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# The Contribution of Agroecology to CSA

**Suwilanji Sinyangwe** [1*], Sithembile Mwamakamba [1,] Njongenhle Nyoni [2,]

[1] *FANRPAN 1; ssinyangwe@fanrpan.org*
[2] *FANRPAN 1; smwamakamba@fanrpan.org*
*3 Dairy Farmers of Washington 2; nmbnyoni@gmail.com*
* *Correspondence: ssinyangwe@fanrpan.org; Tel.: +260976388221*

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**Abstract:**

Climate-smart-agriculture (CSA) involves farming practices that improve farm productivity and profitability, help farmers adapt to the adverse effects of climate change, and mitigate climate change effects. Agroecology, a key contributor to CSA, provides guidelines for developing diversified agroecosystems that take advantage of the integration of plant and animal biodiversity benefits. As a result of such integration, complex interactions are enhanced, nutrient recycling and biomass production and accumulation are synergistically optimized, and the ecosystem's functions and processes become more efficient. The principles of agroecology are not only relevant but are necessary to achieve the goals of adaptation and mitigation. In this paper, we examine the contribution of agroecology to CSA using a bibliographic analysis and interpretation of relevant Agroecological and CSA peer-reviewed research articles related to the African continent. The findings from this paper indicate that the popularity of agroecology has been steadily increasing around the world, with various regions prone to land degradation adopting its approach as not only an adaptation strategy but also as a way to restore the land and increase the continental research on best practices for all aspects of the food system including climate, soil, land management, and crop and animal diversity and further promote participatory and multi-stakeholder approaches in knowledge generation. Agroecology in Africa received much attention from farmers, practitioners, policymakers and other stakeholders during the COVID-19 pandemic. This demonstrated its potential to ensure nutrition security while addressing food insecurity, land degradation, poverty, climate change and shock resilience, among other benefits.

**Keywords:** agroecology; climate change; climate-smart agriculture; ecosystem management; food security; sustainability; resilience

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## 1. Introduction

A promising transformation has already started in Africa's farmlands. Family farmers are increasingly using innovative approaches and scientific research, combined with traditional knowledge, to increase the productivity of their fields, diversify their crops, boost their nutrition, and build on climate resilience. This shift can go much further with the addition of digital tools, increased links to markets, and greater efficiency along agri-food chains, especially if the private sector and national policies also support the effort. The Food and Agriculture Organization of the United Nations (FAO), along with a broad range of partners, are working to promote the African continent to make Africa's agri-food systems more efficient, more inclusive, more resilient, and more sustainable. For this transformation to be achieved, African countries must be in the driver's seat.

Sustainable food systems are fundamental to ensuring that future generations are food secure and eat healthy diets. To transition towards sustainability, many food system activities must be reconstructed, and myriad actors around the world are starting to act locally. Climate-smart agriculture (CSA) is emerging as a convincing response to Africa's agricultural challenges and a viable approach to sustainable agriculture. Climate-smart agriculture is a recently proposed concept, originally presented by FAO at the Hague Conference on Agriculture, Food Security and Climate Change (CC) in 2010, to address the strategic needs of managing agriculture and food systems under climate change. The latest definition of CSA by its original proponents [1,**Error! Reference source not found.**] describes the three objectives of CSA as follows: (1) sustainably increasing agricultural productivity to support equitable increases in incomes, food security and development; (2) adapting and building resilience to climate change from the farm to national levels;

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and (3) developing opportunities to reduce GHG emissions from agriculture compared with past trends. Since then, these three objectives (in short food security, adaptation and mitigation) are designated as the three "pillars" (or criteria) of CSA within the agricultural science and development communities. CSA was developed to help different stakeholders incorporate Climate Change concerns in planning and investment processes. It lies at the interface between science and policy-making and strives to foster action on the ground and mobilize financing, [3].

**Table 1.** Definitions of concepts and characteristics of the agroecology and CSA

| | **Definition** | **First Proponents** | **Shared Principled beliefs** | **Shared casual beliefs or professional judgement** | **Common notions of validity** | **Common policy enterprise** |
|---|---|---|---|---|---|---|
| Agroecolog y | The agroecological approach regards farm systems as the fundamental units of study, and mineral cycles, energy transformations, biological processes, and socioeconomic relationships in these systems are analyzed as a whole [5]. | University of California (Stanford/Sant a Cruz) Social movements | Agroecology is an interdisciplinar y scientific approach that challenged the prevailing agronomic model and a social movement based on the criticism of agricultural modernization. | Agrarian sustainability cannot be achieved using only technological (agronomical or environmenta l) measures but by using agroecology practices. | Scientific peer reviewing and validation by social movement s | Redesign agroecosyste ms sustainably |
| CSA | This is agriculture that sustainably increases productivity and resilience (adaptation), reduces GHG (mitigation), and achieves national food security and development goals [1,**Error! Reference source not found.**]. | FAO CGIAR University of California, Davis University of Wageningen CIRAD. | CSA makes food security, CC adaptation, and mitigation compatible. | Promote the whole series of agroindustrial production models as ecological production models insofar as they use certain practices that favor mitigation and/or adaptation to CC. | Scientific peer reviewing and usefulness for reaching UN's objectives | Produce scientific agricultural knowledge that is "useful" for development and agricultural adaptation to CC |

**Table 2.** Published articles in the Web of Science™ containing the words "agroecology" and/or the targeted three criteria of CSA. The search was undertaken between June and July 2021.

| | | | | |
|---|---|---|---|---|
| research | | | | |
| Agroecology + food security | 100 | 398 | +398% | 58% |
| Agroecology + adaptation | 130 | 301 | +233% | 26% |
| Agroecology + mitigation | 26 | 183 | +704% | 18% |
| Agroecology + 2 or 3 criteria | 23 | 178 | +774% | 7% |

While the total number of publications dealing with agriculture increased by 89%, the Agroecology share in the agricultural research agenda increased by 215% and reached 11% of all published papers in agriculture. Topics related to climate and food security in agroecology increased even more dramatically during the 2012–2021 period, from a share of 10% before 2012, to 58% in 2021 (Table 1) . These figures underline the growing interest of Agroecology researchers in food security and adaptation, of CSA criteria. Thus CSA would probably gain from the use of current and past agroecology research results as shown in Fig. 2. Such a complementary use can help correct current trends in CSA research and give CSA research the opportunity to better tackle mitigation as well as its interactions with adaptation and/or food security [17]. Here is where social organization and movements have a major role to play. Investing in institutional and policy innovation will be at least as important as investing in generating new scientific knowledge on agroecology [18].

