





Review

A Review of Climate-Smart Agriculture Research and Applications in Africa

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Abstract: Funders and governments are promoting climate-smart agriculture (CSA) as key to agricultural adaptation under climate change in Africa. However, with its progressions still at the policy level and framework description, there is a need to understand the current developments and activities conducted within the CSA research field. We conducted a scientific mapping and analyses of CSA research studies in Africa to understand the (i) thematic trends, (ii) developments, (iii) nature of collaboration networks, and (iv) general narratives supporting the adoption and application of CSA in Africa. Results show that several African countries had endorsed CSA as an approach to addressing agricultural productivity challenges, supporting adaptation strategies, and building resilience to climate change. However, a majority do not have national Climate-Smart Agriculture Investment Plans (CSAIPs). Additionally, CSA research in Africa is still developing, with only a few countries dominating the research outputs. For a successful implementation of CSA, a framework provided by the CSAIPs must be established to guide the processes. This will provide a framework to guide the integration of government programs, policies, and strategic plans by combining other inputs from stakeholders to support decision making and implementation of CSA.

Keywords: agroecology; climate change; ecosystem management; food security; policy; sustainability; resilience



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1. Introduction

Climate change modifies agricultural production and food systems, introducing uncertainty and vulnerability risks within farmers and policy decision-makers [1]. There is no doubt that impacts of climate change pose significant challenges to global food security, and this is envisaged to exacerbate over the coming years due to livelihood pressures such as the rise in population, economic development, urbanization, and the frequent occurrences of natural hazards such as extreme temperatures, drought, and floods, among others. It is estimated that the living conditions of about 9 billion people globally will worsen by 2050, whereby hunger and poverty will be taking the lead, making it substantially hard to put food on the table [2–4]. Consequently, various international institutions are working together with the World Bank and the Food and Agricultural Organization (FAO) groups to devise agricultural systems that will enhance and boost food production at all levels, from global to local. Subsequently, a global shift to climate-smart agriculture (CSA) has been applauded by various institutions, including stakeholders such as research, policymakers, and investments, and across private, public, and civil society sectors [5,6].

While the definition of CSA is dispersed in scientific and technical publications, numerous definitions have been proposed by, e.g., climate change organizations, agricultural

scholars, and research organizations. Considering the diversity of definitions reported in the literature, Adesipo et al. [7] compiled a set of keywords that characterize the key attributes of CSA. These keywords include capacity building, sustainability, emission and vulnerability reduction, profit, food security, transformation, new knowledge, technology, and productivity. Although the suggested keywords are not exhaustive, most definitions of CSA are built around them, with at least two of the words considered in the definition. For instance, Engel and Muller [8] defined CSA as a sustainable approach that can enhance agricultural productivity and income through adopting adaptation strategies while promoting resilience to climate change and minimizing greenhouse gas emissions. Campbell et al. [9] defined CSA as methods that transform agricultural systems to enhance food production and security under the changing climate. Similarly, Adesipo et al. [7] comprehensively defined CSA as a transformative and sustainable form of agriculture that aims to improve productivity in food security and production systems, based on coupling the key pillars of climate change (e.g., adaptation, resilience, and mitigation) in addition to smart and advanced technological knowledge, thereby increasing profit, and to minimize vulnerability through reducing greenhouse gas emissions.

The CSA approach, as presented in the literature, advocates the integration of climate change towards the planning and implementation of sustainable agricultural strategies, thus identifying synergies and trade-offs within the three pillars of CSA (known as food security, adaptation, and mitigation), in support of climate change-related policy and decision making [10]. In particular, CSA aims to support efforts that promote food and nutrition security, thereby assimilating essential adaptation and mitigation measures, as per its definition [6]. It provides enabling tools where different technologies and practices can be evaluated concerning their outcomes, specifically national development and food security objectives under the changing climate. In addition, CSA integrates sustainable agricultural development experience and knowledge as well as participatory community-driven approaches [10], taking into account sustainable intensification as the fundamental basis of on-farm productivity and income, in addition to existing agricultural land protection measures. Furthermore, CSA stresses the use of low-income agricultural systems such as conservation of agriculture; agroecology; ecosystems services; small-scale irrigation; aquaculture and agroforestry systems; soil/water conservation and nutrient management; integrated crops; livestock; landscape approaches; grassland and forestry management; and best practices of minimizing tillage and breeds, all in order to enhance food productivity, adaptation, and mitigation measures [11].

Most of these CSA best practices have been tested and promoted in various countries in Africa, as documented in the literature. These include the use of an integrated soil fertility management framework (e.g., combined organic and mineral fertilizers) to increase maize yields in sub-Saharan Africa [12], Uganda [13], Nigeria [14], and Kenya [15]. Successful stories have been reported on the use of soil conservation and multiple stress crop practices in Nigeria [16], South Africa [17], Ethiopia [18], Mozambique [19], Zimbabwe [20], and Ghana [21], resulting in a significant increase in drought-tolerant maize variety yields as well as improving small-scale farmers' and smallholder households' overall income. The importance of socio-economic, integrated biodiversity, and gender aspects was also explored in Nigeria [22], highlighting the empowerment gap between men and women.

In recent years, CSA has substantially become a fundamental notion for most global organizations at the center of the climate change, agriculture, and development nexus [3]. In addition, CSA has been considered an essential mechanism for achieving the Sustainable Development Goals (SDGs) [23]. Most of all, CSA comes in handy to mostly rural African farmers, who are more vulnerable to extreme weather and climate conditions. Most of the developing countries are exploring different ways to create cheap and reliable weather monitoring and forecasting systems and integrate such systems with advanced smart technologies such as agricultural drones, bio-sensors, IoT-based sensors, remote sensing, and husbandry, among others, in order to upscale crop and livestock management as well as increasing food security [24,25]. Precision agriculture, also within the umbrella

of smart agriculture and CSA, has significantly contributed to smart agricultural farming in, for instance, Ghana [26], Kenya [27], Nigeria [28], and South Africa [29], ensuring greater agricultural productivity and minimizing farming losses [24]. While the concept of CSA is well articulated in the literature and has been substantially applauded by various institutions worldwide, the scope of research within this subject matter, especially in Africa, is not exhaustive. Various aspects of CSA research, including the aspect of integration of the three pillars of CSA, have been relatively reported in the literature. In a recent review study by Chandra et al. [11], research on CSA was classified as relatively new, with its progressions still at the policy level and framework description. For Africa to successfully implement CSA, there is a need to understand the current developments and activities conducted within the CSA research field. For this purpose, the current review aims to conduct a scientific mapping and analysis on CSA research studies in Africa to understand thematic trends, developments, the nature of collaboration networks, and general narratives supporting the CSA scientific domain. Consequently, this study will make an important (a) scientific contribution through an exposition of the evolution of CSA research themes and methodology, a fundamental aspect necessary to build the CSA body of science, and (b) practical contribution in terms of keeping the community of practice abreast with current hot topics and the future direction of CSA in support of climate-related policy decision making.

2. Materials and Methods

The current review study considered various search topics to retrieve scientific documents relating to CSA research in Africa. The search themes were widely defined to cover the scope and research topics within the CSA subject matter as much as possible. Consequently, these search topics covered aspects of climate change and areas around policy and decision making, governance, best practices in farming, and technologies involved. Relevant scientific published documents were retrieved using the Web of Science (WoS) and Scopus core collection databases. These databases are widely used in most review studies. They provide a wide range of peer-reviewed research documents, including scientific articles, books/book chapters, and conference proceedings, among others, in almost all scientific disciplines. Documents were searched by entering the keywords “climate-smart agriculture*”, “precision agriculture”, or “precision farming” coupled with “climate change*”, “governance”, “smart farming”, or “technologies” as well as with “Africa”, for areal restriction (see Table 1 for a complete set of the search topics). While the study area was restricted to Africa, the search was open-ended regarding the study period. The retrieved documents contained key information such as authors, title, keywords, abstract text, countries, institutions, journals, and cited references. These document types including articles, book chapters, and conference proceedings are shown in Figure 1. The resulting output consisted of 249 documents, spanning from 2000 to 2020. These scientific documents were co-authored by 869 researchers across different countries, including those from outside the African continent.

