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Review

Climate-Smart Agriculture Amidst Climate Change to Enhance Agricultural Production: A Bibliometric Analysis

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Abstract: Climate change significantly impacts global agricultural productivity. Therefore, a more dynamic farming system is needed to enable farmers to better adapt to climate change while contributing to efforts to produce enough food to feed the growing world population. In the context of climate change, this study analyzed the empirical scientific literature on the link between climate-smart agriculture and farm productivity. To evaluate the relevant articles, the authors used the search term "climate-smart agriculture amidst climate change to enhance agricultural production (CSA-CCAP)" to find studies published between 2009 and March 2022 using innovative bibliometric techniques. One hundred and sixteen published papers in BibTeX format were downloaded for further analysis. The most successful selected CSA approaches in Africa, such as in the Congo Basin forest, including sustainable land management practices, water-efficient maize hybrids, and others, aim to counteract climate change with signs of 200 percent output gains. The findings showed an annual growth rate of about 19%, demonstrating that research on CSA-CCAP expanded over time during the study period. Nonetheless, the research output on CSA-CCAP varied, with 2021 accounting for 30%, followed by 2020 with 16% as of March 2022. The study concluded that boosting agricultural productivity in the face of climate change may be accomplished through CSA to end hunger, eradicate poverty, and improve people's well-being.

Keywords: agricultural production; changing climate; climate-smart agriculture; bibliometrics

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1. Introduction

As the world's population continues to rise, there is growing concern about how agricultural production will cope with feeding everyone. According to the United Nations Food and Agricultural Organization [1], agricultural production must expand by 70% to meet the needs of the 9.8 billion people expected to inhabit the planet in 2050. The current global population of 7.6 billion people is likely to reach 8.6 billion in 2030, 9.8 billion in 2050, and 11.2 billion in 2100, according to the United Nations Department of Economic and Social Affairs, Population Division [2]. This amounts to 1 billion tons more maize, sorghum, and other commodities and 200 million tons more beef and other livestock.

Numerous resources needed for agricultural production are already strained; the challenges are enormous and are being intensified because the global climate is changing fast. For agriculture, changes will be substantial in crop and animal production as fluctuations in rainfall patterns bring about droughts or flooding. Extreme hot or cold temperatures bring about changes in the length of growing crops and in animals with amplified pest and disease occurrences [3]. In the agricultural sector, the changing climate is affecting agricultural productivity and the many inputs used in production [4,5]. By 2030, the world economy has committed to reducing hunger, eradicating poverty, and taking swift action to combat climate change and its repercussions, which are expected to severely hinder agricultural expansion in many nations [6].

Climate change is an incremental modern-day threat to agricultural production, food security, and the livelihoods of millions of people worldwide [7]. Climate change remarkably increases temperatures and dynamic rainfall patterns, as well as variations in the intensity and frequency of extreme events such as droughts and floods; it equally limits agricultural production to various degrees in different parts of the world [7–9]. According to Porter [10], the anticipated negative implications of climate change on cereal crop yields in different regions include a 60% reduction in maize yield, a 50% reduction in sorghum yield, a 35% reduction in rice yield, a 20% reduction in wheat yield, and a 13% reduction in barley yield. In sub-Saharan Africa (SSA), climate variability and change are predicted to continue decreasing the production of major cereal crops including maize, sorghum, and millet. Maize, sorghum, and millet yields are estimated to fall by 22, 17, and 17 percent by 2050 [7,11,12]. Moreover, rain-fed crop yields are also projected to decrease by almost 50% due to climate variability and change. With a rise in average global temperature beyond the 1.5 °C threshold almost inevitable [13,14], these impacts could be worse, with a chance of total crop failure, especially in semi-arid landscapes. It is critical to develop a sustainable form of agriculture, climate-smart agriculture (CSA), to combat climate change difficulties.

CSA is what farmers require if they are to respond quickly to the problems of climate inconsistency [15–17]. CSA is not a modern system of agriculture; instead, it is a tactic to identify which suitable farming operation can be or should be employed by farmers to best respond to the changing climate [18]. According to FAO [19], the main aim of CSA is to repackage agriculture in a changing climate to ensure a 'triple win,' namely, development, adaptation, and mitigation. CSA is defined as a form of agriculture that sustainably increases agricultural productivity and returns, enhances adaptation and resilience to climate change, reduces or removes greenhouse gas where possible, and enhances the accomplishment of national food security and sustainable development goals [20].

The impact of CSA techniques cannot be overemphasized as they increase agricultural productivity and net returns to labor [21–23]. This indicates that variations in planting dates and cropping patterns, the adoption of an alternative form of agriculture, and water-saving techniques (rainwater harvesting, drip irrigation, mulching, etc.) significantly impact agricultural productivity and farm revenue [24,25]. Agricultural practices based on CSA principles extend harvesting time and manage periodic food scarcity, boosting the reliability of household food access [26]. They can also reduce soil erosion by increasing soil cover and producing extra crop residues for mulching material and green manure [26]. Imran [23] demonstrated that cotton farmers that use CSA harvest more cotton than conventional producers. Agricultural production using CSA practices and techniques is thus economically, socially, and environmentally superior to traditional farming. Various studies [23,27–32] established that CSA practices and techniques have shown to be energy and input efficient, to increase productivity and farm revenue, and to address the rising ecological difficulties. Thus, the productivity of the agricultural sector can be improved by adopting CSA practices and techniques amidst our ever-changing climate.

Climate change is a global issue that has already hampered agricultural productivity to varying degrees [8]. The intergovernmental panel on climate change [33] warned that rainfall variability, temperature, and other climatic parameters are likely to increase, leading to increased natural hazards. The evidence of climate change is real, and its impact is felt worldwide, with agricultural households from developed and developing economies suffering the most [34]. Notably, there is a need for a highly dynamic farming system (CSA) that will help these farmers to best respond to climate change while continuing to contribute to the pursuit of producing sufficient food to feed the rising population, which in thirty years will be a staggering 9.8 billion [18,35]. Without the appropriate adaptive tactics in position, farmers will find it very tough to practice sustainable agriculture to feed the ever-growing population in an environment with erratic climatic conditions [36], especially considering that the agricultural sector is the main employer of labor [37].

The current study aims to investigate the available scientific literature on CSA-CCAP through bibliographic network analysis, as only a few studies have performed bibliometric mapping analysis on CSA-CCAP. This inference was derived when only 116 articles appeared after searching the keyword query ("climat* smart agricultur*" AND "climat* chang*" AND "agricultur* product*") in the full texts. Some of the relevant studies and meta-analyses are related to climate change, the application of CSA research, climate-smart agriculture, and the CSA emerging trends and knowledge domain [38–41]. However, to the best of our knowledge, none of the studies has performed a bibliometric analysis on CSA-CCAP. This study presents a summary of some selected successful CSA-CCAP methods across Africa. It conducts a bibliometric mapping and analysis of CSA-CCAP research studies around the globe to demonstrate the structural evolution and dynamic nature of scientific research in this field. We did so by projecting the main and relevant subjects, authors, nations, institutions, and keywords, among others, from 2009 to March 2022, employing R-Studio, Biblioshiny, and Vosviewer software tools, as well as the Scopus database. This study provides important information to scholars who want to have a scientific overview of the multidimensional structure, thematic trends, and future direction of the current field of study, which is necessary to build the CSA body of science.

2. Materials and Methods of Data Collection

This review study considered various search topics to retrieve scientific documents relating to CSA-CCAP research around the globe. The bibliometric method is a good innovation in terms of literature reviews as this method tries to collect every relevant document needed for the research. The bibliometric method uses different databases such as Web of Science, Scopus, etc. It can also be used in all fields of study as long as there are articles published in that field of study (e.g., health science, engineering, environmental and social sciences, etc.). "Bibliometric analysis is one of the most rigorous practices that has been widely recognized for analyzing the various aspects of published academic materials, including highly-cited documents, most influential journals, countries, organizations, and to show a past and present structure of the concerned field through citation, co-authorship, bibliographic coupling, keyword occurrences and cluster analysis" [42,43]. Bibliometrix is one of the numerous software tools scientometricians can use to analyze or visualize bibliometric data. To quantify academic progress, this method uses three fundamental bibliometric indicators: structural indicators (evaluate trends and evolution patterns of scholarly research), qualitative indicators (assess performance), and quantitative indicators (quantify productivity) [44]. Various factors encourage researchers to choose this strategy, such as that a data-driven study is more pertinent and accurate than a subjective evaluation [45]. The research status is evaluated and predicted using statistical and mathematical methodologies [42], and this method also aids in the collection of scientific reviews [46].