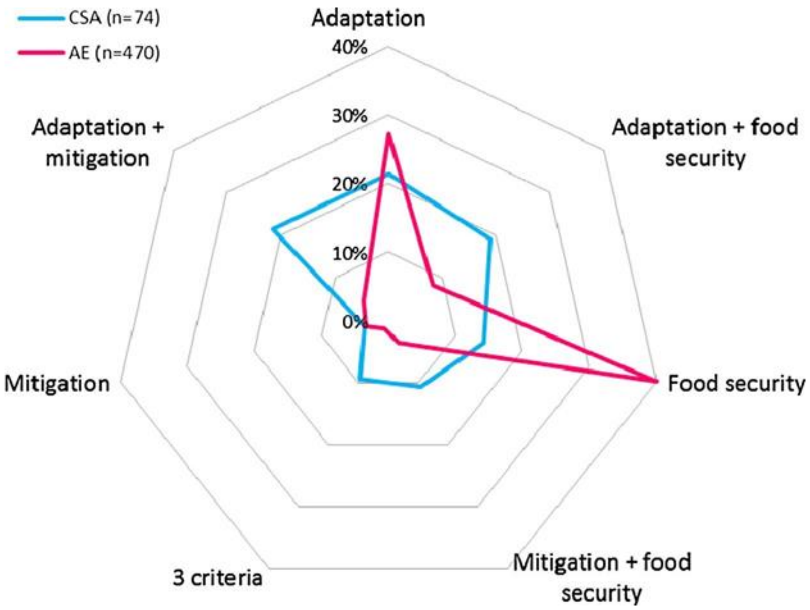


Fig. 1. Occurrence (shares) of "adaptation", "mitigation" and "food security" terms in 74 abstracts, titles and keywords from CSA (blue line) – and 470 from agroecology (pink line) – published articles referenced in the Web of Science™. The search covered the 2012–2016 period and was undertaken between March and April 2017. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article) [17].

## Agroecology and Climate-Smart Agriculture operating scales

CSA and AE concepts can work well together when observing the spatial scales at which they often operate in the eco-system (Figure 1). In fact, the CSA is specifically designed to help manage agriculture and food systems under climate change. As such, part of CSA addresses very large scales (global, regional, national) and uses "soft sciences" that are intertwined with (inter)national issues and which therefore require high political will [19]. CSA is popular with many farmers, but tenants say that institutions and financial support are needed to help them get the most out of this initiative (i.e. to work towards the achievement of the three criteria of CSA). Inter-sectoral coordination (e.g. the combination of climate change, agricultural development and food security policy processes) is, for them, important. Public-private financing synergies are as well required, including climate and food security financing to support innovation in the agricultural sector. This political will appears to be in line with CSA's thrust "at the crossroad of science and policy making" [19].

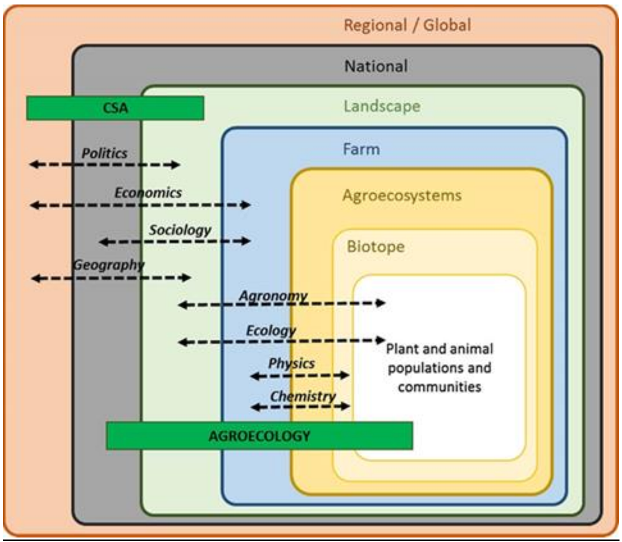

**Fig. 2.** Scales and scientific domains at which Agroecology and Climate Smart Agriculture (CSA) can (co)operate [17].

Yet, while CSA has a strong focus on policies, institutions and financing, it does not state which agricultural practices are climate-smart, and actually, the underlying message is that there is no specific climate-smart blueprint or practice. It rather depends on site-specific conditions and can include, for example, GMOs or intensive practices [19]. However, site-specificity is an advantage for CSA as it allows genuine farmers' practices to be recognized and supported by adequate policies. Famers' assisted regeneration of scattered trees in cropland in Africa (agroforestry) is a case in point: in Niger, following a policy change that gave tree tenure to farmers (as opposed to the state), the practice spread to large areas and contributed to soil and biomass carbon sequestration, while buffering heat stress and erosion, improving soil fertility and finally leading to better food security through commodities and income diversification [20]. Even though the fact that CSA does not recommend specific practices has raised and still raises controversy for agroecology tenants [12], we believe that the complementary nature of CSA and AE in agricultural practices should be explored and promoted (Fig. 2). Indeed, the history of AE research development clearly shows that it acknowledges and embraces site-specificity through the importance it gives to local practices and skills, [8]. Also, AE research began at the field scale and further developed at the agroecosystem and farm levels to finally include landscapes during the 2000's [9]. AE also developed socio-economical approaches since the 90's, ultimately addressing the whole food system. It thus appears that although CSA and AE overlap at landscape and farm levels, CSA is more influential at national and world levels while AE rather deals with agroecosystems and plant or animal populations. This shows where the 2 concepts can enrich each other. Additionally, given the fact that AE's "spirit" seems better recognized by civil society and turned toward local populations needs and will, the inclusion of AE knowledge in CSA is unlikely to be seen as a top-down, business as usual, initiative [17]. Finally, improved proximity between CSA and AE (and eco-efficient agriculture broadly speaking) will help foster an inclusive development pathway for agricultural adaptation to climate change [21].

## 2. Materials and Methods

The review study considered various search topics to retrieve scientific documents related to agroecology and CSA practices in Africa. The search themes were specifically chosen to cover the range of research topics relevant to agroecology and CSA. As such, these search topics cover all aspects of climate change and areas surrounding policy and decision-making, governance, agricultural best practices, and the 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*", "Agroecology", or "agroecology and climate-smart agriculture" coupled with "agroecology transitioning*", "Agro-ecology", "agroecology practices" "Nature-based solutions ", "Nature based solutions", "CSA criteria in agroecology research", or "agroecology and climate change" as well as with "Africa", for areal restriction. The content analysis was done using "climate-smart agriculture" and "agroecology" as the reference. Regarding nature-based solutions, other terms were also considered in context such as "Ecosystem-based management," "Ecosystem-based adaptation," and "Ecosystem-based mitigation." (see Table 3 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 3.** Published articles in the Web of Science™ containing the words "agroecology" and/or the targeted criteria of CSA. The search was undertaken between July and August 2022.

| Search Topic | Areal Restriction | Areal Restriction |
|---|---|---|
| "agroecology" | [AND] "climate smart agriculture" | [AND] "Africa" |
| "CSA criteria in AE research" | | [AND] "Africa" |
| "agroecology practices" | [AND] "climate-smart agriculture" | [AND] "Africa" |
| "agroecology" | [AND] "food security" | [AND] "Africa" |
| "Ecosystem-based management" | | [AND] "Africa" |

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| | | |
|---|---|---|
| “Ecosystem-based adaptation, | | [AND] “Africa” |
| “Ecosystem-based mitigation.” | | [AND] “Africa” |
| “ climate-smart agriculture“ | [AND] “indegenous knowledge” | [AND] “Africa” |
| “agroecology practices” | | [AND] “Africa” |
| “agroecology” | | [AND] “Africa” |
| “Agro-ecology” | | [AND] “Africa” |
| “Nature-based solutions | | [AND] “Africa |
| “Nature based solutions” | | [AND] “Africa |
| “ climate-smart agriculture“ | | [AND] “Africa |