Table 1. Topics used in Scopus and Web of Science collection databases to search and retrieve published documents on climate-smart agriculture in Africa.

| Search Topic | Areal Restriction | Areal Restriction |
|-----------------------------|-------------------------------|-------------------|
| “climate-smart agriculture” | [AND] “climate change” | [AND] “Africa” |
| “climate-smart agriculture” | [AND] “smart farming” | [AND] “Africa” |
| “climate-smart agriculture” | [AND] “governance” | [AND] “Africa” |
| “climate-smart agriculture” | [AND] “farmers” | [AND] “Africa” |
| “climate-smart agriculture” | [AND] “decision making” | [AND] “Africa” |
| “climate-smart agriculture” | [AND] “agricultural policies” | [AND] “Africa” |
| “climate-smart agriculture” | [AND] “technologies” | [AND] “Africa” |
| “Precision agriculture” | | [AND] “Africa” |
| “Precision farming” | | [AND] “Africa” |

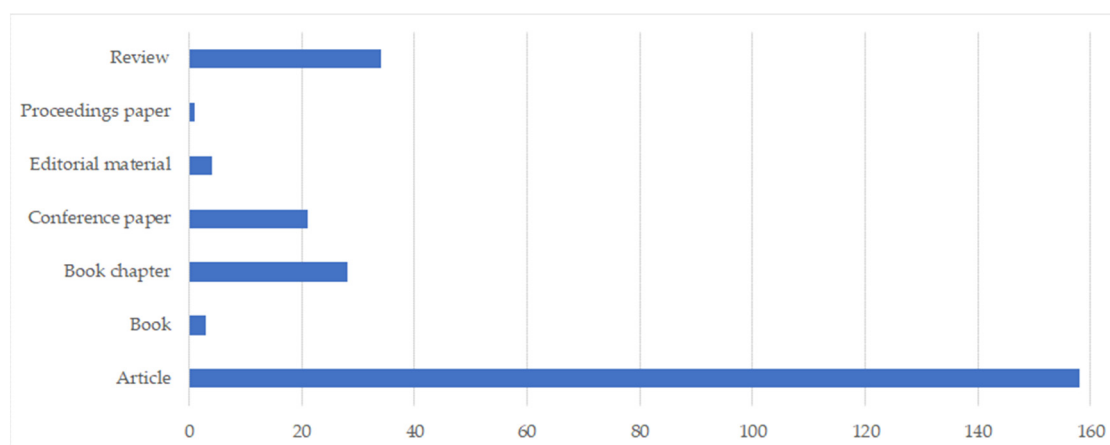


Figure 1. Number and type of documents retrieved and analyzed in the review study of climate-smart agriculture research in Africa.

The review was based on bibliometric analysis; a technique commonly used to study the structural and dynamic aspects of research topics using scientific mapping [30,31]. Consequently, CSA science mapping undertaken in this review study assessed the following themes: (1) annual publication growth and trends; (2) leading countries contributing to the CSA body of knowledge; (3) collaborations; (4) keyword co-occurrences; and (5) emerging themes. In addition, the VOSviewer program was used to create network visualization output maps for both country collaborations and keyword analysis. The strength of country collaboration was measured based on the total link strength given by VOSviewer. VOSviewer also assigns items (e.g., countries and keywords) into specific clusters, where the size of the cluster represents the collaboration strength or high frequency of keywords.

3. Results

3.1. Scientific Mapping of Climate-Smart Agriculture Research in Africa

3.1.1. Growth Patterns in Climate-Smart Agriculture Research

Figure 2 depicts the yearly scientific publications of climate-smart agriculture outputs. As depicted in Figure 2, research in CSA in Africa started to gain momentum from 2014. Since then, there has been a relative increase in scientific publications, suggesting a growing interest in the CSA subject matter. The scientific production of CSA published articles significantly increased from 2017, reaching the highest number of 56 articles in 2020.

Overall, CSA research in Africa is relatively growing, with an annual percentage growth rate of approximately 22.3%. This significant growth rate suggests that CSA is gradually borne out of necessity as the effects of climate change continue to impact people's lives negatively. Consequently, the greater scientific community has explored more innovative farming methods to mitigate inherent future climate impacts on agriculture.

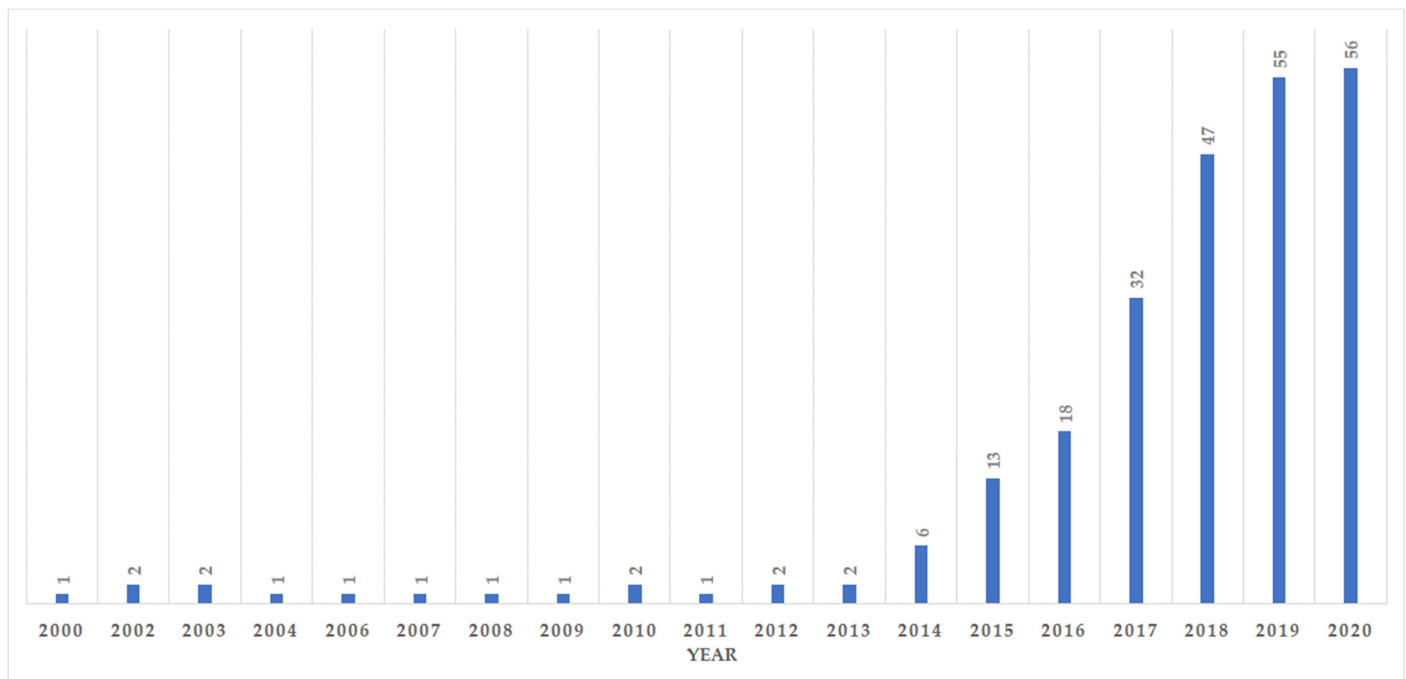


Figure 2. Annual publications of climate-smart agriculture research articles showing a steady increase from an average of 1 publication per year between 2000 and 2010 to 56 publications in the year 2020.

3.1.2. Most Productive Countries in Climate-Smart Agriculture Research

The top ten countries that have significantly contributed to the CSA research output in Africa are shown in Figure 3. It can be observed that only ~40% of the African countries appear in the top ten list. These include Kenya, taking the lead with 20 scientific publications, followed by South Africa with 12, and Zimbabwe and Mali with 11 and 10 scientific outputs. The leading countries are ranked based on the author's correspondence country.

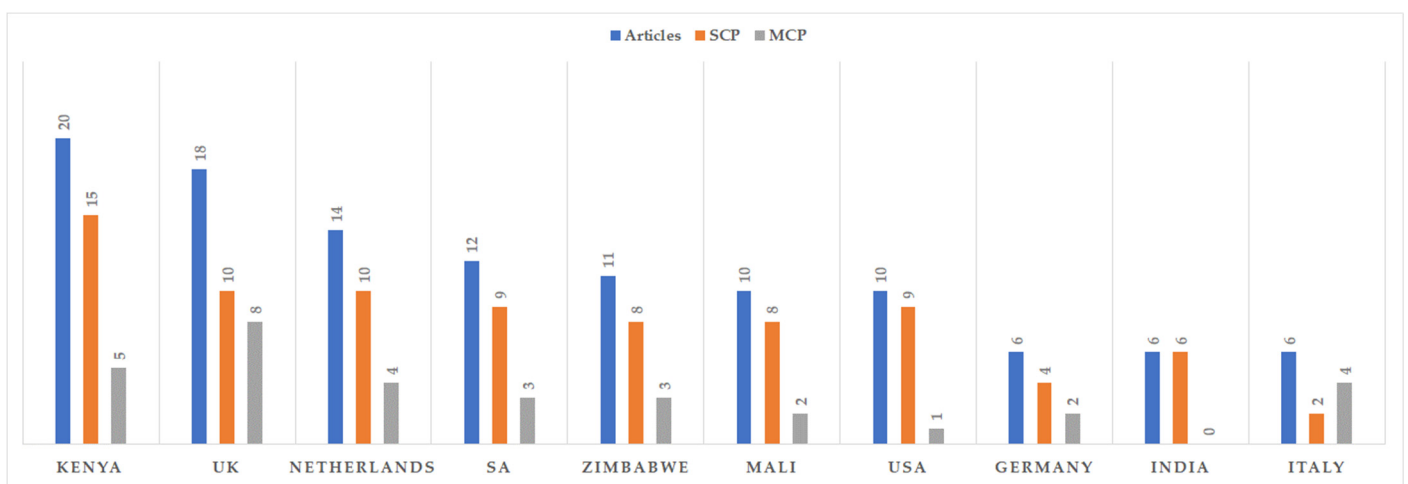


Figure 3. Top ten leading countries in climate-smart agriculture research publications. The ranking is based on the corresponding author's country. SCP: single-country publications; MCP: multiple-country publications.