Relevant scientific published documents were retrieved using the Scopus core collection databases. According to [43,47], the Scopus database is the leading multidisciplinary databank of peer-reviewed literature in the social sciences and is generally accepted for quantitative analyses. This database is used in most review studies [47,48]. They publish a broad range of peer-reviewed scientific articles in practically all scientific disciplines, including research papers, conference proceedings, book chapters, and books, among other things [39].

A number of eligibility and exclusion criteria were taken into account. For speedy visibility and retrieval, we used a title-specific search. The title search was utilized due to its effectiveness as expressed by [49] and followed by [43,48]. First, in terms of document types, we only made use of published articles not book chapters, editorial reviews, short surveys, errata, and notes, etc. Moreover, with respect to source forms, we used only journals and did not include conference proceedings, trade journals, or undefined because some of these documents do not make it to publication. We further eliminated articles in press and only included articles that were in their final form in terms of publication point. In selecting the subject fields, we did not include documents from microbiology, material science, psychology, or the health profession, rather we used articles from agriculture, social science, and environmental science. During the bibliometric review, languages that were not English (Spanish, Dutch, French, etc.) were not included. Lastly, a span of 13 years was used as the review period (see Table 1) [43,48] to capture most of the CSA-CCAP articles. Table 1 shows the criteria, eligibility, and elimination strategies employed to assess the appropriate articles needed for robust research. Documents were searched using a bibliometric approach by entering the keywords ("climat* smart agricultur*" AND "climat* chang*" AND "agricultur* product*"). Table 2 shows the complete search string. The asterisk wildcard (*) includes all the known available suffixes of the original word. We included the following phrases with asterisk wildcards for truncation to cover the terms given in parentheses:

- climat*-smart agricultur* (climate/climatic-smart agriculture/agricultures)
- precision agricultur* (precision agriculture/agricultures)
- conservat* agricultur* (conservation/conservative agriculture/agricultures)
- smart farming
- smart agriculture* (smart agriculture/agricultures)
- Climat* chang* (climate/climatic change/changes/changing)
- climat* warming* (climate/climatic warming)
- global temperatur* (temperature/temperatures)
- global warming* (global warming/warmings)
- greenhouse gas* (gas/gases)
- greenhouse effect* (effect/effects)
- greenhouse warming* (greenhouse warming/warmings)
- agricultur*product* (agriculture/agricultural production/productions/productivity/productivities)

Table 1. Criteria, eligibility, and elimination strategies.

Criterion	Eligibility	Elimination
Scopus database		
Document type	Only published articles	Notes, short surveys, editorial reviews, errata, book chapters, etc.
Source form	Only journals	Trade journals, undefined, conference proceedings, etc.
Publication point	Final point	Article in press
Subject field	Agricultural, biological, social, and environmental sciences	Decision science, health profession, psychology, material science, immunology and microbiology, etc.
Language	English language only	Non-English language
Span	Between 2009 and March 2022	<2009 and > March 2022

Table 2. Search focus (string).

Search Focus1	Search Focus2	Search Focus3
"climat*smart agricultur*"	[AND] "climat* chang*"	[AND]"agricultur*product*"
"precision agricultur*"	[AND] "climat* warming*"	[AND]"agricultur*product*"
"climat*-smart agricultur*"	[AND]"global temperature*"	[AND]"agricultur*product*"
"conservat* agricultur*"	[AND] "global warming*"	[AND]"agricultur*product*"
"smart farming"	[AND] "greenhouse gas*"	[AND]"agricultur*product*"
"smart agriculture*"	[AND] "greenhouse effect*"	[AND]"agricultur*product*"

The review was based on bibliometric analysis, a technique commonly used to study the structural and dynamic aspects of research topics using scientific mapping [39,48]. After a comprehensive assessment, 116 journal articles were found to be relevant and related to the topic under study and were thus kept for the final evaluation. The authors considered that these publications provided an adequate overview and discussion of CSA-CCAP's sustainable elements. As a result, these articles were chosen for additional descriptive and bibliometric analysis. The CSA-CCAP science mapping undertaken in this review study assessed the following themes: (1) annual publication growth and trends; (2) leading countries contributing to the CSA-CCAP body of knowledge; (3) collaborations; (4) keyword co-occurrences; and (5) emerging themes. In addition, the VOSviewer program was used to create density and network visualization output maps for keyword analysis, while Biblioshiny via the R-studio interface was used to create the nation and institution collaboration networks. The strength of the nations' and institutions' collaboration was measured based on the total link strength given by Biblioshiny. VOSviewer and Biblioshiny assign items such as keywords, nations and institutions, respectively into specific clusters, where the size of the cluster represents the collaboration strength or frequency of the keywords. VOSviewer and Biblioshiny also assign clusters to nodes on a map (various colors are used to emphasize them). These clusters describe nodes that are tightly connected and have just one cluster allocated to them [50]. VOSviewer employs a modularity-based clustering approach similar to multidimensional scaling [51], founded on the smart local moving algorithm [52].

3. Selected Successful CSA-CCAP Methods in Africa

In recent years, CSA has become a fundamental notion for most global organizations at the center of the climate change, agriculture, and development nexus [53]. In addition, CSA has been considered an essential mechanism for achieving the Sustainable Development Goals (SDGs) [53]. Most of all, CSA is useful 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 to integrate such systems with advanced smart technologies such as husbandry, remote sensing, IoT-based sensors, bio-sensors, and agricultural drones, among others, in order to increase food security and upscale the management of livestock and crops [54,55].

The summary of selected successful CSA-CCAP methods across Africa is depicted in Figure 1. The yield of important cereal crops in the area including millet, sorghum, and maize is anticipated to continue declining due to climate change. By 2050, millet, sorghum, and maize yields are predicted to decline by 17, 17, and 22%, respectively (7, 12). In addition, rain-fed crop yields are anticipated to drop by about 50% as a result of changing climate [56]. Around 36 climate-smart village sites have been established as part of a pilot project on Climate Change, Agriculture, and Food Security, of which six are in East Africa (Rakai and Hoima in Uganda, Borana in Ethiopia, Lushoto in Tanzania, Wote and Nyando in Kenya) and five in West Africa (Fakara in Niger, Cinzana in Mali, Kaffrine in Senegal, Yatenga in Burkina Faso, and Lawra-Jirapa in Ghana) [57,58].

The Congo Basin Forest Fund implemented in ten Central African regions, attempts to combat the changing climate in the Congo Basin. This was accomplished through encouraging rural development to reduce deforestation, stabilizing the agriculture industry, improving land use planning, implementing feasible management systems for the region's natural forests, and reducing poverty and forest degradation. Stopping the advancement of the Sahara desert and strengthening resilience contributes to weather adaptation and mitigation and has been implemented in Mali, Burkina Faso, and Niger which further expanded to other West African nations bordering the Sahel and the Sahara [59]. Sustainable land management (SLM) in Ethiopia was established to address diminishing agricultural production, climate change consequences, poverty, and food insecurity. By utilizing integrated and cross-sectoral methods, SLM aims to scale up effective practices, methodologies, and technologies to avoid or control land degradation. Its goal in Uganda is to improve the consulting services and effectiveness of agricultural research in the nation in order to increase agriculture production and household revenue [60].

The very first soil and agricultural carbon finance initiative in Africa that benefits smallholder farmers and rural society is the Kenya Agricultural Carbon Initiative, which is located in western Kenya. The initiative deals with issues such as increasing land pressure, unstable livelihoods, and the relative inefficiency of smallholder agricultural production, all of which are made worse by the adverse effects of changing climate [61]. Due to the rising global food demand, unsuitable farming methods, and significant greenhouse gas emissions, farming systems must increase productivity and food production while sequestering more carbon than they release. Agroforestry and terraces have benefits for maize yield [62]. Moreover, throughout the course of the four years, farms participating in the Kenya Agricultural Carbon Project produced more maize than control farms. The development of site-specific agricultural land management practices that support improved crop output while minimizing detrimental environmental effects is essential if the objective of sustainable agricultural intensification is to be achieved [63].

