How Did Research on Conservation Agriculture Evolve over the Years? A Bibliometric Analysis

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How Did Research on Conservation Agriculture Evolve over the Years? A Bibliometric Analysis

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Abstract: Conservation agriculture has recently been a hot topic of agricultural research and has generated significant global interest. Conservation agriculture has three core principles: minimal soil disturbance, permanent soil cover, and crop rotations. The research on this topic has also witnessed a boom in recent years as the number of peer-reviewed literature on conservation agriculture is rising exponentially. This study critically examines all the peer-reviewed documents published on conservation agriculture from the 1990s to 2021 and indexed in the web of science core database. The search returned 3023 documents, which were then processed in the R-based bibliometric package for annual scientific production trend, source, author, document, citation, keyword analysis, and co-occurrence networking using VOSviewer. Our findings show remarkable growth in conservation agriculture research in recent times, although it witnessed a shortfall in 2021. Notably, 15 core source journals contribute the most to the field, while 8692 researchers have authored or co-authored at least a document on conservation agriculture. While the USA, India, and Australia are front runners in conservation agriculture research, the spread of the topic is worldwide.

Keywords: conservation agriculture; bibliometric analysis; bibliometric; R; network analysis; vosviwer; Bradford's law; and publication trend

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1. Introduction

Tilling the soil has always been a crucial part of the agricultural production system and became more intensive after the end of the second world war, which was essential to meet the global food demand [1]. The objective of tillage is to soften the soil and prepare the seedbed for uniform and better seed germination, suppression of weeds, and release of nutrients [2]. However, since the dust bowls hit Northern America, questions were being raised about the consequence of intensive tillage on fragile ecosystems, initially by Edward H. Faulkner and later by others, which have given birth to the concept of conservation tillage [2]. Over time, the practice was transformed into conservation agriculture

(CA) when FAO finally defined it as having three principles: minimum tillage, permanent soil cover, and crop rotation [3,4]. Currently, conservation agriculture/no-tillage farming is becoming a widely adopted practice, as about 180 million hectares of agricultural land are managed using the principles of CA, roughly 12.5% of the global cropland area. Even more astonishing, the growth rate of CA practices is splendid, increasing 69% from 2008–09 to 2015–16 [5].

CA is nowadays not only a method of sustainable farming practice to maintain productivity but also a crucial practice to improve soil carbon storage and overall environmental quality [6]. As a result, the research on CA has become multidimensional, ranging from agricultural science to social science to ecological sciences. In the early days of conversion from conventional to conservation agriculture, the most remarkable changes in soil quality and overall sustainability were observed in the resource-poor countries of Africa [7]. The positive aspects of CA on soil health were achieved primarily by minimizing soil disturbance and conserving soil cover; for instance, it may be possible to reduce soil erosion, water losses via runoff, and soil physical degradation by reducing the movement of heavy and destructive tillage equipment in the field [8].

However, all these positive aspects, especially the soil health benefits, are just one side of the coin. On the other side, the farmers are often reluctant to adopt CA because of the reduction of yield, especially during initial years, which leads to less monetary return, higher input cost associated with machinery and chemicals, lack of technical information, and finally, government policies [9,10]. Considering the mixed research outcome and multidisciplinary nature, CA has generated significant research interest worldwide, which has been growing over the years. As a result, many scientific documents have been published on various aspects of CA and included in scientific databases such as Scopus or Web of Science. Although conventional review articles, as well as systematic reviews and meta-analysis, has been used to review different specific aspects of CA critically, there is hardly any document that quantitatively evaluates the scientific literature based on bibliometric data such as publication trend, top sources, authors, documents, countries, and most used keywords. In this scenario, a bibliometric analysis could be an effective method to analyze the global trend in CA research critically.

Various techniques are employed in bibliometric analysis to examine a corpus of research [10] quantitatively. It deploys mathematical and statistical methods to analyze the published literature based on a macro perspective and collaborative scientific activities. From a macro perspective, bibliometrics provide clear advantages regarding objectivity, quantification, and modeling [11]. Scientific research and its development are usefully tracked by the bibliometric study of published literature [12]. This study's objectives were to evaluate the available literature on conservation agriculture and examine how it has evolved along with the highest contributors regarding the source, documents, and citations.