The results shown in Figure 3 also show that developed countries such as the United Kingdom (UK), the Netherlands, the United States of America (USA), and Germany appear in the top ten list, suggesting that authors in these countries have collaborated in CSA research projects in Africa, resulting in the research work being disseminated through scientific publications. In general, the 249 CSA documents were co-authored

by 849 researchers through multi-country publications (MCP), with only 20 researchers publishing through single-country publications (SCP). In the top ten list of the leading countries, the orange and silver indicate publications achieved through SCP and MCP processes, respectively. It is noted that Africa needs to enhance its collaborations to contribute to the CSA scientific domain significantly.

The published CSA research is well recognized globally, as attested by the citation scores provided in Table 2. Over the study period, the Netherlands has received the highest citations (683), followed by Kenya, Zimbabwe, and Mali, with 159, 154, and 136 total citations. The rest of the countries have received less than 100 citations over the same period, including Burundi and Zambia, with 61 and 46 total citations. Column 3 of Table 2 shows the ten main sources that have published scientific documents related to CSA. The ranking of these sources is based on the total number of the published documents. Most of the sources are journals, reflecting a great interdisciplinary nature of the CSA research field in Africa. Approximately 25% of the documents were published in journals, with *Agricultural Systems* leading with ten published scientific articles, followed by *Frontiers in Sustainable Food Systems* (nine), *Climate Change Management* (eight), and *Sustainability* (Switzerland), with seven published articles. *Food Security*, *Agronomy for Sustainable Development*, *International Journal of Agricultural Sustainability*, and *Field Crops Research* also emerge as key multidisciplinary sources in the CSA research topic.

Table 2. Top ten total citations per country and top publication sources.

| Country | Total Citations (Average Article Citations) | Top Relevant Sources (Number of Articles) |
|----------------|---|---|
| Netherlands | 683 (48.8) | <i>Agricultural Systems</i> (10) |
| Kenya | 159 (8.0) | <i>Frontiers in Sustainable Food Systems</i> (9) |
| Zimbabwe | 154 (14.0) | <i>Climate Change Management</i> (8) |
| Mali | 136 (13.6) | <i>Sustainability</i> (Switzerland) (7) |
| United Kingdom | 82 (4.6) | <i>Food Security</i> (6) |
| Italy | 68 (11.3) | <i>Agronomy for Sustainable Development</i> (5) |
| Spain | 63 (63.0) | <i>International Journal of Agricultural Sustainability</i> (5) |
| Burundi | 61 (61.0) | <i>Agriculture and Food Security</i> (4) |
| USA | 49 (5.0) | <i>Field Crops Research</i> (4) |
| Zambia | 46 (11.5) | <i>Journal of Cleaner Production</i> (3) |

3.1.3. Country Collaboration Network

Figure 4 depicts the top 45 countries' collaboration network of the retrieved CSA documents, assigned into nine clusters. Detailed information on these clusters and the corresponding countries is given in Table 3. The size of the cluster represents the most collaborative country. As noted in Figure 4, Kenya (26) in the light blue cluster is the most collaborative country, followed by Tanzania with 13 links. Similarly, Germany (13) and South Africa (11) are the most collaborative countries in the red cluster, whereas Colombia (13), India (11), and Morocco (10) are the most influential countries in the light brown cluster. Zimbabwe (16) takes the lead in the yellow cluster, followed by the United Kingdom and Zambia, with 11 and 9 country links. Ghana, Switzerland, and Italy are the most influential countries in the green cluster, with 13, 9, and 9 association links, respectively. Furthermore, the Netherlands (21) and Mali (8) are the most collaborative countries in the purple cluster.

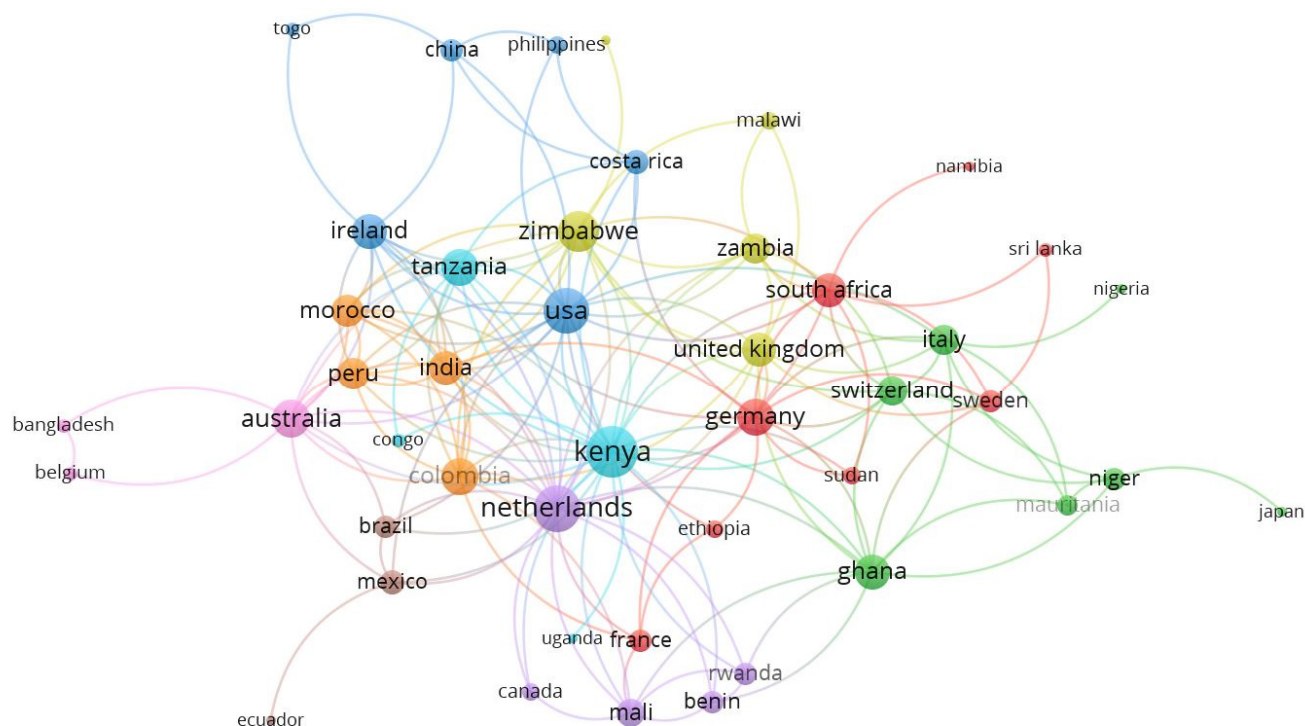


Figure 4. Countries' collaboration network among different countries.

Table 3. Clusters of countries' collaborations in climate-smart agriculture research in Africa.

| Cluster | Leading Countries Per Cluster | Remarks |
|-------------|--|--|
| Red | Germany (13), South Africa (11) | Countries in this cluster have significantly collaborated with countries in yellow, green, and light blue clusters |
| Green | Ghana (13), Switzerland (9), Italy (9) | Ghana, as the leading country in this cluster, has collaborated with countries in the same cluster and the yellow, red, purple, and light blue clusters |
| Dark blue | USA (20), Ireland (12) | The USA has collaborated with most countries across the clusters |
| Yellow | Zimbabwe (16), UK (11), Zambia (9) | Zimbabwe has collaborated with most countries across the clusters, except for the dark brown cluster |
| Purple | Netherlands (21), Mali (8) | The Netherlands has shown a significant collaboration across most countries and clusters |
| Light blue | Kenya (26), Tanzania (13) | Kenya is the most leading country in collaborations across all the clusters |
| Light brown | Colombia (13), India (11) | Countries in this cluster have collaborated with most African countries, including Zimbabwe in the yellow cluster and Tanzania in the light blue cluster |
| Dark brown | Mexico (5), Brazil (5) | Collaborations in this cluster are mostly with Kenya, the Netherlands, the USA, and Australia |
| Pink | Australia (14) | Significant collaborations between Australia and African countries such as Kenya, Zimbabwe, Morocco, and Tanzania |

3.1.4. Main Keywords

Figure 5 depicts the frequently used keywords in the CSA published scientific articles. The core collection databases used in this review study provide two categories of keywords, namely, the author keywords and the keywords-plus (extracted from the titles of the cited references). Table 4 gives the topmost author keywords and keywords-plus generated using CSA published articles. Based on the author keywords analysis, the climate-smart

agriculture keyword was used by approximately 58 authors, making it the most used keyword in CSA published scientific articles. Climate change, food security, and adaptation keywords were mostly used, appearing in 38, 23, and 19 CSA articles, respectively.