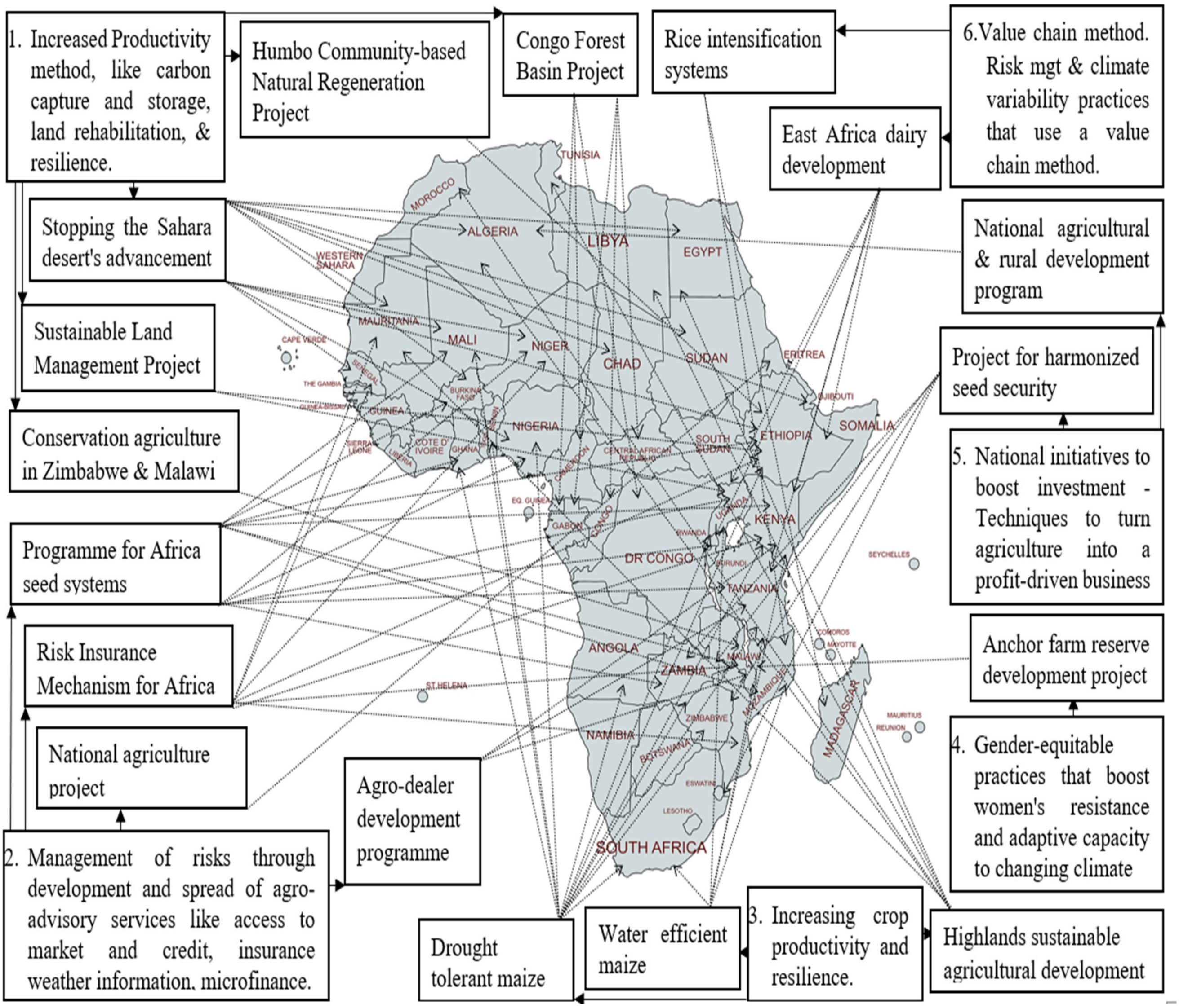

Figure 1. Selected successful CSA-CCAP methods across Africa.

Farmers in Zimbabwe are becoming more interested in conservation agriculture, with indications of output increases of 50 & 200% [59,64]. In thirteen sub-Saharan African nations, the Program for African Seed Systems aims to significantly boost Africa's ability to propagate, produce, and distribute high-quality seeds of basic food crops such as maize, rice, cassava, beans, sorghum, and millet, which are greatly adaptable to a wide range of climatic regimes. A weather-based insurance scheme in Ethiopia helped farmers improve their revenue and food security using a four-part method: risk reserves, risk transfer, prudent risk taking, and community risk reduction. The Eritrea National Agriculture Project aspires to support the alleviation of poverty and regional food security, especially among rural farm dwellers by enhancing smallholder agricultural productivity and production [59]. The agro-dealer programs in Kenya, Malawi, Mozambique, and some other African nations have increased farmers' access to inputs. Agro-dealers are educated to provide seasonal agro-advisory information to lead farmers on the optimum inputs for various agro-ecological locations [59,65].

Examples of climate-smart agricultural methods that could increase output and food security in Nigeria while improving mitigation and adaptation include mixed farming practices; reduced tillage; runoff water harvesting; rainwater harvesting; use of Fadama land (wetland); stocking density management; grazing land improvement; planting crop varieties with early maturity; agroforestry; use of improved varieties tolerant to climate change stressors; use of drought-resistant varieties; construction of dams; planting of cover crops to increase soil fertility, increase water retention, and improve soil structure and aeration; incorporation of residues or other mulches to reduce wind and soil erosion; adjusting planting dates [66]; and rearing improved breeds of livestock [67].

There are techniques in Cameroon that are designed to boost output, accommodate climate change, and emit as few emissions as possible. They also have something to do with sustainable management techniques. These techniques consist of organic matter maintenance for sustainable agriculture that maintains soil fertility (e.g., crop rotation, cover crops, composting, and green manures can both mitigate the adverse effects of drought and boost productivity) [68]. Techniques such as agroforestry, mulching, and crop residue retention conserve soil moisture and safeguard crops from microclimate excesses. In addition, water harvesting techniques also increase the amount of water available to farmers and enable them to rely on water that has been conserved during dry spells [69]. Most of the aforementioned techniques are part and parcel of ecological agriculture and can be quickly put into use to significantly reduce climate change. Simple techniques, such as switching from wasteful surface furrow irrigation to alternate furrow irrigation, can result in significant water savings of about 30% and yield increase of 15–20% in places where approximately 95% of water extraction is used for farming [66]. Partey et al. [70] found that among the many CSA technologies, (i) climate information services; (ii) water and soil conservation techniques (conservation agriculture, contour/tie ridges, half-moon, zai); and (iii) agroforestry (farmer-managed natural regenerations) are among the most highly regarded and promising options for coping with climate change and managing risk in West Africa.

In thirteen African nations, high-yielding drought-tolerant maize varieties were produced and disseminated locally for acceptance, resulting in partnerships between farmer groups, certifying agencies, seed corporations, non-governmental organizations, and national agencies [71]. Water-efficient maize hybrids that can withstand insects and drought pressures have been established to help smallholder farmers in Uganda, Tanzania, South Africa, Mozambique, and Kenya improve their livelihoods and food security [72]. Highlands Sustainable Agricultural Development improves nutrition and food security while decreasing poverty in Tunisia, Morocco, Mauritania, Libya, and Algeria by establishing and distributing modern technologies and increasing the ability to manage wheat, rice, maize, cassava, and other major priority crops [59]. According to Roozitalab [73], farmers in Morocco were taught how to preserve water by using a no-till method. Compared to earlier procedures, this increased wheat yields by at least 25%, and in some cases by as much as 300%. In Malawi, the anchor farm reserve project was established in 2008 as a commercial agricultural venture to help 21,000 smallholder farmers access quality soy and maize inputs.

The Harmonized Seed Security Project was established to manage seed safety in the Southern African Development Community territory. Its goal is to harmonize national seed policies so that smallholder farmers in Zimbabwe, Zambia, Swaziland, and Malawi can access inexpensive, high-quality seeds [74]. In each nation, a major component of the initiative is the formation and enhancement of society-based seed production firms by smallholder farmers (with emphasis on female farmers). The East Africa Dairy Development Project in Kenya, Rwanda, and Uganda aims to help 179,000 smallholder farming households with less than two hectares of land each for profitable participation in the dairy business. According to FAO, [16], it has a lot of climate mitigation and adaptation potential. The system of rice intensification is practiced in twenty African nations and was launched in Madagascar. Rice crops grown using the rice intensification system are more resistant to diseases and pests, as well as cold spells, heat periods, and lodging and drought tolerance. Hoffman [75] noted that 4–5 million smallholder farming households were using and profiting from the system of rice intensification.

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 [39,76], Kenya [77], Nigeria [78], and Uganda [79]. Successful stories have been reported on the use of soil conservation and multiple stress crop practices in Ghana [80], Zimbabwe [81], Mozambique [82], Ethiopia [83], South Africa [84], and Nigeria [85], resulting in a significant increase in drought-tolerant maize variety yields as well as improving overall household income. The importance of socio-economic, integrated biodiversity, and gender aspects was also explored in Nigeria [86], highlighting the empowerment gap between men and women.

