforestry provides avian species feed and shade while minimum tillage leaves soils less disturbed and enhance soil invertebrate survival. Studies in Europe point out that interaction between agriculture and biodiversity is complex because the former influences the latter in various ways based on the farming practices in the area [30]. Agriculture contributes to biodiversity conservation based on land management practices in a given area. Appropriate

policies need to be enacted and implemented supporting CSA and biodiversity conservation, while promoting food security and climate change mitigation.

#### 3.2. Time for Adopting and Applying CSA Approach

As global population escalates, agriculture needs transformation to meet the current food demands without degrading the environment. This does not require any time lag but should be done today in the present century [8]. Transformation of agriculture ensures food security for the people, mitigates impacts of climate change, improves income and promotes environmental conservation. These are all contributing to UN SDGs 2030 [31], which focus on sustainable development for the wellbeing of people across the globe. Both developed and developing countries should embrace CSA approach in the present and centuries to come in order to meet the current and future nutritional demands for their fast-growing populations. It is projected that by 2050, the global population will escalate to 9.8 billion people [4] and these people need food to support their livelihood, which can be achieved through CSA practices at all levels and in all nations.

### 4. Opportunities for CSA in the 21<sup>st</sup> Century

CSA has numerous opportunities including climate change mitigation by reducing GHG emissions, improved crop production, increased household income for smallholder farmers, soil and water conservation, provision of employment opportunities for youth and women and enhancement of biodiversity conservation [15, 31, 32]. CSA offers a triple win opportunity including food security, adaptation and mitigation [34]; availability of crop genetic diversity to support crop varieties that are pest and disease resistant, produce high yields and adaptive to climatic variations. Additionally, availability of some CSA researchers and USA National Center for Biotechnology Information (NCBI) gene bank for genome resources for CSA crop enhancement; enhanced technology for CSA practices such as spring irrigation system and minimum tillage equipment that can be accessed by farmers to promote CSA. Furthermore, vibrant research organizations and keen researchers from both National and international bodies such as Consultative Group for International Agricultural Research (CGIR), Food and Agriculture Organization (FAO), Climate Change, Agriculture and Food Security (CCAFS), National Agriculture Research Organization (NARO) and the International Livestock Research Institute (ILRI) promote CSA research and practices at all levels. Due to the potential of CSA to improve livelihood, both national and international donor agencies have focused their attention to the CSA practices hence giving a golden opportunity for researchers to leverage their research competencies.

### *Challenges of CSA in the 21<sup>st</sup> Century*

However, the application of CSA requires appropriate equipment, skilled manpower and enough capital, which most smallholder farmers from developing countries lack. Most developing countries have weak legal Institutional framework to promote CSA practices [34]. Majority of the smallholder farmers have a negative attitude towards adoption of CSA and other related new technologies as opposed to their traditional agriculture methods that degrade land and emit GHGS. They need to be sensitized to change their attitude from traditional farming methods and use CSA practices [10]. Majority of commercial farmers a cross the globe prefer quick traditional methods of agriculture that degrade soils and earn quick returns.

## **5. Materials & Methods**

A systematic and narrative literature search was done from 2001 to 2019 using key words and relevant phrases. This was done from Elsevier agriculture journals, JSTOR journals, Google web browser, Google Scholar, Research Gate and Nature and Climate Change journals. More than 100 scientific articles, books and reports were retrieved from the search from which 45 were critically reviewed during the preparation of this manuscript. FAO source book on climate smart agriculture [35] and other relevant e-books, conference proceedings, Government and farmer group reports at local, national, regional and International levels from both developing and developed countries were consulted for additional information on CSA applications and practices.