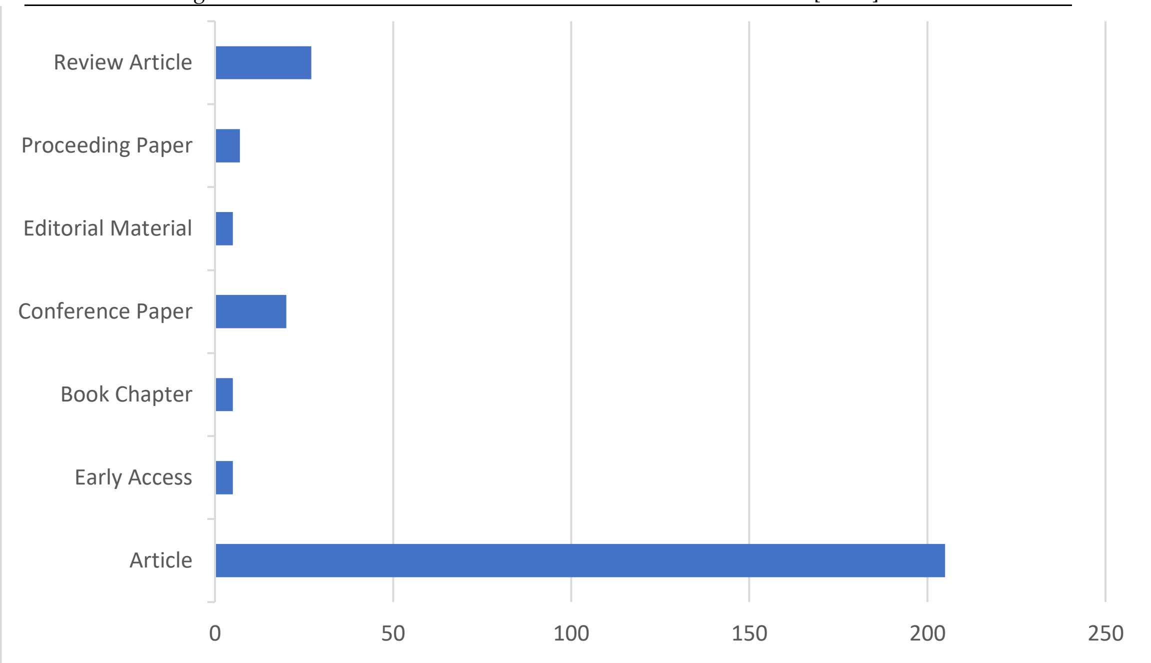


**Figure 3.** Number and type of documents retrieved and analyzed in the review study of agroecology in Africa.

We employed the Web of Science database (WoS), which is acknowledged to be a robust resource in this context [22]. It excludes technical reports and publications in journals whose standards do not meet specific criteria, primarily relating to peer review. WoS is a curated database with holdings in several languages, although its content is primarily in English. It aggregates publications into a number of indexes, notably Science, Social Science, Arts and Humanities and a new category of content in emerging journals which, in a field such as this, will tend towards specialized focus or broad interdisciplinary [23]. Consequently, The contribution of Agroecology to CSA mapping undertaken in this review study assessed the following themes: (1) annual publication growth and trends; (2) leading countries contributing to the agroecology and 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 Agroecology practices and their contribution to CSA in Africa*

#### 3.1.1. Growth Patterns in the science of agroecology in Africa

Figure 4 depicts the yearly scientific publications of agroecology practices. As depicted in Figure 4, research in agroecology 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 agroecology subject matter and its contribution to CSA. The scientific production of agroecology published articles significantly increased from 2017, reaching the highest number of 56 articles in 2020. Overall, agroecology practices in Africa are relatively growing, with an annual percentage growth rate of approximately 22.3%. This significant growth rate suggests that agroecology is gradually borne out of necessity as the effects of climate change continue to impact people's lives negatively. Consequently, the larger scientific community has explored more innovative agricultural methods to mitigate the inherent future climate impacts on agriculture.

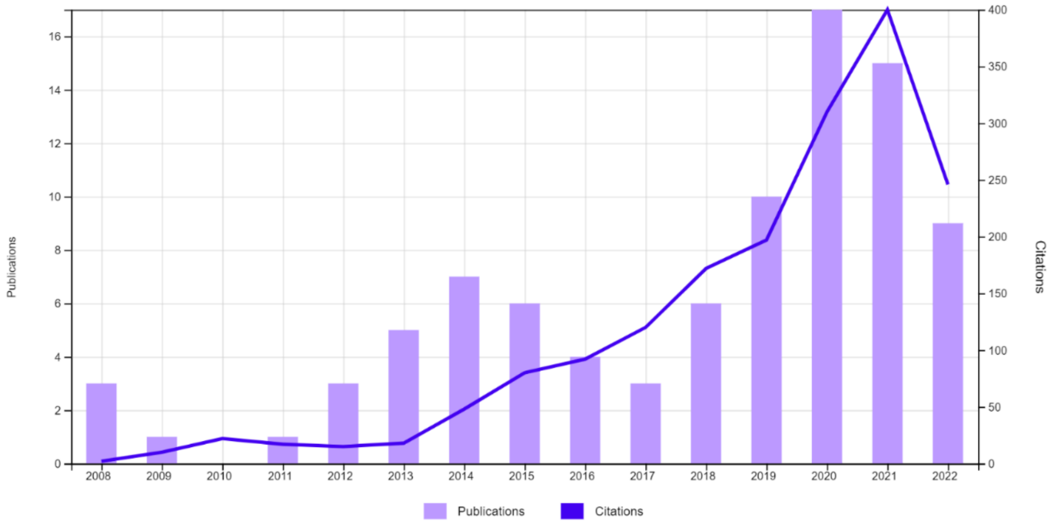


**Figure 4.** Annual publications of agroecology practices articles show a steady increase from an average of 1 publication per year between 2009 and 2011 to 17 publications in 2020.

3.1.2. Most Productive Countries in agroecology practices that contribute to CSA

The top ten countries that have significantly contributed to the CSA using the science of agroecology in Africa are shown in Figure 5. It can be observed that only ~55.56% of the African countries appear in the top ten list. These include South Africa, taking the lead with 16 scientific publications, followed by Ethiopia with 9, and Kenya and Malawi with 8 and 8 scientific outputs. The leading countries are ranked based on the author's correspondence country.

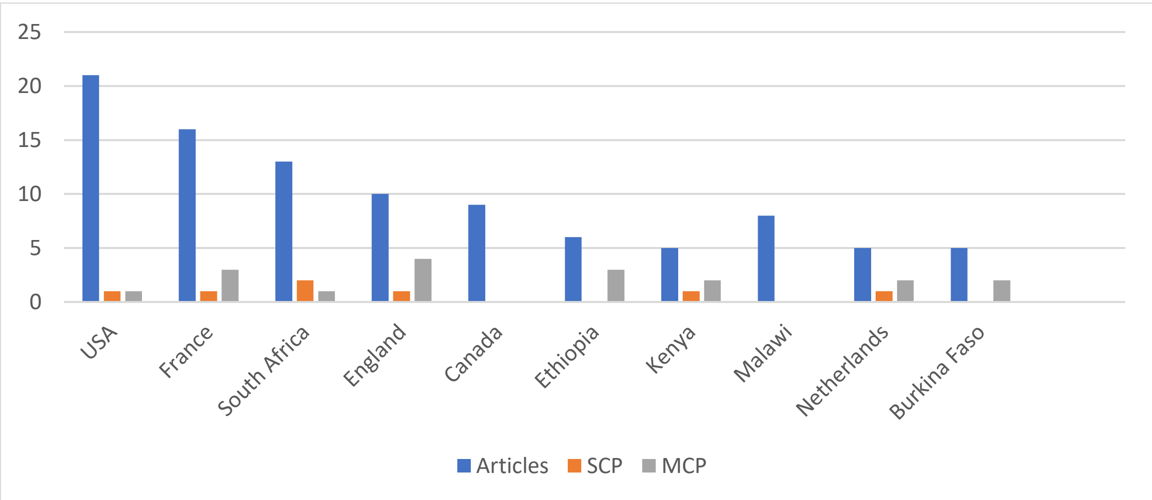


**Figure 5.** Top ten leading countries in agroecology practices that contribute to CSA research publications. The ranking is based on the corresponding author's country. SCP: single-country publications; MCP: multiple-country publications.