4. Findings and Discussion of the Bibliometric Analysis

Main Information and Publication Trend Analysis

The basic bibliometric details on CSA-CCAP, obtained using the R-studio application, are shown in Table 3. During the survey period (2009-March 2022), 116 papers were published from 80 sources. The research had 504 authors and 549 author appearances, with a collaboration index of 5. "The Author Collaboration Index (CI) is obtained as the ratio of the authors of multi-authored documents and total multi-authored documents" [87]. The number of authors divided by the entire number of articles yields the authors/article index (4). The co-authors/article index represents the average number of co-authors per article (5). This index considers author appearances, while "authors/article" only counts an author once, even if he or she has written multiple articles. As a result, authors/article is lower than co-authors/article. Except for 8 solo authors, all the remaining 496 authors were part of multi-author publications. During the research period, an average of 14 citations were recorded per document. For the CSA-CCAP study, Lotka's law of scientific output indicated a constant (L$C) of 0.83 and a beta coefficient (L$B) of 3.80, with a Kolmogorov–Smirnoff goodness of fit (L$R2) of 0.98. Figure 2 and Table 4 show the published research on CSA-CCAP from 2009 to March 2022, together with the average total number of citations per article by year. The annual pace of progress was 19, with an overall mean of 8 (medium = 5, min/max = 0/35), demonstrating that CSA-CCAP research grew with time. This finding is consistent with Barasa [39], who claimed that CSA is gradually becoming necessary as the effects of climate change continue to significantly impact people's livelihoods. The number of articles published in 2017 declined somewhat to six but increased in the following years. The year 2021 was the most fruitful for article publications (n = 35).

This section focuses on two essential indicators: the corresponding author's country and the number of articles published in that country, as well as single-country publications (SCP) and multi-county publications (MCP). Figure 3 and Table 5 show the research output associated with CSA-CCAP for the top ten most active nations. China and India led the way in terms of the total number of published papers (n = 10, 9%), with SCP/MCP (5, 5) and SCP/MCP (4, 6), respectively. The United States trailed China and India with n = 8, 7%, SCP/MCP (7, 1). The Netherlands, Pakistan, and South Africa each had n = 6, 5%, and SCP/MCP (1, 5), SCP/MCP (0, 6), and SCP/MCP (5, 1), respectively.

Table 3. Information summary on retrieved CSA-CCAP studies (2009–2022).

Descriptions	Outcome
Timespan	2009:2022
Source (journal)	80
Number of published articles	116
Authors	504
Author appearances	549
Collaboration index (CI)	5
Authors/article	4
Co-authors/article	5
Single-authored documents	8
Multi-authored documents	496
Average citations per document	14
Author keywords (DE)	409
Keyword-plus (ID)	688
Co-authors per document	5
References	7206

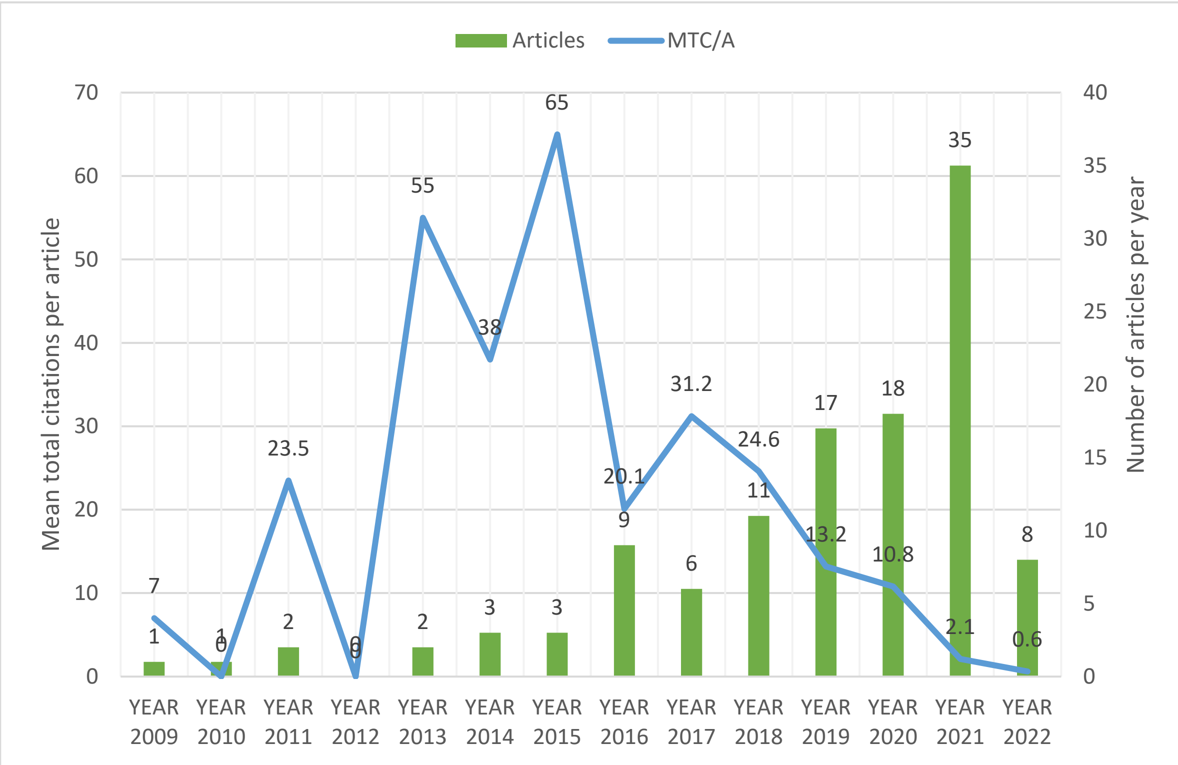

Figure 2. Yearly scientific production of CSA-CCAP publications indexed in Scopus from 2009 to March 2022. MTC/Y = mean total citations of published paper per year. NB: the annual percentage rate of increase was 19.

Except for Germany, which has (5, 4%) published papers with SCP/MCP (2, 3), the other three nations have (4, 3%) published papers with SCP/MCP (2, 2) for Australia and Ethiopia, and SCP/MCP (1, 3) for Italy. The frequency of publication in the top nations ranges from 3 to 9. Table 6 shows that when the number of citations per nation measured productivity, India ranked first with n = 236 total cited articles. Sapkota [27] noted that climate change conditions, increases the cost of fuel, water shortage, and growing labor force, degradation in soil health, imbalanced and inadequate management of nutrients are some of the factors responsible for the stagnation of wheat production in the northwest of India. Italy, the United States, and Australia were mentioned more than a hundred times (*n* = 122, 118, and 115), placing them second, third, and fourth, respectively. Similarly, the Netherlands, Kenya, Pakistan, Ethiopia, and Ireland were mentioned more than fifty times (*n* = 94, 85, 69, 62, and 51). Except for the United Kingdom, which was mentioned fifty times, the other countries were Colombia, Nigeria, Germany, New Zealand, South Africa, China, Mexico, Canada, Cyprus, and Iran (*n* = 48, 42, 40, 34, 33, 32, 25, 20, 12, and 11). This result is consistent with the findings of Li [41]. The level of intellectual endeavor, as assessed by citation count and publication activities, varies across the nation. The dispersion of effort is unequal; gross national product or other metrics of productive capacity are roughly connected with activity levels. The top 20 articles sorted by total citations are displayed in Table 6, together with their digital object identification (DOI) numbers.

Table 4. Annual scientific output of CSA-CCAP published papers (2009–2022).

Year Published	Articles Published	Mean Total Citations per Article
2009	1	7
2010	1	0
2011	2	24
2012	0	0
2013	2	55
2014	3	38
2015	3	65
2016	9	20
2017	6	31
2018	11	25
2019	17	13
2020	18	11
2021	35	2
2022	8	1