## **6. Discussion**

Climate smart agriculture is a new concept especially in developing countries. It has the potential to increase food production, improve farmers' household income and reduce poverty, enhance nutritional security and mitigate climate change. CSA should be promoted because it is in agreement with and supports of UN 2015-2030 SDGs [31]. African Union Agenda 2063 in regard to poverty eradication, climate change mitigation and sustainable development of the population [36]. At the same time, most African countries, including Uganda, have set goals to promote sustainable development priorities, which are supported by CSA technologies and practices [15]. Food security, climate change mitigation, adaption and resilience are of a global concern and are all addressed by CSA practices and technologies [5, 36-38]. People of all nations and age groups are beneficiaries of CSA practices and technologies but at the same time most of them are contributors to environmental degradation, pollution, global warming and climate change [40, 41]. Additionally, CSA practices and technologies globally benefit and promote biodiversity conservation based on particular approaches used per region. The particular approach used can benefit terrestrial, aquatic and soil biodiversity at local and global scales [20, 39-41]. The benefits include provision of ecosystem services, provision of

suitable habitat, obtaining feeds, providing shelter and provision of nutrients for the plant species. CSA adoption rate in developing countries is still low compared to developed countries. As a new concept, it is associated with many opportunities and challenges at both national and international levels in the present century. The opportunities can be exploited and challenges addressed by combined effort from all relevant stakeholders at all levels of governance and education. If this is done, sustainable development targets can be achieved and people live in a better world with sufficient resources to support their wellbeing.

## **7. Conclusions**

As long as the world population continues to grow, especially in developing countries, the only way to support people is to increase food production while minimizing the impact of climate change. This can be attained by embracing CSA practices and technologies across the globe. The need for agriculture transformation from traditional methods to CSA practices and technologies is paramount in the present century. This will enable individual countries attain the UN 2015-2030 SDGs and enhance sustainable development and achieve their own targets. All stakeholder at all levels need to combine efforts in promoting CSA practices and technologies for the benefit of the global population. A few developing countries have understood and started application of CSA and the rest need to be sensitized and encouraged to follow suit. The practices and technologies of CSA should start locally but can be scaled up globally to benefit a larger population and the entire universal environment.

## **8. Recommendations**

All stakeholders (researchers, smallholder farmers, religious groups, churches, mosques, policy makers, private sector, NGOs, donor agencies, World Bank, FAO, national governments, research institutes, farmer groups, youth, women, men, entrepreneurs, universities, colleges, technical institutes, secondary schools, primary schools, etc.) need to work together and put in sufficient effort to advance CSA technology and practices.

Capacity building for the farmers, researchers, policy makers, government institutions, private sector and non-government Institutions need to be done across all government levels for the benefit of humanity and promotion of CSA practices because people lack relevant information and skills.

National Governments and donor agencies should provide soft agriculture loans or equipment to smallholder farmers to enable them implement CSA practices in their regions. The money they get will help them buy machinery, farm inputs, pay labor and assist minimize post-harvest handling losses.

Policy makers should enact appropriate policies related to CSA and local government leaders should ensure their implementation to enhance CSA practices and application of

related technologies in different areas. These policies and associated bylaws should be area specific based on farmers preferences per region.

Networking and collaboration between researchers from developed and developing countries should be encouraged and supported by all employer organizations so that knowledge sharing is enhanced to promote CSA across the globe. The research expertise in developed countries should help researchers from developing countries to promote CSA practices and improve food security and people's livelihood. The laboratory findings should be translated into on farm agriculture practices that support sustainable development and community wellbeing.

Farmers' and researchers' exchange visits at local, national, regional and international levels should be encouraged and promoted by relevant employers to enhance knowledge sharing across the globe. This will motivate farmers and increase CSA adoption rate while encouraging further research in CSA practices and technologies.

CSA technology education should start with children from nursery and kindergarten schools and proceed to university levels. The earlier the better for children learning and this will make it easier for the implementation of CSA practices when they reach maturity levels in secondary, higher institutions and become prominent researchers in their communities.

## Acknowledgements

I thank the African Centre of Excellence for Climate Smart Agriculture and Biodiversity Conservation management for the funding support they provided through World Bank which enabled me pursue my PhD study at Haramaya University. Special thanks go to Dr. Abebe Aschalew for teaching me the course and the time he spent reviewing the manuscript for publication. I thank the Professor Maud Kamateni-Mugisha for giving me a study leave to pursue PhD. God bless you all, *Our God Reigns!*

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