The results shown in Figure 5 also show that developed countries such as the United States of America (USA), France, England, the Netherlands, and Canada appear in the top ten list, suggesting that authors in these countries have collaborated in agroecology practices research projects in Africa, resulting in the research work being disseminated through scientific publications. In general, the 90 agroecology practices documents were co-authored by 1,749 researchers through multi-country publications (MCP), with only 7 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 and documentation of agroecology practices publications that contribute to the CSA scientific domain significantly.

The published agroecology practices research is well recognized globally, as attested by the citation scores provided in Table 4. Over the study period, the United States of America has received the highest number of citations (317), followed by France, Ethiopia, and the Netherlands, with 201, 159, and 156 total citations respectively. The rest of the countries have received lesser citations over the same period, including Kenya and South Africa, with 125 and 90 total citations. Column 3 of Table 3 shows the ten main sources that have published scientific documents related to agroecology. The ranking of these sources is based on the total number of published documents. Most of the sources are journals, reflecting a great interdisciplinary nature of the agroecology practices research field in Africa. Approximately 84.9% of the documents were published in journals, with *Environmental Sciences* leading with 442 published scientific articles, followed by *Sustainable Science Technology* (235), *Environmental Studies* (234), and *Agriculture Multidisciplinary*, with 226 published articles. *Food Security*, *Agronomy, Food Science Technology, Soil Science, Ecology*, *Plant Sciences and water resources* also emerge as key multidisciplinary sources in the agroecology practices research topic.

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**Table 4.** Top ten total citations per country and top publication sources.

| Country | Total Citations (Average Article Citations) | Top Relevant Sources (Number of Articles) |
|---|---|---|
| USA | 317 (19.7) | *Environmental Sciences* (77) |
| France | 201 (12.5) | *Agronomy* (63) |
| Ethiopia | 159 (9.8) | *Environmental Sciences* (89) |
| Netherlands | 156 (9.6) | *Agriculture Multidisciplinary* (40) |
| England | 149 (9.2) | *Environmental Sciences* (43) |
| China | 128 (7.9) | *Environmental Sciences* (73) |
| Kenya | 125 (7.8) | *Environmental Sciences (30)* |
| German | 122 (7.6) | *Environmental Sciences (41)* |
| Australia | 99 (6.1) | *Environmental Sciences (30)* |
| Brazil | 93 (5.8) | *Green Sustainable Science Technology* (9) |

3.1.3. Country Collaboration Network

Figure 6 depicts the top 37 countries' collaboration networks of the retrieved agroecology practices documents, assigned into seven clusters. Detailed information on these clusters and the corresponding countries is given in Table 5. The size of the cluster represents the most collaborative country. As noted in Figure 4, Benin (27), Burkina Faso (24) Cameroon (7), Germany (27), Ghana (25), Madagascar (4), Namibia (5), Nigeria (17), Portugal (12), Senegal (14), Switzerland (27) and Uganda (22) in red clusters are the most collaborative countries, followed by Belgium (27), Ethiopia (24), Italy (22), Japan (5), China (11), Scotland (5) and South Africa with 31 links in green clusters. Similarly, Algeria (20), France (32), Mali (5), Norway (19) and Tunisia (20) in dark blue clusters. Canada (32), Malawi (28), Rwanda (9) and USA (32), in yellow clusters. England (32), Spain (24), Sweden (29) and Wales (3), in purple clusters. Australia (24), Kenya (26) and Tanzania (24) in light blue clusters. The Netherlands (29) and Zimbabwe (13) are the most collaborative countries in light brown clusters.

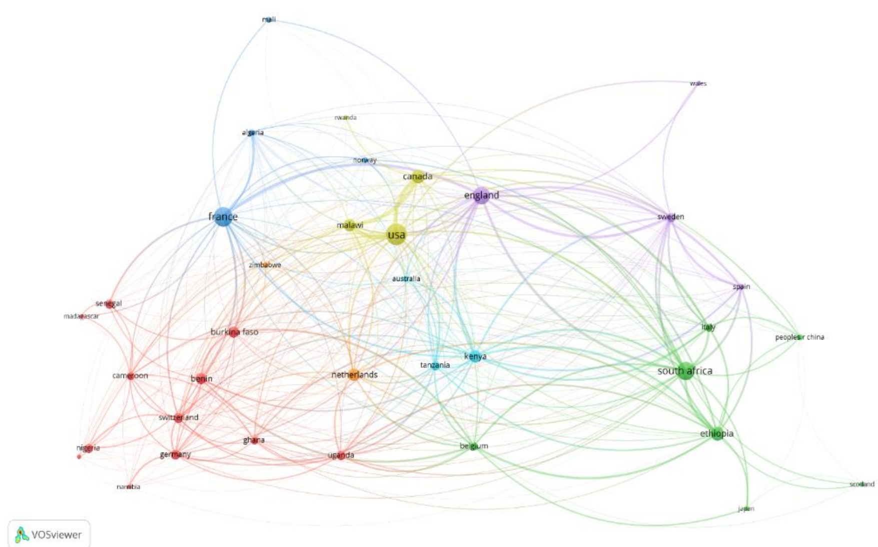


**Figure 6.** Countries' collaboration network among different countries.

**Table 5.** Clusters of countries' collaborations in climate-smart agriculture research in Africa.

| Cluster | Leading Countries Per Cluster | Remarks |
|---|---|---|
| Red | Benin (27), Burkina Faso (24) Cameroon (7), Germany (27), Ghana (25), Madagascar (4), Namibia (5), Nigeria (17), Portugal (12), Senegal (14), Switzerland (27) and Uganda (22) | Countries in this cluster have significantly collaborated with countries in yellow, green, and light blue clusters |
| Green | Belgium (27), Ethiopia (24), Italy (22), Japan (5), China (11), Scotland (5) and South Africa (31) | South Africa, 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 | Algeria (20), France (32), Mali (5), Norway (19) and Tunisia (20) | France has collaborated with most countries across the clusters |
| Yellow | Canada (32), Malawi (28), Rwanda (9) and USA (32) | USA has collaborated with most countries across the cluster |
| Purple | England (32), Spain (24), Sweden (29) and Wales (3) | England has shown a significant collaboration across most countries and clusters |
| Light blue | Australia (24), Kenya (26) and Tanzania (24) | Kenya is the most leading country in collaborations in this cluster |
| Light brown | The Netherlands (29) and Zimbabwe (13) | Countries in this cluster have collaborated with most African countries, including USA in the yellow cluster and France in the dark blue cluster |

### 3.1.4. Main Keywords

Figure 7 depicts the frequently used keywords in the agroecological practices 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 6 gives the topmost author keywords and keywords-plus generated using agroecology practices published articles. Based on the author keywords analysis, the agroecology keyword was used by approximately 48 authors, making it the most used keyword in agroecology published scientific articles. Climate change, climate smart agriculture, food security, and adaptation keywords were mostly used, appearing in 38, 37, 23, and 19 agroecology practice articles, respectively.