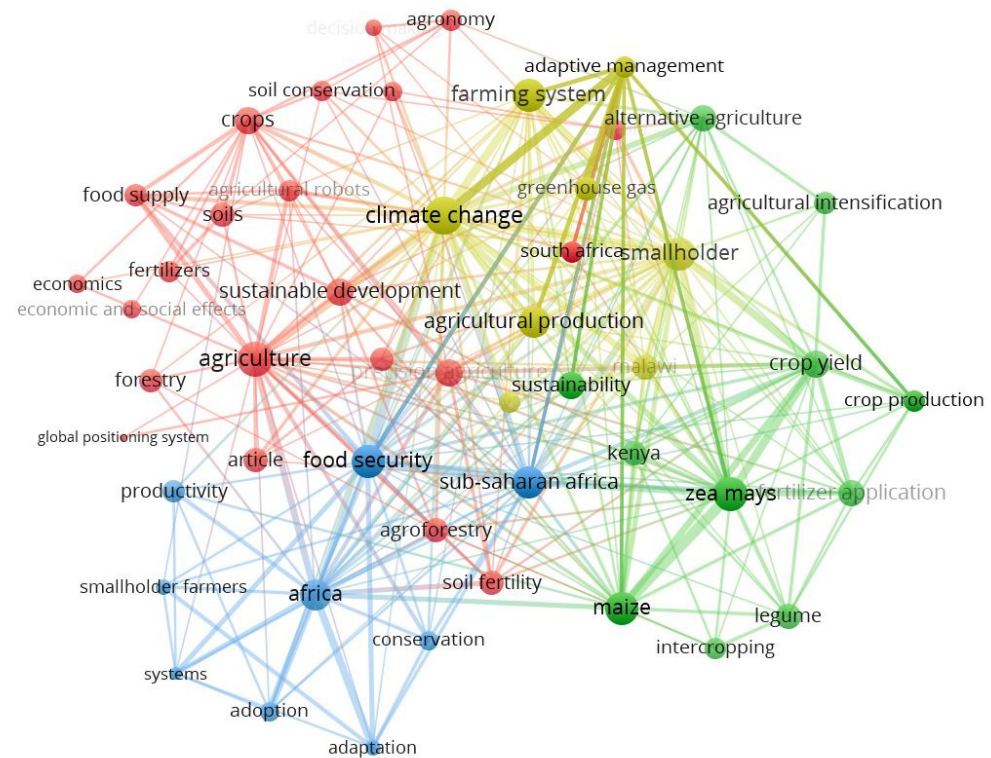


Figure 5. Keyword occurrences.

Table 4. Most relevant keywords.

| Author Keywords (Number of Articles) | Keywords-Plus (Number of Articles) |
|--------------------------------------|------------------------------------|
| Climate-smart agriculture (58) | Climate change (51) |
| Climate change (38) | Africa (47) |
| Food security (23) | Agriculture (45) |
| Adaptation (19) | Sub-Saharan Africa (32) |
| Sub-Saharan Africa (18) | Food security (30) |
| Agriculture (17) | Smallholder (25) |
| Mitigation (14) | Precision agriculture (24) |
| Precision agriculture (14) | Maize (20) |
| Sustainable intensification (12) | Adaptation (18) |
| Conservation agriculture (11) | Sustainable development (15) |

On the other hand, climate change is the most frequently used keyword-plus, appearing in 51 titles of cited references, followed by Africa, agriculture, sub-Saharan Africa, and food security, appearing in 47, 45, 32, and 30 titles of the cited references. The mapping of keyword occurrences resulted in four clusters, as shown in Figure 5. As noted in the figure, climate change, the leading keyword in the yellow cluster, is linked with other important keywords in CSA such as agriculture (red), food security (blue), crop production (green), farming systems, and smallholder (both in the yellow cluster). Such linkages suggest that the scientific community is increasingly paying attention to these keywords, with a common interest in advancing CSA research in Africa. Overall, the identified keywords are a combination of the three pillars of CSA and agricultural best practices.

3.1.5. Thematic Network

A thematic map is used to assess the evolution of themes or topics in the CSA research field. As shown in Figure 6, the thematic map is sub-divided into four quadrants, where the upper-right quadrant indicates the motor themes (hot topics); themes appearing in the upper-left quadrant are considered very specialized topics; and words in the lower right and lower left are termed basic themes and emerging/disappearing themes, respectively. Consequently, the scientific community pays greater attention to the hot topics appearing in the upper-right quadrant of Figure 6 within the CSA subject matter. These motor themes include “conservation agriculture”; “sustainable development”; “sustainable land development”; “breeding”; “broomrape”; and “chemical control”, among others. Similarly, “precision agriculture”; “remote sensing”; “aquaponics”; “agro-ecological gradient”; “farming systems”; “maize production”; “minimum tillage”; and “soil degradation”, in the upper-left quadrant, are well-developed and integral topics to the advancement of CSA research in Africa. Themes in the lower-left quadrant such as “pearl millet”; “agricultural intensification”; “sorghum”; “crop modelling”; “small farms”; “food systems”; “greenhouse gas emissions”; “agricultural transformation”; and “agroecology” are considered as emerging or disappearing with a low density and centrality. These themes are considered to have marginal relevance to the CSA research field. Basic themes in the lower-right quadrant cover words such as “climate-smart agriculture”; “climate change”; “food security”; “climate change adaptation”; “precision farming”; “gender”; and “livestock”, among others.

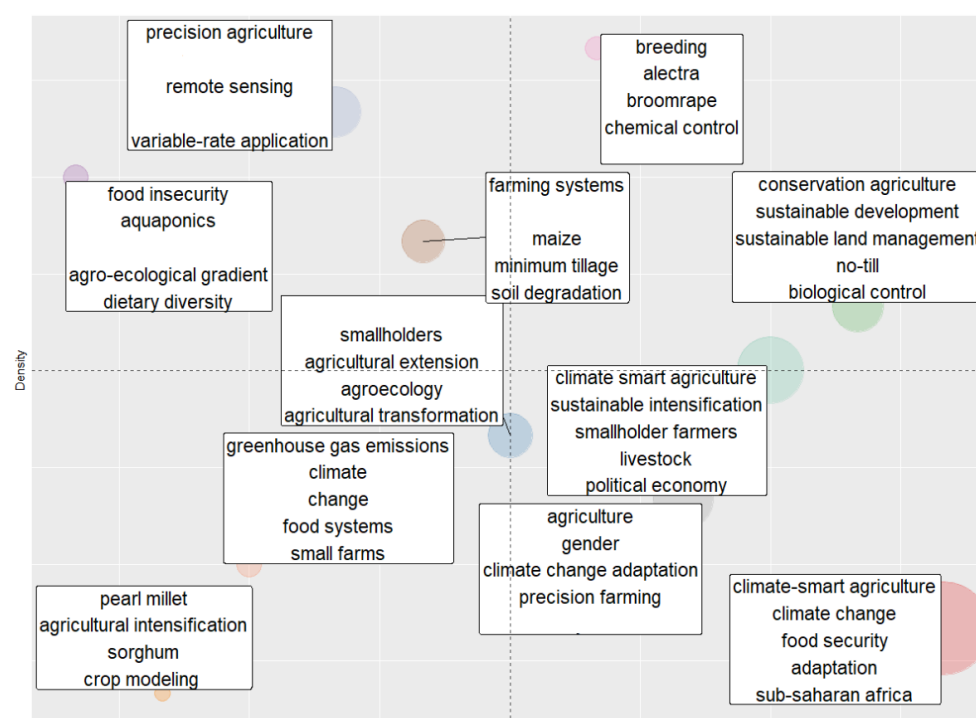


Figure 6. Thematic map of emerging themes in CSA research.

4. Discussion

4.1. Salient Features of Climate-Smart Agriculture Research in Africa

Food security is at the greatest risk, particularly in sub-Saharan Africa, due to various factors that include, but are not limited to, uncertainties of climate change, market fluctuations, and land degradation [32], as well as the region’s ongoing population growth, which is projected to double by 2050 [3,4]. Several African countries have accepted a proposed solution of implementing CSA to tackle agricultural productivity challenges, thereby increasing food productivity, supporting adaptation strategies, building resilience to climate change, and minimizing the effects of greenhouse gas emissions [4]. There is

substantial evidence that CSA has been welcomed in Africa. This notion is attributed to the number of countries that have already conceptualized and implemented the framework of CSA and the significant research output available from published agricultural-related scholars. Based on the current review study, CSA research in Africa commenced in 2000, as reported in Gandah et al. [33]. In the Gandah et al. [33] study, the authors explored the possibilities of using a simplified scoring approach in the context of low-tech precision farming to estimate millet yields, and the results were greatly encouraging. While CSA research progressed at a very minimal rate between 2000 and 2013, the research began to gain momentum from 2014, reaching a tremendous achievement in 2020, resulting in 56 published articles. There is no doubt that such significant growth can be attributed to African countries paying greater attention to the impacts of climate change, which manifests in drought, floods, and extreme temperatures on agriculture, and wanting to find possible solutions to minimize such impacts to increase productivity. This great progression suggests that the scientific community and all relevant stakeholders in the African continent are becoming more familiar with CSA applications and exploring avenues to enhance their knowledge for implementing the CSA framework. Implementation of CSA is also encouraging, particularly at a country level, where integration of both agricultural practices/technologies and the local relevant innovations that tend to uplift the three pillars of CSA can be fully realized [34].