2. Methodology

The research design used for this study is bibliometric analysis. It is a type of analysis used for critically explaining available literature related to certain disciplines or areas of scientific research. Bibliometric analysis has proved to be a powerful technique for investigating scientific outputs quantitatively [13]. It is useful in analyzing quantitatively large datasets and tracking their evolution over time [14]. Bibliometric analysis, also known as scientometric analysis, can thus help a researcher study and characterize the kinds of literature of all kinds to (a) examine the trends, (b) evaluate its impacts, and (c) analyze the structures [15].

2.1. Formulation of the Research Question

As the World's population is increasing rapidly, so is the demand for food. Sustainable intensification could be a viable option, as it can address the increasing food demand with minimum environmental impact. The importance of conservation agriculture as a

major strategy for sustainable intensification has been emphasized [16]. As a result, research on conservation agriculture gained momentum over the years. In this context following research questions have been framed:

- What is the trend of research over the years on conservation agriculture?
- What are the major sources of publishing research articles related to conservation agriculture?
- Who are the most relevant authors who have published the maximum number of research articles, and who are the top authors with high citations?
- What are the leading countries across the World related to research on conservation agriculture?
- Which subjects have the highest share of published research articles?
- What are the most cited documents related to conservation agriculture?
- Which are the most relevant keywords used in research studies related to the topic?

As mentioned above, we attempted to find the answers to these questions using bibliometric analysis.

2.2. Selection of the Query of Search and Database

The formation of the appropriate query is the major challenge of bibliometric analysis. In our search, we kept the query simple enough to gather the maximum number of publications. Hence, after thoroughly reviewing numerous pieces of literature, we have decided to use the query "conservation agriculture" OR "conservation farming" as the final search query. We intentionally have not used "zero tillage", "minimum tillage", or "reduced tillage" as we want to focus on conservation agriculture as a whole and not individual principles of conservation agriculture. The advanced search option of the Web of Science database was used to conduct the query search. The constructed search term "conservation agriculture" OR "conservation farming" was searched on the topic field of advanced search option of Web of Science. The timeframe we kept limited to 1990 to 2021; the current year (2022) was not included because the year is yet to be over, and the year's inclusion could change the publication trend.

Another important point should be noted that although the search criteria were limited to conservation agriculture, there might be documents that, although included in the retrieved data list, do not address all three principles. The reason is that the topic search option searches for the exact phase of "conservation agriculture" OR "conservation farming" in the document's title, abstract, and keyword field. Therefore, if any document includes either of these two phases in its title, abstract, or keyword, the document will be included in the list, no matter whether all three principles were addressed in the main body of the document or not, which might be considered as a limitation of this bibliometric studies. The search outcome is downloaded in .bib format, which is subsequently analyzed.

2.3. Data Analysis

The Bibliometric package of the R programming language was used to conduct the bibliometrics analysis [14]. This tool is selected for bibliometric analysis because Bibliometric provides a straightforward workflow from data retrieval and analysis to visualization. The network analysis was conducted using VOSviewer [17].

3. Results and Discussions

3.1. General Overview of the Data

The general overview of the retrieved data is presented in Table 1. Literature searched in the Web of Science database on conservation agriculture using the query mentioned in the methodology section yielded 3023 published documents between 1990 and 2021. In addition, 670 sources (journals, book chapters, proceedings, etc.) published documents on 'Conservation agriculture. The topic recorded an average annual growth rate of 21.77% over the years, while each document has received 25.12 citations. The total citation count stood at 106,085 on 19th October 2022.

Table 1. General overview of the bibliometric data on conservation agriculture.