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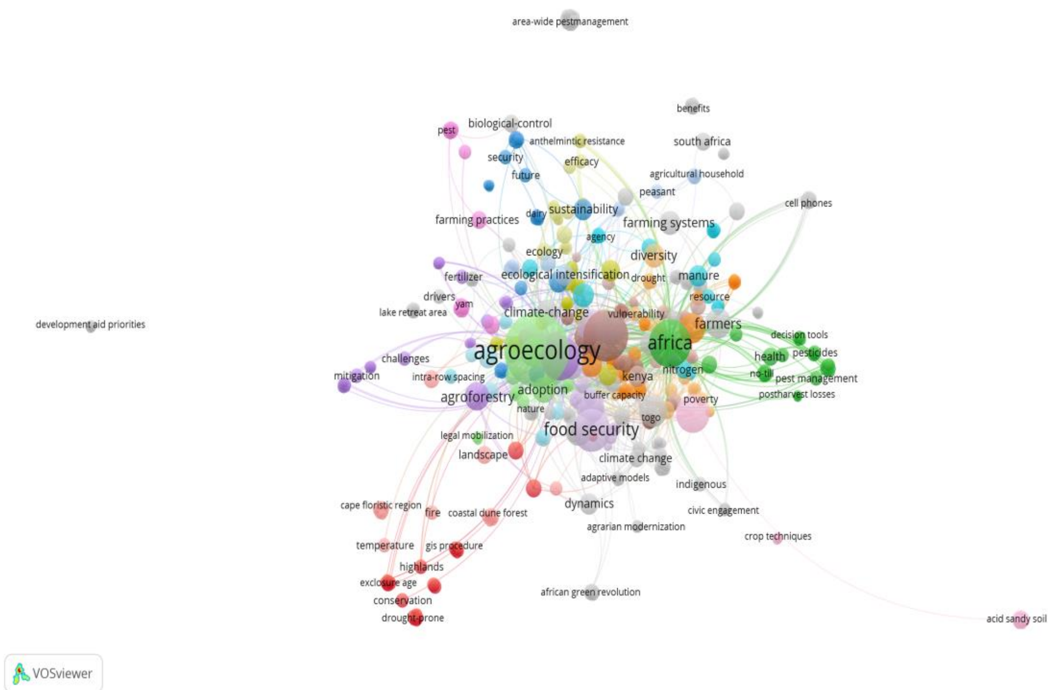


**Figure 7.** Keyword occurrences.

**Table 6.** Most relevant keywords.

| Author Keywords (Number of Articles) | Keywords-Plus (Number of Articles) |
|---|---|
| Agroecology (48) | 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) |
| Ecology 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 7. As noted in the figure, climate change, the leading keyword in the yellow cluster, is linked with other important keywords in agroecology practices such as conservation (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 agroecology practices that contribute to CSA research in Africa. Overall, the identified keywords are a combination of the three pillars of agroecology and CSA best practices.

3.1.5. Thematic Network

A thematic map is used to assess the evolution of themes or topics in the agroecology practices research field. As shown in Figure 8 [24], 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 8, within the agroecology and 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 agroecology and CSA research field. Basic themes in the lower-right quadrant cover words such as "agroecology "climate-smart agriculture"; "climate change"; "food security"; "climate change adaptation"; "precision farming"; "gender"; and "livestock", among others, [24].

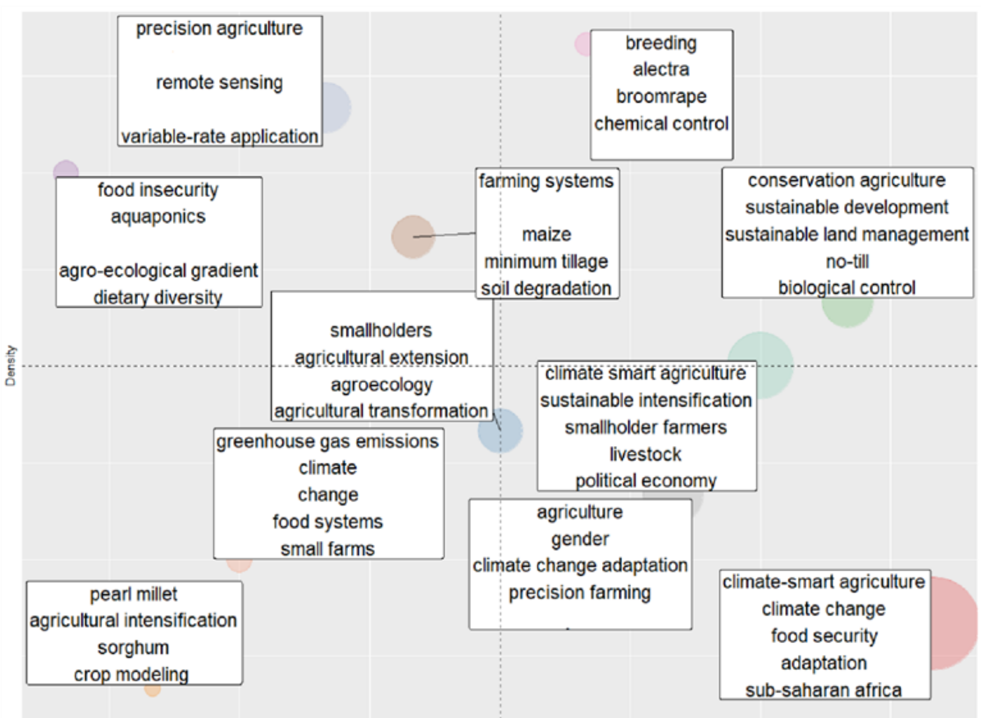


**Figure 8.** Thematic map of emerging themes in CSA research [24].

## 4. Discussion

### *4.1. Salient Features of agroecology practices that contribute to CSA 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 [25], as well as the region's ongoing population growth, which is projected to double by 2050 [**Error! Reference source not found.**,26]. The COVID-19 crisis highlights the need for food system innovations, particularly in re-localizing and diversifying these systems in order to ensure their resiliency. Changes in food system organization can prioritize food access for vulnerable communities, promote sustainable agriculture including biodiversity protection, and encourage healthy and nutritious diets. Fundamental to these transitions is to increase producer-consumer exchanges and to change how they interact with and influence their food environments. Rather than staying passive, consumers are becoming increasingly active in the reorganization of food systems as they seek healthy and sustainably grown food, as well as trade systems that build local economies and include smallholder farmers. 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. There is substantial evidence that the practice of agroecology has been welcomed in Africa and that it complements the work of scientists studying agricultural practices [2]. This concept is attributed to the number of countries that have conceptualized and implemented the CSA framework using agroecology practices and the significant research results provided by published academics related to agroecology and CSA. Based on the current review study, CSA research in Africa commenced in 2000, as reported in [27]. In the [27] 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 agroecology research progressed at a very minimal rate between 2008 and 2013, the research began to gain momentum from 2014, reaching a tremendous achievement in 2020, resulting in 87 published articles. Undoubtedly, such a significant increase can be attributed to African countries being more concerned about the impacts of climate change, manifested in the effects of droughts, floods and extreme temperatures on agriculture, and looking to find possible solutions to minimise such impacts to increase productivity. This significant progress indicates that the scientific community and all relevant stakeholders on the African continent are becoming more familiar with agroecology practices and exploring ways to enhance their knowledge of implementing the CSA framework.