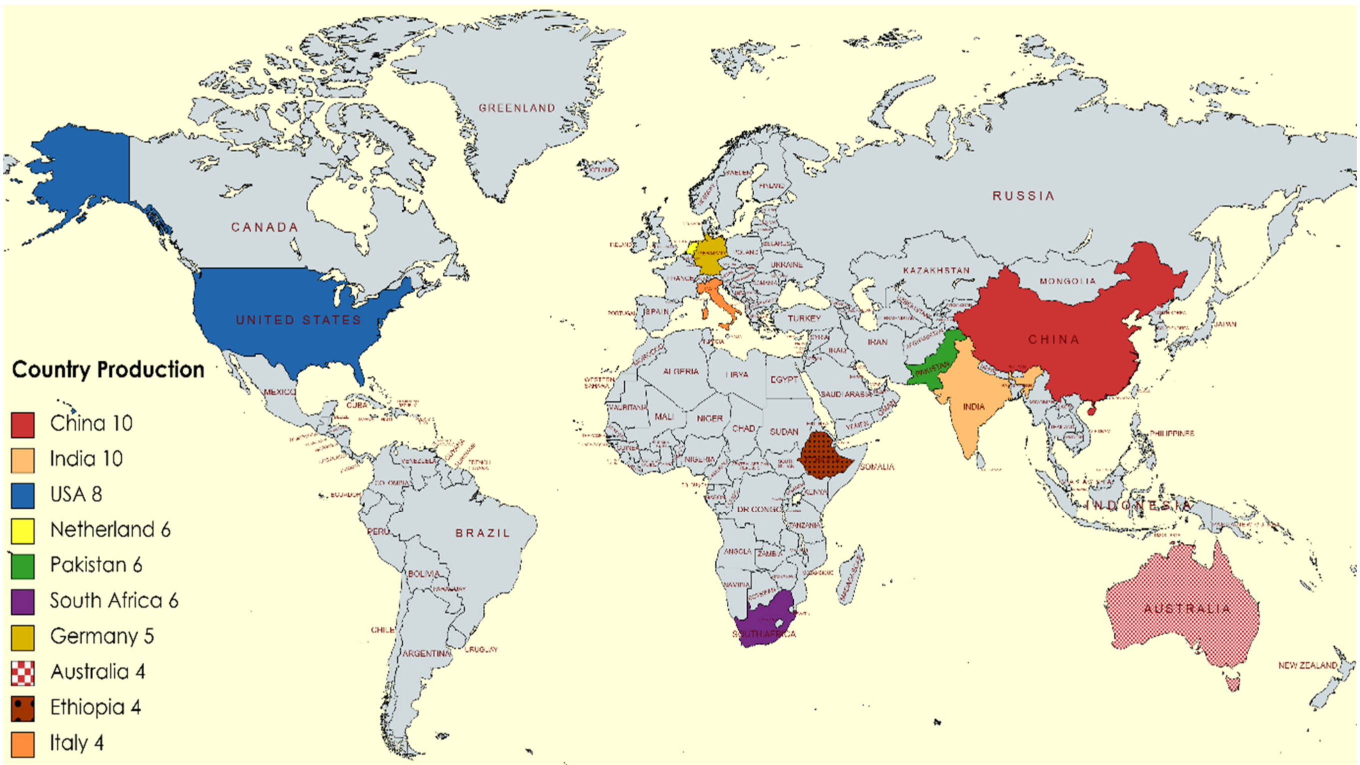

Figure 3. Top ten most active nations by corresponding authors within the period 2009–2022.

Table 5. The top ten most active countries by corresponding authors within the period 2009–2022.

Nations	Papers	SCP	MCP	Proportion%	MCP Ratio
China	10	5	5	9	1
India	10	4	6	9	1
USA	8	7	1	7	0
Netherlands	6	1	5	5	1
Pakistan	6	0	6	5	1
South Africa	6	5	1	5	0
Germany	5	2	3	4	1
Australia	4	2	2	3	1
Ethiopia	4	1	3	3	1
Italy	4	2	2	3	1

Table 6. Top twenty most cited nations and top twenty most cited published papers within the period 2009–2022.

Most Cited Nation		Most Cited Paper		
Nation	**Tc/(Av) Citations**	**Paper**	**DOI Number**	**TC**
India	236 (24)	[27]	10.1016/j.fcr.2013.09.001	99
Italy	122 (31)	[88]	10.1016/j.eja.2011.11.003	98
USA	118 (15)	[89]	10.1111/1477-9552.12107	90
Australia	115 (29)	[90]	10.1016/j.agsy.2016.05.003	78
Netherlands	94 (16)	[91]	10.1002/2015WR017522	68
Kenya	85 (21)	[92]	10.1016/j.jclepro.2017.06.019	66
Pakistan	69 (12)	[83]	10.1016/j.jenvman.2018.10.069	58
Ethiopia	62 (16)	[93]	10.5751/ES-09844-230114	58
Ireland	51 (26)	[94]	10.1177/0971852416640639	49
United Kingdom	50 (13)	[95]	10.1016/j.agsy.2017.02.008	48
Colombia	48 (48)	[96]	10.1016/j.jeem.2018.11.008	47
Nigeria	42 (42)	[97]	10.1111/1477-8947.12152	45
Germany	40 (8)	[98]	10.1016/j.energy.2016.12.068	43
New Zealand	34 (34)	[99]	10.1016/j.agwat.2016.08.034	42
South Africa	33 (6)	[100]	10.1016/j.geoforum.2015.01.016	37
China	32 (3)	[23]	10.3390/su10062101	34
Mexico	25 (25)	[101]	10.1007/s10584-010-9948-9	34
Canada	20 (10)	[102]	10.1016/j.agsy.2019.03.002	29
Cyprus	12 (12)	[103]	10.1007/s11027-014-9570-7	29
Iran	11 (11)	[104]	10.1111/agec.12307	28

Tc = total citations; Av = average citation, in parenthesis; DOI = digital object identification.

The article by Sapkota [27] entitled "Precision nutrient management in conservation agriculture based wheat production of Northwest India" is a highly cited document with 99 citations; followed by Hochman [88], "Prospects for ecological intensification of Australian agriculture", with 98 citations; followed by Arslan [89], "Climate smart agriculture," "assessing the adaptation implications in Zambia", with 90 citations; and Hammond [90], "the rural household multi-indicator survey (RHoMIS) for rapid characterization of households to inform climate-smart agriculture interventions: description and applications in East Africa and Central America", with 78 citations. Except for Zipper [91], Senyolo [92], Makate [83], and Aggarwal [93], the remaining twelve articles have total citations of 68, 66, 58, and 58, respectively.

Figure 4 depicts the top 41 nation collaboration networks of the retrieved CSA-CCAP documents, assigned into five clusters. Detailed information on these clusters and the corresponding countries is given in Table 7. The country with the largest cluster is the most collaborative. As noted in Figure 4, India (19) in the green cluster is the most collaborative country, followed by the USA in the red cluster with 16 links. Similarly, Kenya (14) and Germany (11) are the most collaborative countries in the green cluster after India, whereas

Zimbabwe (6) and Zambia (6) are the most influential countries in the red cluster after the USA. Netherlands (14) takes the lead in the purple cluster, followed by the United Kingdom and Colombia, with 13 and 11 nation links. Australia, China, and Italy are the most influential nations in the blue cluster, with 13, 11, and 8 collaboration links, respectively. Furthermore, Ghana (4) and Switzerland (4) are the most collaborative countries in the yellow cluster. Figure 5 depicts the top 28 institution collaboration networks of the retrieved CSA-CCAP documents, assigned into four clusters. Detailed information on these clusters and the corresponding institutions is given in Table 8. The institution with the largest cluster is the most collaborative. As noted in Figure 5, Haramaya University in Ethiopia and the International Center for Tropical Agriculture (6 each), in the red and green clusters, respectively, are the most collaborative institutions, followed by Borlaug Institute in South Asia in the green cluster with 5 links.