Description	Results
Main Information about the Data	
Timespan	1990:2021
Sources (Journals, Books, etcetera.)	670
Documents	3023
Annual Growth Rate (%)	21.77
Average citations per doc	25.12
References	106085
Document Contents	
Keywords Plus (ID)	4212
Author's Keywords (DE)	5965
Authors	
Authors	8692
Co-Authors per Doc	4.79
International co-authorships %	46.87
Document Type	
Article	2339
Book Chapter	204
Data paper	7
Proceedings Paper	149
Book	9
Correction	9
Editorial Material	28
Letter	4
Meeting Abstract	3
News item	1
Review	270

A total of 8692 authors across the World have written a document on this topic either as primary Authors or co-author. Each document has 4.79 co-authors on average, which indicates a relatively higher degree of collaboration. Generally, more authors per document indicate the interdisciplinary nature of the article, as authors from different subject groups often collaborate to conduct in-depth research [13]. The claim is also supported by the international co-authorship percentage of 46.87%, which means many authors across different countries have collaborated to produce a document. This scenario is often witnessed when the topic has a global scope of research rather than regional interest [13,18].

Among different document types, article or original research article is the prominent type contributing 77.37% of the total document count, followed by review article (8.93%) and book chapter (6.74%). To date, nine books have been written on the topic, while 149 proceedings paper is also published. To further discuss the obtained results, they were

separated into the following sections: Annual scientific production, source analysis, author analysis, and document analysis.

3.2. Annual Scientific Production

Annual scientific production in CA is represented in Figure 1. Initial years included in the search showed very slow development, and until the early 2000s, the curve started taking a spike. Although in 2003, many documents were published (n = 36), it was short-lived. From 2007, gradual development in the annual number of scientific publications was observed. The number of publications, only ten in 2006, leaped to 32 in 2007, and the curve touched the highest peak of 534 publications in 2020. However, in 2021, a sharp publication decline can be seen when 449 documents were published. The annual growth rate of 21.77 percent in the context of the number of annual scientific productions was also obtained to be considerably high. However, due to the decline of publication in 2021, a steady increase cannot be predicted unless it is confirmed that the decline in 2021 is a temporary dip due to current issues (such as COVID-19) or a permanent decline due to reduced research interest.

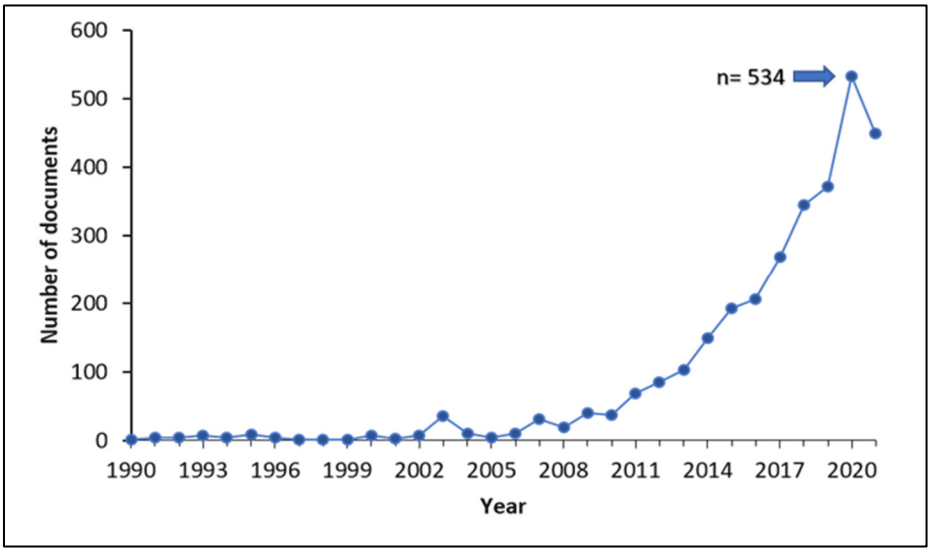

Figure 1. Annual scientific production of literature on conservation agriculture from 1990 to 2021.