Although the interest in CSA research in Africa is notable, only a few countries have taken the lead in advancing the research domain. For instance, considering the top ten leading countries in CSA research publications, only 40% of the countries appeared on the list. The corresponding author is usually based in Africa (e.g., Kenya, South Africa, Zimbabwe, and Mali). This can be seen to suggest that CSA research in Africa is still nascent, as it has been reported in Chandra et al. [11]. In general, there is a wealth of evidence available on CSA research in East Africa, particularly in Kenya, Ethiopia, Uganda, Burundi, and Tanzania; West Africa in Nigeria, Mali, and Ghana; and Southern Africa in South Africa and Zimbabwe. This plethora of evidence suggests that Africa can do much better if its countries expand and extend collaborations with neighboring countries and those abroad, particularly outside the continent. This review has shown that Africa still lacks in terms of international collaborations. It is also alarming to note that such collaborations are mostly between developing countries, such as South Africa, Kenya, Tanzania, and Zimbabwe, with strong collaborations with international countries such as the USA, Germany, the Netherlands, and Australia. While these collaborations are well appreciated, it is imperative to include under-developed countries in the CSA subject matter. This will be a stepping stone to implementing the CSA concept, realizing its benefits, and, consequently, achieving the much-needed agricultural transformation in sub-Saharan Africa.

According to keywords analysis, most research studies reported in Africa have focused on potential CSA technologies and practices, summarized in Table A1 of Appendix A. Much of these production systems are reflected in the main keywords network shown in Figure 5. The keywords are mostly under the low-cost sustainable agriculture practices umbrella, such as crop conservation, maize (*Zea mays*), fertilizers, precision agriculture, soil conservation, agronomy, agroforestry, legumes, remote sensing, and grazing land management, among others. The frequency of these keywords' frequency agrees with the notion that most farmers/farming communities in Africa are exploring advanced technologies as part of good farming practices. Most of the low-cost sustainable agriculture practices identified in this review study are available. They have been implemented in some African countries, as evidenced in the selected scientific publications summarized in Table A1. In particular, there is a wealth of evidence of positive impacts of CSA on agricultural productivity, including applications of maize production systems, especially in South Africa [35,36], Zimbabwe [37,38], and Kenya [39,40].

CSA research in Africa has focused on conservation agriculture, sustainable development, sustainable land development, animal breeding, broomrape, and chemical

control, which build on top of CSA practices. According to the documents assessed in this review, we have noted topics such as the precision agriculture; remote sensing; aquaponics; agro-ecological gradient; farming system; maize production; minimum tillage; and soil degradation parts of CSA research in Africa. As CSA research continues to progress in Africa, new emerging issues and more scientific knowledge are becoming imperative. Emerging issues identified in this review study include agricultural extension/intensification/transformation, farming systems, crop modeling, agroecology, pearl millet, and sorghum, among others. While these topics are not completely new in the CSA subject matter, they are considered important issues that constantly emerge during CSA conceptual framework discussions, mostly at country levels.

4.2. Progression and Adoption of Climate-Smart Agriculture Technologies in Africa

Forty-eight countries share mainland Africa and six islands totaling 54 sovereign African countries. According to the World Bank, only 14 (26%) have developed CSA country profiles. These are Benin, Côte d'Ivoire, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Rwanda, Senegal, Tanzania, The Gambia, Uganda, Zambia, and Zimbabwe. Despite the slow uptake, there are two highlights among the early adopters of CSA, demonstrating that the approach is beneficial [41].

- The current agricultural production pathway in Lesotho focuses on extensive animal grazing and expansion of cropland. It is characterized by a monoculture cropping system dominated by maize, which is unsustainable. The Lesotho Climate-Smart Agriculture Investment Plan (CSAIP) offered two alternative pathways for scaling up CSA by focusing on commercialization and a resilient landscape. The latter combines modern scientific knowledge with a traditional farming system, the Machobane Farming System. The MFS uses crop rotation, relay cropping, and intercropping practices to apply manure and plant ash to conserve soil moisture and replenish soil fertility that is highly adapted and resilient to climate change. As a result, CSA achieved increased productivity and incomes; enhanced food security and dietary diversity; reduced impacts of climate change on agricultural produce; and improved commercialization, employment opportunities, and rural livelihoods.
- Further, the CSA approach enhanced the reduction in soil erosion, addressed generation and carbon sequestration, promoted conservation biodiversity, and provided other public goods that accrue to society. Upon its success, the Government of Lesotho is currently implementing the second phase, referred to as the Smallholder Agricultural Development Project (SADP II). This phase supports transformative interventions for agricultural productivity and resilience at the farm and landscape levels; provides solutions at the institutional level to ensure the sustainability of agricultural outcomes; encourages commercialization that would contribute to improved livelihoods; and promotes better nutritional outcomes towards improved human capital development [41].
- Mali was involved in a multi-country effort coordinated by the World Bank to develop a national Climate-Smart Agriculture Investment Plan (CSAIP). The Malian CSAIP uses an established framework and builds on programs, policies, national strategic plans, and local, national, regional, and international institutions. Mali prioritized a set of 12 investments and actions required to boost crop resilience and enhance yields for over 1.8 million beneficiaries and their families by helping them adapt to climate change. The process used to develop this plan also supports engagement and capacity strengthening [41].
- Kenya established the Kenya Climate-Smart Agriculture Program (2015–2030) to deal with increased productivity, adaptation, and mitigation across production systems. Kenya's demographics also indicate that 74% of the population reside in rural areas and that 11 million people are actively employed in primary production agriculture [42,43]. The agricultural sector in Kenya is categorized as Very Small Landholdings (0.3–3.0 ha), Medium Scale Production (3–49 ha), and Large-Scale Production of

>50 ha of crops or >30,000 ha of livestock [44]. Most farmers still rely on traditional agricultural practices, and nearly 24% of the population is undernourished. The other key factor is that agriculture contributes 28% of the gross domestic product (GDP), and 80% of the total agricultural production units are at the small scale (<3 ha) of land area [2,4,42,43,45] (Kenya, therefore, had to develop the Kenya Climate-Smart Agriculture Program (2015–2030) to coordinate domestic and international CSA interventions to address a socio-economic challenge). Such long-term strategic policies are lacking in most African countries. It was noted that many initiatives in Kenya have elements of CSA but are not referred to as CSA, nor do they address them using a climate change perspective. Still, socio-economic considerations were more important in making decisions than climatic and environmental factors [46]. Nonetheless, given that Kenya has an existing framework, it is much easier to incorporate CSA concepts into existing practices.

Thus, the positive outcomes in the sampled projects that emphasize CSA have proven that the approach in agricultural production is sustainable and can uplift the living standards of smallholder farmers. The projects, however, have had a short lifespan of only 2–5 years. This, therefore, leaves a gap as there is little literature regarding follow-ups or sustained support to enable farmers to become self-reliant. For CSA to be more beneficial, CSA needs to be embedded into policy or long-term strategic plans. The benefits have addressed all the main pillars of CSA: sustainability and increasing productivity, adaptability and resilience, mitigation, and the spinoff benefit of gender mainstreaming. The overall effect has been changing in smallholder farmers' mindset to deviate to crops suited for their respective agro-ecological zones for both consumption and cash crops.

A major theme of CSA technology that has witnessed rapid growth is precision farming [26]. The integration of Earth observation satellites, the Global Positioning System (GPS), and geographical information system (GIS) technologies has provided the expanded scope of precision agriculture practices vital for fine-scale (at the field) monitoring and mapping of crop phenology parameters and yield. In this regard, the review results show evidence that these precision agriculture practices have continued to provide more data to farmers supporting robust decision making under changing economic and environmental factors. The reality of climate change and its negative impact on the environment, socio-economic activities, and food security cannot be emphasized. Various approaches to CSA have been proposed and implemented on the continent. However, there is a missing link: the fusion of information technology into CSA suited for smallholder farmers. In this regard, the use of unmanned aerial vehicles (UAVs) or drones is proposed.

Regarding the adoption of drones for sustainable agricultural management, the uptake of drone technology has steadily grown from a global perspective, e.g., [7]. Notwithstanding this noticeable drone technology adoption growth globally, the present review results illustrate that drone use in the agriculture industry in the African continent remains minuscule, especially among the smallholder farmers, who have been identified as critical in ensuring food security on the African continent. It is opined that the continent's agriculture industry stands a chance to be revolutionized and thereby lift the African populace out of poverty if the various barriers impeding the adoption of drone technology (such as cost, infrastructure, legislation, and human capital) are addressed.