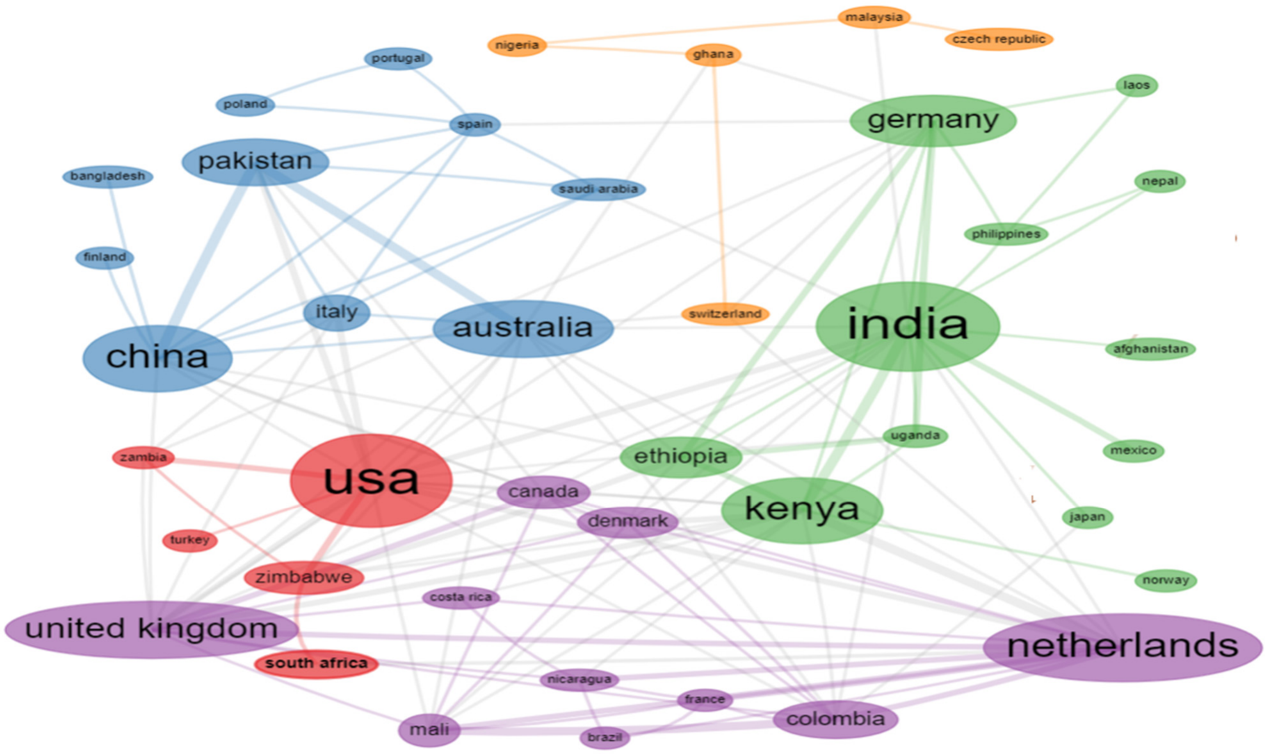

Figure 4. Nation collaboration networks.

Table 7. Cluster of nation collaborations around the globe within the period 2009–2022.

Clusters	Lead Nations per Cluster	Remarks
Green	India (19), Kenya (14), Germany (11)	India is the leading country in collaboration across all the clusters and has a significant collaboration with Kenya and Germany. It equally has a significant collaboration with USA.
Red	USA (16), Zimbabwe (6), Zambia (6)	USA, the leading country in this cluster, has significant collaboration with India, Netherlands, United Kingdom, Pakistan, and Italy.
Purple	Netherlands (14), United Kingdom (13), Colombia (11)	Netherlands, as the leading country in this cluster, has a significant collaboration with Kenya, USA, United Kingdom, Mali, and Columbia. The United Kingdom equally has a significant collaboration with Canada, Kenya, and USA.
Blue	Australia (13), China (11), Italy (8)	Australia is the leading country in this cluster and has a significant collaboration with Pakistan.
Yellow	Ghana (4), Switzerland (4)	Ghana and Switzerland collaborate with Germany and Australia, though their collaboration is not significant.

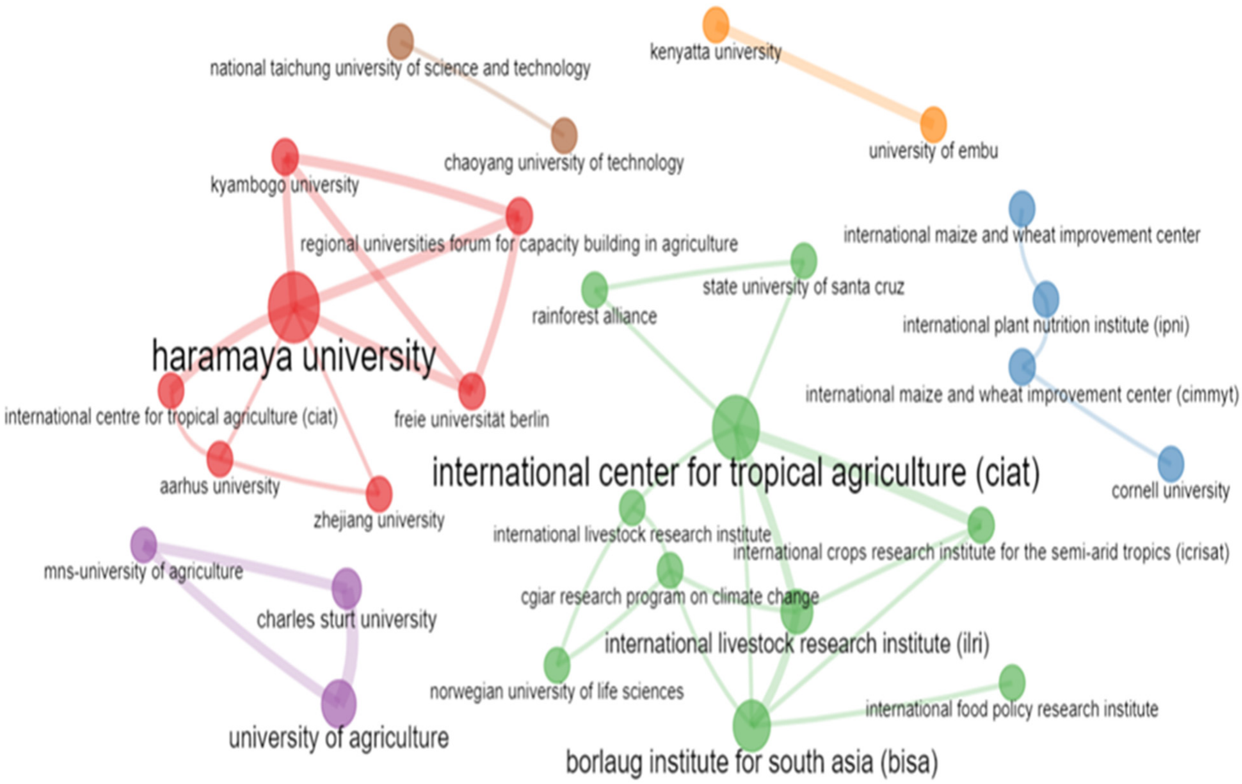

Figure 5. Institution collaboration networks.

Table 8. Cluster of institution collaborations around the globe within the period 2009–2022.

Clusters	Lead Institutions per Cluster	Remarks
Red	Haramaya University (6), Regional Universities Forum for Capacity Building in Agriculture (3)	Haramaya University is the leading university in this cluster and collaborates significantly with Kyambogo University, Regional Universities Forum for Capacity Building in Agriculture, and Freie University Berlin.
Green	International Center for Tropical Agriculture (6), Borlaug Institute for South Asia (5), International Livestock Research Institute (4)	International Center for Tropical Agriculture (IITA) is the main university in this cluster and has a significant collaboration with the International Crop Research Institute for Semi-Arid Tropics in India and the CGIAR research program on climate change.
Purple	University of Agriculture (2), Charles Sturt University (2)	University of Agriculture and Charles Sturt University have significant collaboration with each other.
Blue	International Maize and Wheat Improvement Center (2), International Plant Nutrition Institute (2)	International Maize and Wheat Improvement Center with the International Plant Nutrition Institute have collaboration, though not significant, as well as collaboration with other institutions such as the International Maize and Wheat Improvement Center and Cornell University.

Similarly, the International Livestock Research Institute and the CGIAR research program on climate change (4) are the second most collaborative institutions in the green cluster, whereas the International Crop Research Institute for Semi-Arid Tropics in India and the International Livestock Research Institute in the green cluster have three links each. Kyambogo University in Uganda, Regional Universities Forum for Capacity Building in Agriculture, Freie University Berlin, and Aarhus University in Denmark have three collaborations each in the red cluster.

The Scopus core collection database, which was used in this bibliometric research, included two sets of keywords: author keywords (DE) and keyword-plus (ID) (based on the titles of published resources from 2009 to 2022). Table 9 lists the top fifteen most important author keywords with keyword-plus, as detected in CSA-CCAP printed articles. The phrase "climate smart agriculture" was used in about n = 55, 47% of the writers, making it the most frequent keyword in CSA-CCAP published scientific works. Climate change, agriculture, food security, and adaptation have the most frequently used keywords, occurring in n = 30, 26%; 11, 10%; 11, 10%; and 10, 9% CSA-CCAP scholarly papers, respectively. This result shows that climate-smart agriculture is very important for agricultural production in the face of climate change and is what farmers require if they are to respond quickly to the problems of climate inconsistency [15–17]. Furthermore, keyword-plus (ID) revealed that climate change (n = 69, 60%) had the most occurrences in the articles reviewed, followed by agricultural production (n = 38, 33%), climate-smart agriculture (n = 27, 23%), adaptive management (n = 16, 14%), and crop production (n = 14, 12%). Author keywords (DE) and keyword-plus (ID) have ten keywords in common (climate-smart agriculture, climate change, agriculture, food security, precision agriculture, mitigation, smart farming, India, crop yield, and greenhouse gases). These are due to the numerous hotspots and the evolution of CSA-CCAP research in this sector. Precision agriculture, also within the umbrella of climate-smart agriculture and smart agriculture, has significantly contributed to smart agricultural farming, for instance, in South Africa [105], Nigeria [106], Kenya [105], and Ghana [107], ensuring greater agricultural productivity and minimizing farming losses [55].