Although the interest in agroecology 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 agroecology practices research publications, only 31% of the countries appeared on the list. The corresponding author is usually based in Africa (e.g., Kenya, South Africa, Malawi, and Benin). This can be seen to suggest that CSA practices research in Africa is still nascent, as it has been reported in [28]. In general, there is a wealth of evidence available on agroecology practices 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 abundance of evidence suggests that Africa can do much better if its countries collaborate with neighbouring countries and those 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, France, the Netherlands, and England. While these collaborations are well appreciated, it is imperative to include under-developed countries in the agroecology and CSA subject matter. This will serve as a starting point for implementing agroecology and CSA concepts, realizing their benefits and, in turn, achieving much-needed agricultural transformation in Africa [24].

According to keywords analysis, many of the production systems are reflected in the main keywords network shown in Figure 7. The keywords are mostly under the low-cost sustainable agriculture practices umbrella, such as crop conservation, maize (*Zea mays*), fertilizers, precision agriculture, soil conservation,

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agronomy, agroforestry, legumes, remote sensing, and grazing land management, among others. The frequency of these keywords supports the notion that most farmers/farming communities in Africa are exploring indigenous farming practices 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 analysed in this paper using the web of Science. 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 [29,30], Zimbabwe [31,32], and Kenya [33,34].

Agroecology practices research in Africa has focused on conservation agriculture, sustainable development, sustainable land development, soil fertility management, biodiversity conservation, and plant health, which build on top of CSA practices. According to the documents assessed in this review, we have noted topics such as agroforestry; integrated crop-livestock; rainwater harvesting; agro-ecological gradient; farming system; maize production; minimum tillage; and smallholder irrigation are parts of agroecology research in Africa which contributes to CSA.

*4.2. Progression and Adoption of Climate-Smart Agriculture practices 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 [35].

Focus on agroecology and CSA for its multiple benefits, including addressing challenges of climate change, is gaining global attention. Building on scientific and practical evidence, multi-stakeholders in Africa, working in partnership with development partners, are investing in innovations and opportunities for agroecology practices to enhance the productivity, resilience and profitability of smallholder farming systems in Africa. Investments in research, developing ecologically sustainable systems and working on markets for organic produce would guarantee sustainable food systems in Africa. Therefore, the necessary intensification of agricultural production in Africa should be ecological, maintain ecosystem services and restore, build and maintain natural resources, particularly soil, water and biodiversity. A better future for the organic sector requires African governments, their relevant institutions, farmers, farmer organisations, development partners and the private sector to invest resources in research, policy and programmes to establish platforms for experience sharing, learning and collaboration, thereby building the basis for poverty reduction and sustainable, long-term food and nutrition security. There were more than 2.0 million hectares of organic agricultural land in Africa in 2020, representing 0.2 percent of the continent's total agricultural area and 2.8 percent of the global organic agricultural area. The organic agricultural land in Africa has increased by more than 148'000 hectares or 7.7 percent compared to 2019, and it has increased by more than 2 million hectares since 2000. In 2020, 35 African countries reported data on organic activities. Since 2017, Tunisia has been the country with the largest organic area, with over 297'000 hectares. Ethiopia was the country with the highest number of organic producers, with almost 220'000 producers in 2020, followed by Tanzania with nearly 149'000 producers and Uganda with over 139'000 producers. For more than a decade, the island state of São Tomé and Príncipe has been the country with the highest organic share of the total agricultural land, reaching a share of 20.7 percent in 2020. For the second time in a row, Sierra Leone and Réunion (France) were among the top three countries with the highest organic share, reaching 5.6 percent and 4.0 percent in 2020, respectively [36].

In 2020, land use information was available for 96.8 percent of the organic agricultural area in Africa. Two-thirds of all organic agricultural land was used for permanent crops (almost 1.4 million hectares).

Almost 30 percent was used for arable crops (nearly 620’000 hectares), and less than 1 percent (nearly 915 hectares) was grassland/grazing area. The most important organic permanent crops were nuts (mainly cashew nuts), which were grown on an area of over 291’000 hectares, followed by olives, coffee, and cocoa – each with an area above 200’000 hectares. The countries with the largest permanent crop areas were Tunisia (mainly olives), which reported an area of nearly 269’000 hectares, followed by Sierra Leone, Ethiopia (mainly coffee), Congo (cocoa and coffee), and Kenya (mainly nuts), with the latter reaching an area of nearly 113’000 hectares [36]. The most important organic arable crops were textile crops (mainly cotton), which were grown on an area of over 206’000 hectares, and oilseeds (mainly soybeans and sesame), with an area of almost 185’000 hectares. The countries with the largest arable crop areas were Tanzania (mainly textile crops), which reported an area of nearly 159’000 hectares, followed by Togo (mainly oilseeds) and Egypt, with an area of over 113’000 hectares and over 96’000 hectares, respectively. Wild collection has an important role in Africa, with more than 11.7 million hectares certified as organic in 2020. Zambia was the country with the largest area (3.2 million hectares, mainly bee pastures), followed by Namibia (nearly 2.6 million hectares, mainly medicinal and aromatic plants – devil’s claw), Mozambique (1.8 million hectares, exclusively baobab fruit), Lesotho (nearly 1.0 million hectares, exclusively rose hips), Somalia (940’000 hectares, mainly gums natural), and South Africa (nearly 860’000 hectares, mainly medicinal and aromatic plants and rose hips). Medicinal and aromatic plants, such as devil’s claw (Harpagophytum procumbens), were the commodities that had the largest area (nearly 3.3 million hectares), followed by rose hips (over 1.4 million hectares). For beekeeping, 2.5 million hectares were reported for Zambia.

CSA activities being implemented in Africa put greater emphasis on increasing productivity and building smallholder farmers’ resilience and adaptive capacity to climate-related hazards and other shocks. As such, CSA largely promotes yield-enhancing technologies and intensification approaches that can deliver food and nutrition security and increase rural incomes [37]. One such initiative is the Rwanda Climate Services for Agricultur**e** project (2016-2019), which was implemented by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), and aimed to transform smallholder farming activities and the national economy through improved climate risk management [38]. The project enabled Rwanda’s National Meteorological Agency to enhance the accuracy of climate information by merging satellite data with its in-station observations. This data was translated into site-specific climate informed agro-advisories that were incorporated into the national agricultural extension system, known as “Twigira Muhenzi”, and disseminated to 112,000 farmers across Rwanda’s 30 districts using interactive information and communications technology (ICT) tools (i.e., interactive radio broadcasts, Short Message Services (SMS), Unstructured Supplementary Service Data (USSD) and Interactive Voice Response (IVR) in combination with other interventions [39]. The expansion of contextualized climate services to reach large numbers of farmers and other agricultural decision makers is a response aimed at de-risking rural livelihoods through inclusive early warning systems, adaptive safety nets, and climate-informed advisories and other services [40]. Among the Beacon of Hope case studies from Africa is a collection of 33 Agroecology Case Studies from across the continent that demonstrate the potential of agroecological methods to sustain productivity, raise incomes, improve livelihoods, and adapt to climate change [41].