4.3. Implications of Climate-Smart Agriculture Research for Policy and Decision Making

Nearly 74% of the continent's countries do not have national Climate-Smart Agriculture Investment Plans (CSAIPs). Only 5%, namely, Ghana, Mali, and Niger, have CSAIPs under development. For a successful implementation of CSA, a framework provided by the CSAIPs must be established to guide the processes. However, CSA focuses specifically on agriculture, a multi-dimensional approach that includes commitments to enhancing livelihood benefits, ensuring food security, and promoting sustainability. Thus, CSAIPs provide a framework and processes and then incorporate the government programs, policies, and strategic plans by combining other inputs from stakeholders locally, nationally,

regionally, and globally. Without CSAIPs, most CSA-based projects will be ad hoc and short-lived. CSA policies in the sampled African countries are anchored on the United Nations Framework Convention on Climate Change (UNFCCC) 22nd Conference of Parties in Marrakech, Morocco [47]. The Moroccan government launched the Adaptation of African Agriculture (AAA) Initiative, emphasizing investment needs for helping African countries cope with climate change risks to agriculture and best position themselves for a future of higher temperatures and uncertain precipitation. The AAA Initiative also builds on the Comprehensive African Agriculture Development Programme (CAADP), first launched in 2003 through the African Union. All the African countries featured in the analysis are signatories to the UNFCCC Paris Agreement. They have submitted their Nationally Determined Contributions (NDC), committing to adaptation to climate change and reducing greenhouse emissions [41]. These countries have also mainstreamed CSA as a core aspect of their long-term strategic plans in agriculture and formulated policies that govern the establishment, administration, collaboration, and funding aspects. The real benefits of CSA can only be achieved in the long term after understanding and mitigating any challenges as the new paradigm shifts. It is hoped that the African CSA investment strategies will be developed with urgency and with strong stakeholder engagement, expert input, and scientific evidence.

5. Conclusions

A bibliometric analysis study was conducted to assess and systematically synthesize the nature of CSA research's salient features, such as developmental patterns, research collaborations, keywords, and emerging themes within the subject matter, in Africa. Annual scientific publications have substantially increased from 2014, reaching the highest number of outputs in 2020. African countries need to uplift their collaborations with sister countries as well as international organizations. Most collaborations are between developed countries, implying that under-developed countries are being left behind, yet the impacts of climate variability and change cut across the countries, with no regard to the country status. Adopting and integrating new CSA technologies (including drones) and big data applications (such as artificial intelligence and machine learning) is still nascent. The key implications of this study include (a) putting forth the argument that there is evidence that adopting CSA throughout the agricultural industry could revolutionize the sector, thereby lifting the African populace out of poverty, and (b) the CSA technologies are expected to change and be diversified, especially with the advent of the Fourth Industrial Revolution. The eminent changes in CSA technologies are expected to radically change the agricultural industry, suggesting that all the stakeholders, including policymakers, should be prepared to embrace these disruptive technologies. While CSA research in Africa has shown substantial progression in multidisciplinary aspects, there is still a gap in policy implementation. For the sub-Saharan region to reap the benefits of CSA, concrete actions must be undertaken to, among other things, promote the implementation of context-specific CSA technologies by farmers, avail appropriate funds to farmers, promote investments, and develop policy frameworks that are supportive of CSA.

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Appendix A

Table A1. A summary of selected scientific publications on climate-smart agriculture studies in Africa published from 2000 to 2020. The information is only limited to published scientific articles. Hence, conference papers, proceedings, reviews, and books/book chapters are excluded in the summary. CA—corresponding author; PY—publication year, Ref #—reference number.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|----------------------|--------------|--|---|
| [26] | Zakaria A, 2020 | Ghana | Precision agricultural farming | <ul style="list-style-type: none"> - Participation in capacity building training, family labor, and agricultural insurance influence farmers' CSA practices adoption intensity. - It is recommended that climate change and agricultural projects consider farmer training for effective CSA practices |
| [48] | Musafiri CM, 2020 | Kenya | Farm-level soil fertility management and greenhouse gas emission (nitrogen application rate) | <ul style="list-style-type: none"> - Smallholder farming is vital in pinpointing greenhouse gas emission hotspots. - It is recommended that policies and intervention measures for CSA take into account both farm-level soil fertility management technologies and socio-economic characteristics that affect their adoption. |
| [49] | Shilomboleni H, 2020 | Kenya | | <ul style="list-style-type: none"> - The key challenges that are critical to African agricultural development were highlighted. |
| [50] | Kganyago M, 2020 | South Africa | Snap-derived leaf area index (precision agriculture) | <ul style="list-style-type: none"> - Significant errors with marked differences between SENTINEL-2 processing levels and insignificant differences between spatial resolutions were reported, suggesting that LAI is unsuitable for precision farming. - Further research on LAI with localized farm-level applications is recommended. |
| [12] | Gram G, 2020 | Uganda | Organic and mineral nitrogen applications | <ul style="list-style-type: none"> - The combination of mineral and organic fertilizers significantly increases maize productivity. |
| [51] | Ogada MJ, 2020 | Kenya | Livestock breeding | <ul style="list-style-type: none"> - The use of multiple stress-tolerant crops advances household revenue by 83%. Additionally, the application of enhanced livestock breeds substantially minimizes household revenue by 76%. |
| [27] | Maindi NC, 2020 | Kenya | Multivariate probit and ordered probit models (precision agriculture) | <ul style="list-style-type: none"> - It was noted that interdependence of tailored strategies, complementarity, and substitutional relationships are closely related. - Capital, gender, water availability, market access, and infrastructure and social networks are the most important determinants of adoption of CSA-related decision making and adoption and intensification of CSA strategies to enhance climate-smart dairy production systems. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|--------------------|--------------|--|--|
| [16] | Oladimeji TE, 2020 | Nigeria | Soil conservation practices (e.g., animal manure, crop residue retention, inter-cropping, and crop rotation) | <ul style="list-style-type: none"> - It was noted that a positive correlation exists; consequently, adoption decisions for soil conservation practices are interrelated, and the practices are measured by accompaniments by the farmers. - It is recommended that policy interventions strongly leverage important factors, such as contract farming, crop–livestock integration, and off-farm income diversification. |
| [35] | Abegunde VO, 2020 | South Africa | Social, technical, economic, and environmental compatibility | <ul style="list-style-type: none"> - Farmers have different perceptions of the social, technical, economic, and environmental compatibility of the practices. - It was noted that farmers showed high acceptance for the cultivation of cover crops, agroforestry, and diet improvement for animals (social compatibility assessment). - The use of organic manure was highly accepted, followed by rotational cropping, mulching, and cultivation of cover crops (technical compatibility assessment). - Farmers highly preferred mulching, organic manure, and rotational cropping (economic compatibility assessment), and the use of organic manure was highly embraced based on environmental compatibility assessment. |