Table 9. Most vital keywords relating to CSA-CCAP within the period 2009–2022.

Keyword (DE)	Freq (% of 116)	Keyword-Plus (ID)	Freq (% of 166)
Climate-smart agriculture	55 (47)	Climate change	69 (60)
Climate change	30 (26)	Agricultural production	38 (33)
Agriculture	11 (10)	Climate-smart agriculture	27 (23)
Food security	11 (10)	Adaptive management	16 (14)
Adaptation	10 (9)	Crop production	14 (12)
Precision agriculture	6 (5)	Precision agriculture	13 (11)
Climate change adaptation	5 (4)	Food security	12 (10)
Mitigation	5 (4)	Greenhouse gases	12 (10)
Smart farming	5 (4)	Agriculture	11 (10)
India	4 (3)	Crop yield	11 (10)
Sustainable agriculture	4 (3)	Pakistan	10 (9)
Conservation agriculture	3 (3)	Global warming	10 (9)
Crop yield	3 (3)	Mitigation	10 (9)
Greenhouse gases	3 (3)	India	9 (8)
Farmers	3 (3)	Smart farming	9 (8)

In author keywords (DE) and keyword-plus, India emerged as a prominent country (ID). This could be due to many authors or the discipline's frequent use of India as a case study [27,97,98]. The keywords and keyword-plus capture the views of some previous authors pertaining to CSA. For instance, Adesipo [108] sees climate-smart agriculture as a sustainable form of farming with the aim of improving yield in production systems and food security, centered on combining the major pillars of changing climate. Campbel [109] view climate-smart agriculture involving techniques that transform agricultural procedures towards boosting food security and food production in the changing climate. According to Barasa [39], "climate smart agriculture is a sustainable tactic that can increase agricultural production and income through adopting adaptation strategies while reducing greenhouse gas emissions and promoting resilience to changing climate".

The mapping of density and network visualization of co-occurrence of author keywords within the period of 2009–2022 resulted in four clusters, as shown in Figure 6. The size of the circle in the intellectual network describes the frequency of the number of papers appearing with these terms in the titles [38]. As noted in the figure, climate change, the leading keyword in the green cluster, is linked with other important keywords in CSA-CCAP such as food supply (blue), agriculture (red), Africa (yellow), climate-smart agriculture, and agricultural production (both in the green cluster). Such linkages suggest that the authors are increasingly paying attention to these keywords, with a common interest in advancing CSA-CCAP research around the globe. The size of every keyword in the density and network visualization of co-occurrence of author keywords reveals its significance and rate of recurrence in the CSA-CCAP literature. In line with [43,110], it can be inferred that the closer the keywords are to each other, the more likely they interact throughout the literature review period. The result of the CAS-CCAP research showed a considerable disparity in the density and network visualization of co-occurrence of author keywords in the individual articles. This has shown the multidimensional and multifaceted nature of this scientific field. This finding is in line with the studies of [48,111].

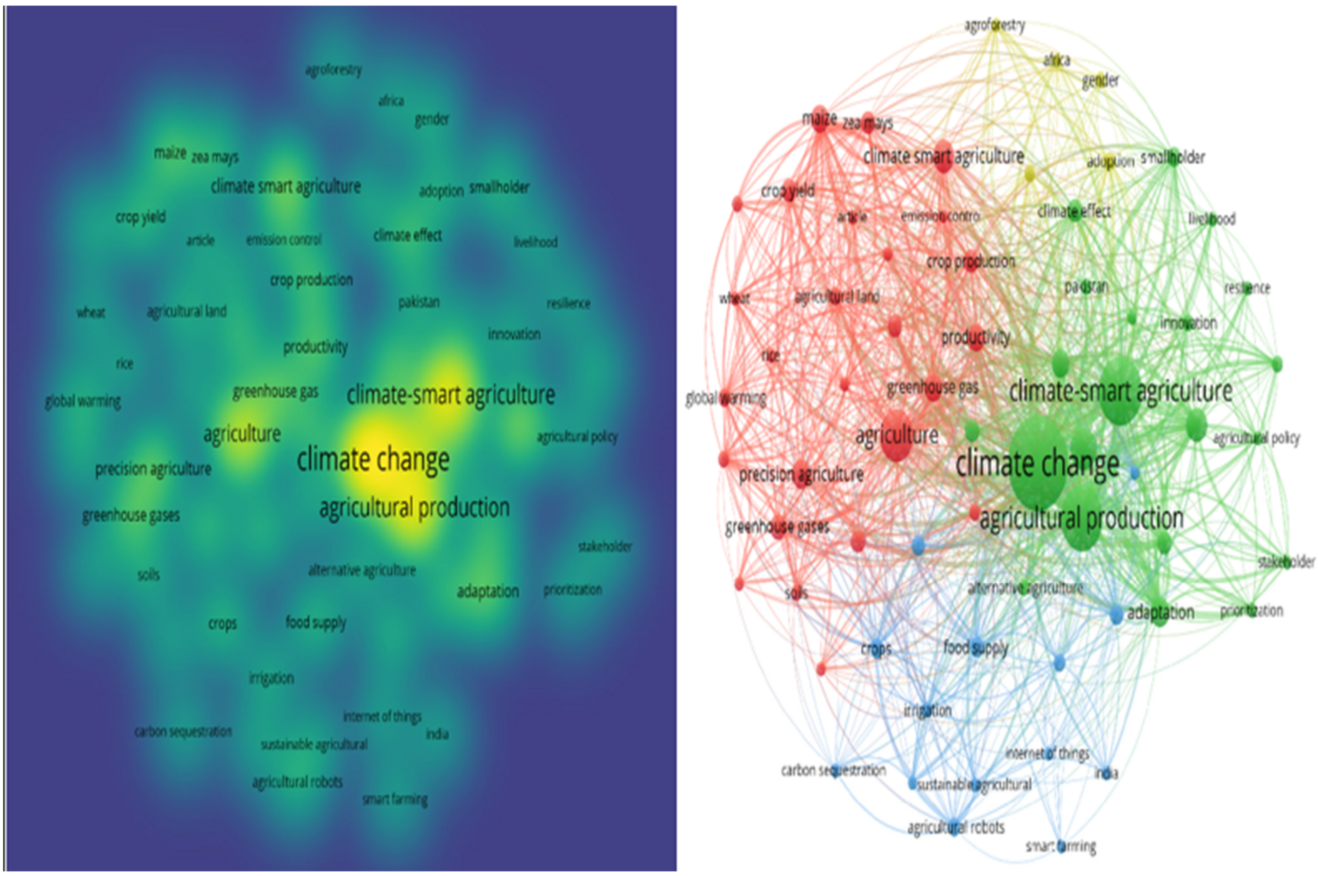

Figure 6. Density and network visualization of co-occurrence of author keywords within the period 2009–2022.

A thematic map is used to explain the evolution of themes or topics and their relationships [112] in the CSA-CCAP research field. The thematic evolution technique identifies the changing paths of studies, evolutionary relationships, structures, contexts, and strengths of emerging themes that appear over time. This method plays a vital role in portraying the degree and direction of the field's development and forecasting the field's trends [113]. The Sankey diagram (Figure 7) displaying thematic evolution is a flow chart where the width of the arrow is proportional to the flow quantity. Each node in Figure 7 corresponds to a topic and the node's width is proportional to the frequency of keywords that occurred under the theme. A thick node characterizes the relevance of that theme. Three time periods (2009–2014, 2015–2019, and 2020–2022) are wired to illustrate the temporal movement between research topics. This Sankey graph clearly shows the evolution and extinction of themes related to the current field of study over time. During 2009–2014, themes such as climate change and food security were a major part of the research, and smart farming and climate-smart agriculture with climate change came out on top during 2015–2019. In the time slice of 2009–2014, there was no sign of CSA, which emerged for the first time during 2015–2019. The "climate-smart agriculture" topic, which is the main focus of this study, came out on top during 2020–2022, signifying researchers' awareness of addressing the impact of climate change on agricultural production.