The Ecological Organic Agriculture Initiative (EOA-I), funded by the Swiss Agency for Development and Cooperation (SDC) and the Swedish Society for Nature Conservation (SSNC), continues to reach out to smallholder farmers. Based on 2020 data (2021 data is under compilation), about 1.76 million farmers (49 percent women, 45 percent men and 5 percent youth) received information and communication materials to enhance their organic farming knowledge and uptake. Additionally, EOA-I information reached 2 percent of value chain actors (transporters, input suppliers, marketers and consumers). After being exposed to information and communication pathways, 13’852 farmers (5’794 males, 4’036 females and 4’022 youth) adopted EOA practices. The communication pathways used included knowledge databases, training events, workshops, social media (especially YouTube, Twitter and Facebook) and other websites. The initiative's databases continued to be strengthened to make research findings and EOA knowledge available and accessible for various users. About nine EOA practices were promoted during this period, including consumption and the management of crops, livestock, soil, diseases, pests, social activity and the postharvest stage. Approximately 35'000 stakeholders were trained, with the majority being farmers. The multiplier approach for training teams of facilitators who then train larger numbers of value chain actors was used. This approach saw 272 master trainers train 35'000 value chain actors [42].

*4.3. Policies fostering agroecology and CSA*

A growing number of governments worldwide support the development of agroecological and CSA policies by designing new initiatives and programmes that help achieve the set goals. On the other hand, there are more ambitious governments that have announced and launched policies aiming at a complete transition to organic agriculture. These include the following [43]:

- *Madagascar;* In Madagascar, the first law on organic agriculture was promulgated in 2020. Based on this work, the first National Strategy for Organic Agriculture (SNABIO) will soon be adopted. Madagascar's ambition is to establish a policy to support organic farming for both export and the domestic market, with the aim of democratising access to healthy and sustainably produced food and leveraging all the benefits of this. These include a fair and stable income for producers, preservation of human health (farmers and consumers), a source of foreign currency for the country, conservation of ecosystems and natural resources, agricultural practices adapted to climate change and rural development. The main focus of the law and the SNABIO is supporting the growth of exports, promoting the development of the national market, and guaranteeing the organic nature of products without hindering the sector's growth. The next steps will be to put the policy and its regulatory features into practice by developing supporting tools, launching pilot projects, and further financial support from donors.
- *Burkina Faso;* In Burkina Faso, the Ministry of Agriculture, Hydro-Agricultural Development and Mechanisation is leading the development of a national strategy for agroecology and an accompanying action plan. The strategy has emerged from consultations with various actors of different sectors in the country. A commonly-defined objective is to support a consistent vision to make agroecology the engine of ecological, sustainable, competitive agro-sylvo-pastoral production, creating jobs and ensuring food security for all. A recent assessment led by FAO on agroecology in Burkina Faso identified three key strengths: the political will, the dynamism and commitment of civil society and the development of technologies and approaches by grassroots actors. In parallel, a new version of the national programme for the rural sector (PNSR 3) is also in progress. This programme is planned to be the main federal strategy and action plan for sectoral policies, including agriculture, food security, value chains, land management and water management. Synergies between the national strategy for the development of agroecology and the PNSR 3 are to be explored. This will offer a unique opportunity to align the structural investment in the productive sectors with agroecological principles.
- *Uganda*; Uganda's Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) launched the National Organic Agriculture Policy (NOAP) in 2019. Since then, steps have been taken towards implementing the NOAP by consolidating a roadmap that prioritises scaling up agroecology and organic at the farm level, supply chain and market development and strengthening the policy framework and the stakeholder platform built. Finally, the roadmap identifies actions to mobilise development partners in supporting and financing the implementation of the NOAP. In addition, the NOAP asks partner nations to integrate organic

agriculture into their national strategic frameworks and assist in policy and technical issues as well as in the design, implementation, management and financing aspects of organic programmes.

- *Togo*; The Government of Togo published their National Development Plan in 2018 (2018- 2022 with a vision to 2030), which includes provisions for the development of the organic sector in the country. In 2019, the Ministry of Agriculture, Animal Production and Fisheries (MAPAH) published a “concept note for the national conversion of the agricultural sector to organic” outlining the programme's key elements. Within this context, in 2020, MAPAH published the national strategy for developing organic and ecological agriculture for the period 2020-2030. These documents indicate a political will to support organic agriculture with the primary objective of exporting but also building the domestic market.

**5. Conclusions**

A bibliometric analysis study was conducted to assess and systematically synthesize the agroecology practices in Africa and their contribution to CSA, 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’s status. The popularity of agroecology has been steadily increasing around the world, with various regions prone to land degradation adopting its approach as not only an adaptation strategy but also as a way to restore the land and increase regional research on best practices for all aspects of the food system including climate, soil, land management, and crop and animal diversity. Yet little is known about agroecological practices and their impacts on labour, incomes and food security, the benefits of agroecology are, however, not in doubt. Donors and policy-makers should be confident in increasing their efforts in agroecology.

The key implications of this study include (a) farmers are applying agroecology, adapting the practices of CSA that are suitable for their areas but may not be able to define precisely what agroecology is but speak according to their context and (b) the various interventions in the region have supported the adoption of agroecology and promoted different practices, which are determined by the knowledge base in a particular setting. While agroecology research in Africa has shown substantial progression in multidisciplinary aspects, there is still a gap in policy implementation. We live in a critical moment when it is clear that humanity must take immediate steps to ensure that the food systems that feed us today, tomorrow and in the future are sustainable [**Error! Reference source not found.**]. For Africa to reap the benefits of agroecology and CSA, concrete actions must be undertaken to, among other things, promote the implementation of agroecology practices by farmers, avail appropriate funds to farmers, promote investments, and develop policy frameworks that are supportive of CSA. Looking forward to the United Nations Framework Convention on Climate Change’s Conference of the Parties (COP 27), set to take place in Sharm El-Sheikh, Egypt later in 2022, inclusion of agroecology as an adaptation mechanism in countries’ nationally determined contributions should be done as a matter of urgency.

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## Appendix A

**Table A1.** A summary of selected scientific publications on agroecology studies in Africa published from 2000 to 2022. The information is only limited to published scientific articles. Hence, conference papers, proceedings, reviews, and books/book chapters are excluded in the summary. A—authors; PY—publication year, Ref #—reference number.