| [15] | Paul BK, 2020 | Kenya | livestock intensification (on-farm forage cultivation, dairy breedings) | <ul style="list-style-type: none"> - Sustainable livestock intensification is essential to the CSA portfolio in Tanzania; it provides synergies between productivity and income increases and climate change mitigation as a co-benefit. - It recommended further research to increase understanding of the institutional settings, incentives, and coordination between stakeholders to sustainably transform the livestock sector. |
| [17] | Ighodaro ID, 2020 | South Africa | Soil conservation | <ul style="list-style-type: none"> - The adoption of CSA/soil conservation practices by smallholder farmers substantially influences farmers' overall revenue. |
| [52] | Abegunde VO, 2020 | South Africa | Organic manure, crop rotation, and crop diversification | <ul style="list-style-type: none"> - It was noted that climate change-related education through enhanced agricultural extension interaction and contact with media platforms could reinforce integrated farm activities, thereby boosting farm revenue. - It is recommended that farmer associations be given the necessary attention to facilitate CSA adoption for climate change mitigation and resilience. |
| [53] | Dadzie SKN, 2020 | Ghana | Precision farming | <ul style="list-style-type: none"> - Farmers' misperception on meteorological variables such as increased temperature and delayed/reduced precipitation, and the possibility of farmers' misperception of reduction in soil moisture. |
| [13] | Rware H, 2020 | Uganda | Fertilizer optimization tool (components: an optimizer tool, a nutrient substitution table, and a fertilizer calibration tool) | <ul style="list-style-type: none"> - There is a progressive shift in farmers' attitude towards the value of fertilizer. More fertilizer optimization tool users disagree with the suggestion that fertilizers destroy soils compared with non-fertilizer optimization tool users. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|-------------------|--------------|---|---|
| [22] | Oyawole FP, 2020 | Nigeria | Gender and women empowerment | <ul style="list-style-type: none"> - Men are more empowered than women and more likely to adopt crop rotation. - Female plot managers are likely to adopt green manure and agroforestry than organic manure and zero/minimum tillage. - There is a need for costing the empowerment gap between women and their spouses, as this has a positive influence on the adoption of agroforestry. |
| [28] | Olajire MA, 2020 | Nigeria | Precision farming (indigenous adaptations and climate-crop modeling system) | <ul style="list-style-type: none"> - An integrated approach to indigenous climate change adaptation strategies can minimize the negative effects of impending warming on agricultural crop yields. |
| [39] | Kurgat BK, 2020 | Kenya | Crop and livestock diversity, irrigation, chemical fertilizers, and agroforestry | <ul style="list-style-type: none"> - It was noted that farmers fairly adopted the application of chemical fertilizers, whereas irrigation was the least adopted, and that crop diversity and irrigation application of chemical fertilizer and agroforestry supplemented each other. - It was identified that major determinants of adoption included female control of farm resources, farm location, and household resources. - Recommended implementation of strategies that can enhance building household resource. |
| [29] | Mazarire TT, 2020 | South Africa | Precision agriculture | <ul style="list-style-type: none"> - Sentinel-2 data performed better in mapping crop types based on support vector machine compared to the SVM classifier compared to random forest classifier. |
| [54] | Mudereri BT, 2020 | Kenya | Precision agriculture | <ul style="list-style-type: none"> - Hyperspectral, resampled Sentinel-2 multispectral datasets and machine learning discriminant algorithms can be considered fundamental to discern Striga in heterogenous maize agro-ecological systems. |
| [55] | Moshia ME, 2019 | South Africa | Crop management, agronomy, precision farming | <ul style="list-style-type: none"> - It was recommended that a site-specific weed control plan using a row-guided robot be designed to detect and identify weeds with accuracy, control speed timeously, and spray herbicides with a high level of precision and automation. - These robotic methods are reported to be environmentally conscious and economically efficient with less labor and management. |
| [56] | Zougmor RB, 2019 | Mali | Adaptability, adoption, mitigation, resilience | <ul style="list-style-type: none"> - It was found that the effect of agricultural insurance on the adoption intensity of CSAPS is significant. - They recommended that climate change and agricultural projects incorporate farmer training on CSAPS to guide the adoption of multiple practices. Extension agents and FBOs should be targeted to disseminate information to farmers. |
| [37] | Mutenje MJ, 2019 | Zimbabwe | Productivity, sustainability, resilience (risk management), soil and water management | <ul style="list-style-type: none"> - The study provided evidence of the importance of cultural context, social relevance, and intra-household decision making in tailoring suitable combinations of CSA for smallholder farmers in Southern Africa. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|----------------------|--------------|---|--|
| [57] | Sanou L, 2019 | Burkina Faso | Land use, conservation of biodiversity, agroforestry, soil management | <ul style="list-style-type: none"> - The researchers conclude that an agroforestry project will be more successful if the local biophysical conditions and diversity of smallholder socio-economic characteristics and their perceptions, needs, and preferences are considered in its design. - They recommended an immediate need for the coordinated development of information and training to raise local community awareness of agroforestry's potential and disseminate information about adding value to tree products to encourage farmers to protect on-farm trees. |
| [58] | Makate C, 2019 | Ethiopia | Institutional credit (financing) and extension services | <ul style="list-style-type: none"> - It was noted that there is an enhanced collective impact of simultaneous access to credit and extension on CSA technology adoption. - It was found that joint impacts of credit and extension on adoption were less pronounced in youthful and women farmer groups than their old and male farmer group counterparts. - It recommended that prudent policy and institutional strategies improve access to credit and extension services in Malawian and Zimbabwean smallholder farming that are mindful of disadvantaged groups such as youth and women farmer groups to improve adoption and upscaling CSA technologies. |
| [18] | Makate C, 2019 | Ethiopia | Conservation agriculture, drought-tolerant maize, and improved legume varieties, adaptation, productivity | <ul style="list-style-type: none"> - Suggested that effective institutional and policy efforts targeted towards reducing resource constraints that inhibit farmers' capacity to adopt complementary climate-smart agriculture packages such as conservation agriculture, drought-tolerant maize, and improved legume varieties must be gender-sensitive and context-specific. |
| [14] | Hammed TB, 2019 | Nigeria | Productivity, organic fertilizer | <ul style="list-style-type: none"> - It was noted that organic fertilizers enriched with rock-based and plant-based materials could ameliorate the threat of climate change and seasonal variation to food security. |
| [21] | Bashagaluke JB, 2019 | Ghana | Soil and crop management | <ul style="list-style-type: none"> - The study showed that biochar/NPK interactions could be exploited in minimizing soil loss from arable lands in SSA. |
| [59] | Otieno NE, 2019 | South Africa | Productivity, pest control, crop management, organic farming | <ul style="list-style-type: none"> - The results showed significantly stronger predator–herbivore trophic linkages within intercropped than monoculture fields, while the farming system showed no effect. - For the first time in sub-Saharan Africa, the application of stable isotope analyses to characterize multitrophic feeding interactions that indicate effective agronomic practices for fostering top-down arthropod herbivore suppression in non-bt maize fields was demonstrated. - The results are useful in prescribing field practices with low-impact habitat management for sustainable small-scale agriculture rather than pesticide-based arthropod herbivore control. |