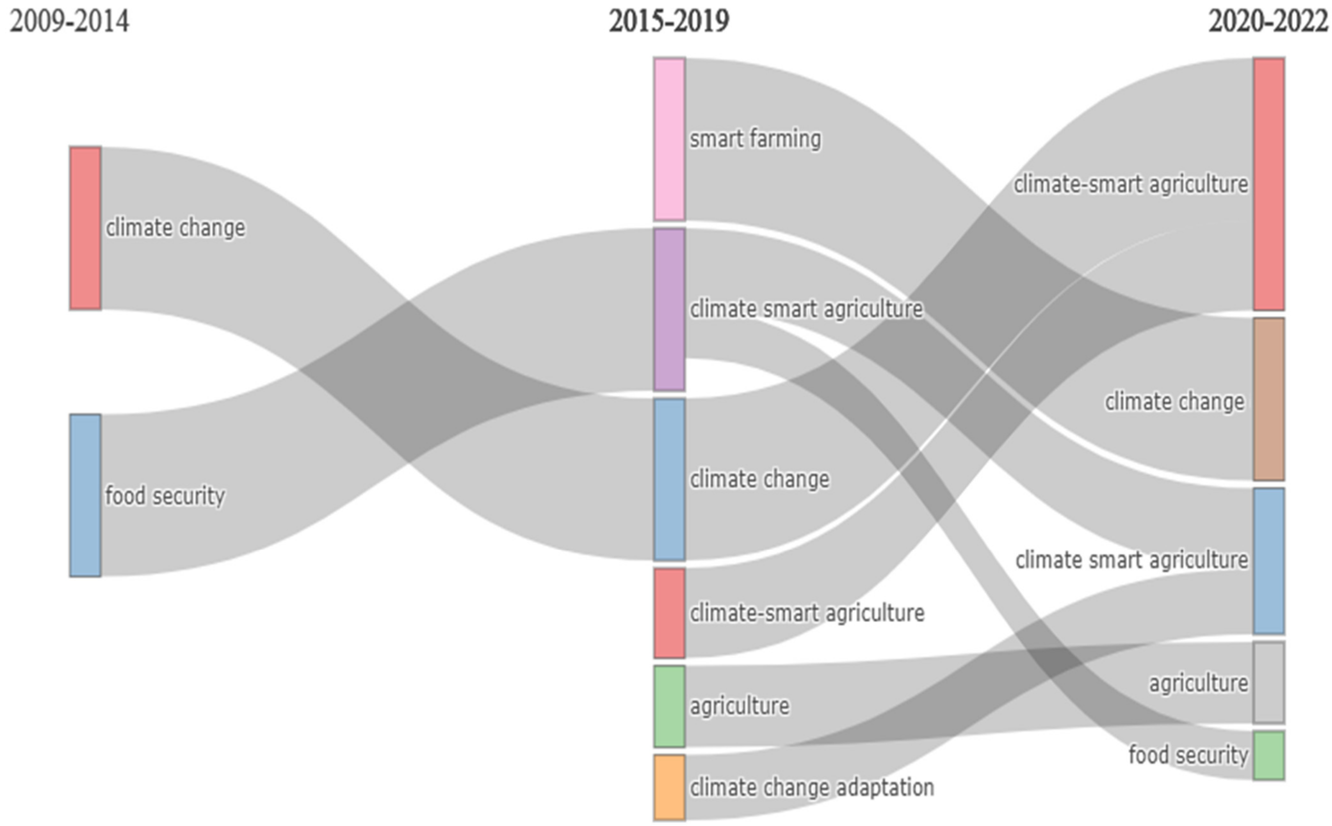

Figure 7. Thematic evolution based on word occurrences within 2009 - 2022.

5. Limitations

Bibliometric research was conducted using papers indexed in Scopus to establish how important this topic is in the scientific literature. Presently, bibliometric studies on a wide range of subjects and topics may be obtained from a number of thoughtfully organized and carefully chosen bibliographic databases, such as PubMed, SciFinder, MathSciNet, IEEE Xplore, ProQuest, and EBSCO databases. One of the most comprehensive and thoughtfully organized databases is Scopus, which contains data on papers or proceedings from conferences, short surveys, book chapters, editorial reviews, books, academic articles, and more [114]. Because information given in conference presentations and short surveys is often not published in scientific journals at a later date, the conference proceedings were not analyzed. Further research on CSA-CCAP could incorporate more datasets such as SciFinder, PubMed, Web of Knowledge, DOAJ, and others.

Asterisk wildcards (*) were used for truncation to find specific terms with our search string. Though asterisk wildcards help to include all the known available suffixes of the original word, it can also include documents that may not be needed for the review. This makes the work tedious and laborious as the authors will have to cross-examine the documents properly and know which to retain and which to delete.

6. Conclusions

Without a doubt, the greatest environmental and human problem of our time is climate change. The developing nations and the African continent are predicted to suffer the most from this problem. The detrimental consequences of climate change on agricultural output and food security in sub-Saharan Africa have been the subject of much research. Due to the region's predominately rain-fed farming system, sub-Saharan Africa's agricultural productivity is extremely vulnerable to climate change. The livelihoods of vulnerable people will worsen as a result of losses encountered in the agricultural sector brought on by climate change, which will ultimately lead to a decrease in gross domestic product and income.

Agriculture is the principal economic sector in various nations and is vital in meeting the essential needs and livelihoods of 70% of the world's poorest people. There is a strong indication in research articles that temperature will generally increase due to changing climate, which may have a significant adverse impact on agricultural production. CSA uses strategies to address food security and climate change through a sustainable increase in food production, reduced GHG emissions, and boosted resilience. CSA is globally embraced as a tactic to protect and transform the agricultural sector. Climate-smart agriculture's policy requirements include reducing GHG emissions, mobilizing farmers' investments, feeding the growing population of 9 billion people by the year 2050, and increasing food yields. Adaptation of CSA seems to be a suitable strategy to enhance agricultural production while also mitigating and adapting to climate-related risks.

Climate-smart agriculture, climate change, and agricultural production are the three interlocking domains of this study. The contributions of CSA to resist the effect of climate change on agricultural production systems should not be underestimated. Research has shown that agricultural practices based on CSA techniques are energy- and input-efficient, improve farmers' livelihoods and food security, promote biodiversity, enhance productivity and net returns to labor, address rising ecological difficulties, improve the effectiveness of managing water and energy resources, restore or maintain soil fertility, prolong the harvesting time and address periodic food scarcities, and hence improve the stability of household food access. Agricultural production using CSA practices and techniques is economically, socially, and environmentally better than conventional farming. CSA practices such as sustainable land management, stopping the advancement of the Sahara desert, community-based natural regeneration projects, agro-ecology, risk insurance mechanisms for Africa, conservation agriculture, drought-tolerant maize, ecosystem-based management, gender-equitable practice, agroforestry, water/soil conservation, rice intensification systems, and grazing land management have been implemented in Africa.

The selected successful CSA-CCAP approaches across Africa demonstrate the diversity of CSA practices and the multiple benefits they provide for farmers in the face of climate change. This study also demonstrated the bibliometric analysis carried out to assess and systematically synthesize the salient features of CSA-CCAP research, such as developmental patterns, research collaborations, keywords, and thematic trends within CSA-CCAP around the world from 2009 to 2022 using Scopus databases. Since 2016, the field of CSA-CCAP has had annual growth in scholarly publishing, with the largest number of outputs in 2021.

Considering research at the country level, India and China hold the top spots with the highest numbers of published articles, and India has the greatest academic influence with the most cited articles emerging from India-affiliated institutions and research centers, such as the International Maize and Wheat Improvement Center and International Plant Nutrition Institute (IPNI).

Based on the density and network visualization of co-occurrence of author keywords within the period, climate change is at the center of issues related to climate-smart agriculture and agriculture production, suggesting the relatedness of climate change for further research. More research on the effects of climate change on food security at the global and rural agricultural community levels is needed now to address the challenge of hunger crises and poverty among the 9.8 billion people who will occupy the world by 2050.

This study provides a road map for navigating the intellectual network of CSA-CCAP research and identifying the direction for future research in this field. Sustainable partnerships among public, private, national, and international agencies are highly recommended. It should be noted that this study focuses on the core field of CSA-CCAP research; as a result, new empirical research and solutions related to sustainable agricultural practices and food security are anticipated to emerge.

The creation of the West Africa CSA Alliance and the creation of nationwide science policy dialogue systems, and multi-stakeholder innovation systems on CSA in some parts of West Africa, are examples of institutional settings at the regional, national, and local levels that are crucial for fostering capacity development and raising awareness of CSA techniques and innovations in the area. However, CSA still has to overcome a number of obstacles, such as the absence of funding, illiteracy of farmers, restricted enabling legislation, finite practical capability to handle the CSA choices, absence of information pertaining to CSA options, and absence of a clear conceptual understanding of CSA. The possibility of CSA in West Africa depends on the ability of the national institutions and farming households in the area to comprehend the social, economic, and environmental challenges brought on by climate change and, as a result, mobilize themselves to create and put into action responsive policies at the proper scales. It is essential to create site-specific agricultural land management practices that encourage improved crop output while minimizing detrimental environmental effects if the objective of sustainable agricultural intensification is to be achieved.

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