| Ref # | A, (PY) | Country | Agroecology Practice | Key Findings and Future Research Direction |
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| [44] | Mnkeni et al (2008) | South Africa | Human urine as fertilizer | - Human urine is as effective as urea or ammonium fertilizers as a source of nitrogen for crops<br>- The use of human urine should not be considered for salt-sensitive crops such as carrots and for soils that are known to have salinity problems.<br>- The salinity status of soils that are regularly fertilized with urine should be monitored to guard against salt build-up.<br>- The use of human urine in crop fertilization should be promoted in areas where the use of urine-diversion toilets permits its safe collection. |
| [45] | Ameur et al (2020) | Tunisia, Algeria, and Morocco | Agroecology in North African irrigated plains | - This study shows that a diverse set of interesting practices, up to now largely invisible to the eyes of managers, researchers, and farmers, exist, interweaved with more intensive practices in these irrigated and productive areas.<br>- Taming the extensive local knowledge related to ecological intensification strategies, as identified in this study, can help to pave the way for a more sustainable agriculture, in this intensively cultivated region of the world. |
| [46] | Hell et al (2000) | Benin | The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, west Africa | - Lower aflatoxin levels were related to the use of storage or cotton insecticides, mechanical means or smoke to protect against pests or cleaning of stores before loading them with the new harvest.<br>- Fewer aflatoxins were found when maize was stored in the "Ago" made from bamboo or when bags were used as secondary storage containers. |
| [47] | Mdee et al (2019) | Tanzania | A pathway to inclusive sustainable intensification in agriculture? Assessing the evidence on the application of agroecology in Tanzania | - Supported adoption of the agroecological practice in conjunction with suitable market access has considerable potential for creating inclusive sustainable agricultural livelihoods. |
| [48] | Akanvou et al (2000) | Côte d'Ivoire | Fallow residue management effects on upland rice in three agroecological zones of West Africa | - The research concluded that incorporation of legume residues is a desirable practice for rice-based fallow rotation systems in savanna environments. |
| [49] | Kesselman et al (2021) | South Africa | The challenge posed by urban dietary norms to the practice of urban agroecology | - The benefits of agroecology can be enhanced by targeting changes in food preparation and consumption practices. |

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| [50] | Madsen et al (2021) | Malawi | Agroecological practices of legume residue management and crop diversification for improved smallholder food security, dietary diversity and sustainable land use in Malawi | - These findings provide evidence of agroecology's potential to address food insecurity while supporting sustainable food systems. |
| [51] | Kangmennaang et al (2017) | Malawi | Impact of a participatory agroecological development project on household wealth and food security in Malawi | - Results indicate that agroecological methods combined with farmer led knowledge exchanges can be welfare enhancing, both in terms of food security and in terms of income for family farm households.<br>- Agroecological approaches should be promoted through upscaling of farmer-to-farmer knowledge exchanges, community involvement and attention to nutrition and social equity to enhance farmer learning and household welfare benefits. |
| [52] | Bezner Kerr et al (2019) | Malawi and Tanzania | Farming for change: developing a participatory curriculum on agroecology, nutrition, climate change and social equity in Malawi and Tanzania | - Preliminary results indicate that the resulting curriculum will help advance agroecology among smallholder farmers in low-resource settings, while simultaneously attending to, and improving gender equity and human and soil nutrition. |
| [53] | Mashapa et al (2013) | Zimbabwe | Adoption of agroecology practices in the semi-arid environment of Chimanimani district, eastern Zimbabwe | - The widespread adaptation and adoption of the agroecology practice of planting basins, mulch-based cropping systems and related conservation agriculture techniques in rain-fed agriculture in the study area are likely to tackle complex issues of household food security, vulnerability, degraded natural resources and lack of diversification. |
| [54] | Iyabano et al (2021) | Burkina Faso | Farmers' Organizations as innovation intermediaries for agroecological innovations in Burkina Faso | - Famer Organisations fulfil both knowledge and innovation intermediation functions in the process of stimulating their farmers' adoption of agroecological innovations. |
| [55] | Bottazzi et al (2021) | Senegal | Political Agroecology in Senegal: Historicity and Repertoires of Collective Actions of an Emerging Social Movement | - Adopting a socio-political approach to agroecology and understanding the implications behind the technical challenges is very important<br>- Better characterization of Agroecological Advocacy Coalitions and social movements in sub-Saharan Africa by detailing their repertoires of collective action tools at the productive, territorial, food system, and broader institutional scales has multiple benefits |
| [56] | Musafiri et al (2020) | Kenya | Farm-level soil fertility management and greenhouse gas emission (nitrogen application rate) | - Smallholder farming is vital in pinpointing greenhouse gas emission hotspots.<br>- 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. |
| [57] | Gram et al (2020) | Uganda | Organic and mineral nitrogen applications | - The combination of mineral and organic fertilizers significantly increases maize productivity. |
| [58] | Ogada et al (2020) | Kenya | Livestock breeding | - 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%. |
| [59] | Oladimeji et al (2020) | Nigeria | Soil conservation practices | - It was noted that a positive correlation between the soil conservation practices exists; consequently, adoption |

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| | | | (e.g., animal manure, crop residue retention, inter-cropping, and crop rotation) | decisions for soil conservation practices are interrelated, and the practices are measured by accompaniments by the farmers.<br>- It is recommended that policy interventions strongly leverage important factors, such as contract farming, crop–livestock integration, and off-farm income diversification. |
| [60] | Abegunde et al (2020) | South Africa | Social, technical, economic, and environmental compatibility | - Farmers have different perceptions of the social, technical, economic, and environmental compatibility of the practices.<br>- It was noted that farmers showed high acceptance for the cultivation of cover crops, agroforestry, and diet improvement for animals (social compatibility assessment).<br>- The use of organic manure was highly accepted, followed by rotational cropping, mulching, and cultivation of cover crops (technical compatibility assessment).<br>- Farmers highly prefered mulching, organic manure, and rotational cropping (economic compatibility assessment), and the use of organic manure was highly embraced based on environmental compatibility assessment. |
| [61] | Ighodaro et al (2020) | South Africa | Soil Conservation | - The adoption of soil conservation practices by smallholder farmers substantially influences farmers' overall revenue. |
| [60] | Abegunde et al (2020 | South Africa | Organic manure, crop rotation, and crop diversification | - 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.<br>- It is recommended that farmer associations be given the necessary attention to facilitate CSA adoption for climate change mitigation and resilience. |
| [62] | Olajire et al (2020) | Nigeria | Indigenous adaptations and climate-crop modeling system | - An integrated approach to indigenous climate change adaptation strategies can minimize the negative effects of impending warming on agricultural crop yields. |
| [63] | Zougmor et al (2019) | Mali | Adaptability, adoption, mitigation, resilience | - It was found that the effect of agricultural insurance on the adoption intensity of CSAPS is significant.<br>- 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. |
| [64] | Mutenje et al (2019) | Zimbabwe | Productivity, sustainability, resilience (risk management), soil and water management | - 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. |
| [65] | Sanou et al (2019) | Burkina Faso | Land use, conservation of biodiversity, agroforestry, soil management | - 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.<br>- 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. |
| [66] | Makate et al (2019) | Ethiopia | Conservation agriculture, drought-tolerant maize, and improved legume varieties, adaptation, productivity | - 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. |

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| [67] | Hammed et al (2019) | Nigeria | Productivity, organic fertilizer | - 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. |
| [68] | Bashagaluke et al (2019) | Ghana | Soil and crop management | - The study showed that biochar/NPK interactions could be exploited in minimizing soil loss from arable lands in SSA. |
| [69] | Otieno et al (2019) | South Africa | Productivity, pest control, crop management, organic farming | - The results showed significantly stronger predator–herbivore trophic linkages within intercropped than monoculture fields, while agroecology farming system showed no effect.<br>- 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 maize fields.<br>- 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 |
| [70] | Kiwia et al (2019) | Kenya | Sustainability, intercropping | - It was noted that intercropping combined with the application of small amounts of inorganic fertilizers is superior to unfertilized intercrops.<br>- 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. |
| [70] | Nyamadzawo et al (2015) | Zimbabwe | Soil management (fertility), adaptation, sustainability, variability | - 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).<br>- 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. |

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