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| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|---------------------|--------------|--|--|
| [59] | Otieno NE, 2019 | South Africa | Productivity, pest control, crop management, organic farming | <ul style="list-style-type: none"> - The results showed significantly stronger predator–herbivore trophic linkages within intercropped than monoculture fields, while the farming system showed no effect. - For the first time in sub-Saharan Africa, the application of stable isotope analyses to characterize multitrophic feeding interactions that indicate effective agronomic practices for fostering top-down arthropod herbivore suppression in non-bt maize fields was demonstrated. - The results are useful in prescribing field practices with low-impact habitat management for sustainable small-scale agriculture rather than pesticide-based arthropod herbivore control. |
| [40] | Kiwia A, 2019 | Kenya | Sustainability, intercropping | <ul style="list-style-type: none"> - It was noted that intercropping combined with the application of small amounts of inorganic fertilizers is superior to unfertilized intercrops. - They recommended that the strategic application of small amounts of inorganic fertilizers is essential for the productivity and economic sustainability of cereal–pigeon pea intercropping under smallholder farming in ESA. |
| [60] | Kamara A, 2019 | Sierra Leone | Productivity | <ul style="list-style-type: none"> - The study revealed that smallholder agriculture would be a driver of economic growth and development in Africa. - Recommended that adequate investment should be focused on eliminating the challenges faced by smallholder farmers. |
| [38] | Baudron F, 2019 | Zimbabwe | Productivity | <ul style="list-style-type: none"> - The study showed that wheat productivity could be increased through increased seeding rate, increased nitrogen (n) application combined with frequent weeding, and labor-saving technologies. - Recommended that resource-saving technologies (input-saving, e.g., precision agriculture, labor saving, e.g., mechanization) may be as much in demand by African smallholders as yield-increasing technologies. |
| [61] | Kpadonou RAB, 2019 | Ethiopia | Adoption of modern seeds and the use of manure | <ul style="list-style-type: none"> - The study suggests that organic fertilizer can serve as an enabling factor for greater adoption of modern seeds, especially in less favorable climate areas - Suggested that there is a need to breed seeds suitable for the use of organic fertilizers. |
| [62] | Antwi-Agyei P, 2018 | Ghana | Adaptation, mitigation | <ul style="list-style-type: none"> - Noted that agriculture and energy are priority sectors where NDCS have pledged significant commitments. - Recommended that cross-sectoral discussions in Ghana identify and address challenges relating to institutional capacity, lack of coordination among institutions and agencies, and insufficient resources in moving towards integrated implementation of national planning priorities to address both NDC priorities and the SDGs' commencement successfully. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|---------------------|--------------|---|---|
| [63] | Mango N, 2018 | Zimbabwe | Irrigation farming | <ul style="list-style-type: none"> - The study revealed that off-farm employment, access to irrigation equipment, access to reliable water sources, and awareness of water conservation practices, such as rainwater harvesting, significantly influence the adoption of small-scale irrigation farming. - Noted that the farmer's age, distance traveled to the nearest market, and nature of employment negatively influence the adoption of small-scale irrigation farming decisions. The adoption of small-scale irrigation farming as a climate-smart agriculture practice has a significant positive influence on agricultural income. - Recommended that to empower smallholder farmers to respond quickly to climate variability and change, practices that will enhance the adoption of small-scale irrigation farming in the Chinyanja triangle are critical, as this will significantly affect agricultural income. |
| [64] | Paul BK, 2018 | Kenya | Environmental degradation, productivity, crop intensification, inorganic fertilizer, improved seeds, zero-grazing, crossbreeds, GHG emissions | <ul style="list-style-type: none"> - Revealed that consumed and sold food crops were the mainstay of food availability and that livestock and off-farm income were the most important pathways to higher FA. - Noted that the scenario assessment of the three policy options showed strong differences in potential impacts: although Girinka only reached one third of the household population and acted highly pro-poor by decreasing the households below the 2500 kcal mae 1 yr 1 line from 46% to 35%, it also increased GHG by 1174 kg co2e hh 1 yr 1 and can therefore not be considered climate-smart. |
| [36] | Oosthuizen PL, 2018 | South Africa | Animal husbandry, sustainability | <ul style="list-style-type: none"> - Revealed that breeds can be differentiated in terms of genetic production potential. - Noted that each breed can generate additional G by feeding them according to their unique PMFP. - Projected that according to the case study, the additional gross profit that the implication of the PMFP model can generate was 6%. |
| [65] | Makate C, 2018 | Zimbabwe | Adoption rates of CSA, socio-economic analysis | <ul style="list-style-type: none"> - The study revealed that farm typology identification is an important step towards promoting climate-smart agriculture practices in smallholder agriculture. - Noted that multivariate analysis provides useful tools suitable for identifying the important socio-economic characteristics of households influential in determining adoption of climate-smart agriculture practices. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|--------------------|--------------|--|--|
| [66] | Chakona G, 2018 | South Africa | Productivity | <ul style="list-style-type: none"> - The study showed that agro-ecological potential significantly influences children's nutritional status, which is also related to household food security and socio-economic status. - Recommended that malnutrition in South Africa be prioritized and move beyond relying on food security and nutritional-specific interventions, but rather on nutrition-specific and sensitive programs and approaches, and building an enabling environment. |
| [67] | Mathews JA, 2018 | South Africa | Resilience, sustainability | <ul style="list-style-type: none"> - The findings revealed that agricultural communities should focus on the identification and application of adaptation strategies such as CSA. |
| [68] | Bhatasara S, 2018 | Zimbabwe | Resilience, adaptation, sustainability | <ul style="list-style-type: none"> - An expansion of the knowledge base around the concept of climate-smart agriculture towards effectively incorporating sustainability aspects in climate change adaptation discourse. |
| [20] | Setimela P, 2018 | Zimbabwe | Mitigation, drought-tolerant maize varieties, multi-stress maize germplasm, conservation agriculture | <ul style="list-style-type: none"> - Noted that a combination of climate-smart agriculture technologies is required to mitigate the negative effects of extreme events such as El Nino and increase the resilience of low-input farming systems. - Recommended that an expansion of the knowledge base around the concept of climate-smart agriculture towards effectively incorporating sustainability aspects in climate change adaptation discourse be enhanced. |
| [69] | Thornton PK, 2018 | Kenya | Framework, research investments, adaptability | <ul style="list-style-type: none"> - Recommended that a mix of actions that span spatial and temporal time scales need to adapt to a changing climate, address immediate problems, and create enabling conditions for enduring change. |
| [70] | Magombeyi MS, 2018 | South Africa | Water management, resilience. | <ul style="list-style-type: none"> - Revealed that large yield change variations for different AWM technologies present a huge opportunity to meet the existing yield gaps and enhance coping capacity in dry years and under climate change. |
| [71] | Hammond J, 2017 | Kenya | Adaptation, productivity, GHG emissions | <ul style="list-style-type: none"> - Noted that the climate smartness of different farm strategies is determined by an interaction between the farm household characteristics and the farm strategy. - Recommended that small farms' off-farm income needs to be in place before interventions can be promoted successfully. In contrast, on the larger farms, a choice is made between investing labor in off-farm incomes or investing that labor into the farm, resulting in a negative association between off-farm labor and intensification, market orientation, and crop diversity on the larger farms. |
| [72] | Notenbaert A, 2017 | Kenya | Innovation, food security, adaptation, mitigation, investment | <ul style="list-style-type: none"> - Developed a framework that is applicable in many different forms, scales, and settings. It has wide applicability for integrating the concepts in the planning process for climate-smart agriculture, which invariably involves multi-stakeholder, multi-scale, and multi-objective decision making. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|---------------------|----------|---|--|
| [73] | Shikuku KM, 2017 | Kenya | Productivity, adaptation, livestock management | <ul style="list-style-type: none"> - The study revealed that both households with local cows and those with improved breeds had increased income and food security. - The expected methane emissions intensity declined with the adoption of improved livestock feeding strategies in stratum 1 and stratum 2. More impacts were observed when households in stratum 2 received an additionally improved cow breed. - Recommended that a cow be provided to households that were not keeping cows due to substantial economic gains. |
| [74] | Nyasimi M, 2017 | Tanzania | Innovation, adaption, agroforestry, weather information | <ul style="list-style-type: none"> - Farmers are adopting various CSA technologies, practices, and institutional innovations after participating in the farms of the future (FOTF) approach using improved crop varieties, agroforestry, and scientific weather forecast information cited as the main practices. - It was noted that to minimize their risks and reduce vulnerabilities, farmers are diversifying and integrating 5 to 10 CSA practices in one season. - Recommended improvements to make on the FOTF include longer trip duration, increased number of farmer participants, and gender balance and age considerations to include youth. |
| [19] | Thierfelder C, 2016 | Zimbabwe | Soil degradation, conservation agriculture, manual seeding systems | <ul style="list-style-type: none"> - Suggested that there is a need for site-specific recommendations and adaptation of CA systems to different agro-ecological environments. - Recommended that blanket recommendations of one CA system across many agroecologies must be discouraged, leading to underperformance of CA in some areas and rejection by smallholder farmers if yield benefits are not achieved. |
| [75] | Kimaro AA, 2016 | Tanzania | Conservation agriculture, productivity, environmental sustainability, resilience, adaptability, GHG emissions | <ul style="list-style-type: none"> - It was revealed that CA could deliver benefits consistent with the objectives of CSA for farmers in this region, particularly when soil nitrogen limitation is alleviated, providing other constraints to adoption are removed. |
| [76] | Schut M, 2016 | Burundi | Innovation, sustainability, intensification, constraints, productivity | <ul style="list-style-type: none"> - It was noted that much of the R4D investments and innovation in the Central Africa highlands remain targeting household productivity at farm level due to (1) a narrow focus on sustainable intensification, (2) institutional mandates and pre-analytical choices based on project objectives and disciplinary bias, (3) short project cycles that impede work on middle- and long-term NRM and institutional innovation, (4) the likelihood that institutional experimentation can become political, and (5) complexity in terms of expanded systems boundaries and measuring impact. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|---------------------|--------------|--|---|
| [77] | Ncube M, 2016 | South Africa | Adaptation, mitigation | <ul style="list-style-type: none"> - It was revealed that climate change would hit crop yields hard and that households consisting of the elderly and households headed by females with less capital are most vulnerable. - It was noted that households that receive remittances or extension services or participate in formal savings schemes in villages are less vulnerable. - Recommended that households need to move towards climate-smart agriculture, which combines adaptation, mitigation, and productivity growth. |
| [78] | Thierfelder C, 2016 | Zimbabwe | Conservation agriculture, direct seeding | <ul style="list-style-type: none"> - It was revealed that systems could perform differently in contrasting agro-ecological environments. - The study showed that direct seeding systems out-yielded other treatments in higher rainfall areas and responded better to a favorable environments than conventional tillage practices. - It was noted that blanket recommendations of one CA system across many agroecologies will lead to underperformance of CA in some areas and rejection by smallholder farmers if yield benefits are not achieved. |
| [79] | Murage AW, 2015 | Kenya | Productivity, gender mainstreaming, push and pull technology, crop management, soil management | <ul style="list-style-type: none"> - It was noted that women who are the most vulnerable of the smallholder farmers are bound to benefit from the technology, mostly because its attributes favors their (women) preferences. |
| [80] | Nyamadzawo G, 2015 | Zimbabwe | Soil management (fertility), adaptation, sustainability, variability | <ul style="list-style-type: none"> - The study revealed that farmers grow crops in dambos (seasonal wetlands) as an adaptive strategy to climate change and variability and have largely abandoned upland fields where yields are <1 t ha (−1) in preference of dambos where yields average 2–3 t ha (−1). - It is recommended that dambo cultivation be properly designed and managed as it may result in habitat degradation. Therefore, further research is needed to evaluate options for sustainable dambo utilization as an intensification of dambo agriculture is important for food security. |
| [81] | Gyau A, 2014 | Kenya | Cocoa agroforestry systems and trees plantation and shades | <ul style="list-style-type: none"> - It was noted that tree plantations with cocoa are likely to be influenced by extension and certification programs, including the severity of diseases affecting cocoa and geographic zone. - The study also revealed that the farmers' age, household size, and the cocoa farm's average age would influence associate trees with cocoa. |
| [82] | Maine N, 2010 | South Africa | Precision farming (variable-rate nitrogen application) | <ul style="list-style-type: none"> - The study revealed that the farm size and the price of maize are the fundamental factors in the productivity of variable-rate nitrogen. |

Table A1. Cont.

| Ref # | CA, (PY) | Country | CSA Technology | Key Findings and Future Research Direction |
|-------|----------------|--------------|--|--|
| [83] | Cho MA, 2010 | South Africa | Precision farming (hyperspectral remote sensing) | <ul style="list-style-type: none"> - The study also demonstrated the ability of continuum-removed spectral features to produce information on the physiological state of vegetation. - The study illustrated the ability of hyperspectral remote sensing of vegetation canopies in detecting site factors influencing the growth of <i>E. grandis</i>. |
| [84] | Maine N, 2007 | South Africa | Precision farming (maize yield modeling) | <ul style="list-style-type: none"> - It was revealed that maize yield response to phosphorus application fluctuated between variable-rate and single-rate application methods, accompanied by management zones. |
| [33] | Gandah M, 2000 | Niger | Low-tech precision agriculture (manure) | <ul style="list-style-type: none"> - Recommended that the application of a simple scoring approach be considered the low-priced and dependable practice to identify field trends in support of effective precision agriculture. |

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