Although we have been analyzing the bibliometric data since 1990 because there were not many publications before the period, a quick look at the documents published before the 90s could be useful to understand the research trend. As per the Web of Science database, the first document published on this topic is "Procedures of Studying Returns from Conservation Farming", a note published in the Journal of Farm Economics [19]. However, the note did not receive any citations (in the WoS database) to date. From 1945 to 1990, 11 more documents were published. The term "conservation agriculture" was finalized in 1997 at a regional workshop organized by FAO on the topic of Soil Management and Conservation—Efficient Tillage Methods for Soil Conservation in Ibadan, Nigeria; before that, "conservation agriculture" was primarily focused on only no-tillage practices. This may account for the rise in publications after 2000. The FAO held its first regional workshop on CA in Harare in 1998. During this workshop, a code of practice for CA was drafted, outlining the three interconnected CA principles currently known and how they might be used in a real-world situation [20]. The European Conservation Agriculture Federation (ECAF) and the Food and Agriculture Organization of the United Nations (FAO) hosted the First World Congress on Conservation Agriculture in Madrid, Spain, in 2001. Seven other World Congresses have since taken place: in Foz do Iguassu, Brazil (2003); Nairobi, Kenya (2005); New Delhi, India (2009); Brisbane, Australia (2011);

Winnipeg, Canada (2015); Rosario, Argentina (2017), and Bern, Switzerland (2021). After each of these congresses, the number of published documents on CA increased with the only exception of 2021. In the 8th congress in Bern, Switzerland, many new steps were taken to advance CA in the future; as a result, it can be assumed that the publication decline in 2021 is temporary and will rise again.

3.3. Analysis of Source

A total of 670 unique sources (journals, conference proceedings, etc.) have been identified and have published at least one document on CA. However, the productivity (number of articles published by the source on CA) of these sources greatly differs. Bradford's law is a well-known method to classify sources based on their contribution [21]. Bradford's law is used to classify all the sources into three groups; a highly productive nuclear or core zone (Zone 1), a moderately productive (Zone 2), and a less productive (Zone 3). Although the contribution of each zone is nearly equal, the number of sources varies significantly. The nuclear zone (Zone 1) constitutes a minimum number of sources yet a very high contribution.

The analysis indicates only 15 sources (all journals), constituting Zone 1 (Table 2). It means only 2.23% of sources published 33.80% of documents in CA. The classification of sources based on Bradford's law has several advantages; such as any researcher wants to search a minimum number of sources/journals where he/she can find the relevant highest number of documents; searching in Zone 1 sources will be the best strategy [13]. Among the 15 most contributing sources, the Soil and tillage research journal has the maximum contribution of 190 articles, accounting for 6.285% of the total article share, followed by Field crops research (3.837%) and Agriculture ecosystem and environment (3.473% contribution) journal. Sustainability, which is 4th on our list, is a multidisciplinary open-access journal that has published a significantly higher number of articles in a shorter time span on a diverse range of topics yet primarily focusing on the sustainable production system. The majority of the sources had a high impact factor of more than 2; however, 'The Indian Journal of Agricultural Sciences' although having less impact factor of 0.39, had a noteworthy number of publications (57 publications), contributing about 1.886% of the total publications and ranked 7th in the list. All of these enlisted sources are peer-reviewed and reputed among the scientific community, which can be assumed from their respective impact factor indicates that documents published in those sources are cited regularly. By identifying these top source journals using bibliometric analysis, a portrait of the journal is created, demonstrating a description that goes beyond the surface and revealing the journal's quality, maturity, and productivity in any discipline [22]. The Soil and tillage research got the highest attention of CA researchers primarily because of the minimum tillage aspect of CA. On the other hand, the Field crop research published articles on crop management, cropping system, and yield attributes related to CA. Agriculture, ecosystem, and environment, as well as Sustainability journal primarily focus on the environmental aspect of CA, essentially a multidisciplinary scope, ranging from the ecosystem service of CA to its role in climate change, adoption practices of CA, and impact on the soil environment.

Table 2. Top ten most relevant journals which have published the maximum number of articles on conservation agriculture.

Bradford's Law				
	Zone 1 (Nuclear Zone)	**Zone 2**	**Zone 3**	
Number of Sources	15	69	586	
Number of Documents	1022	1009	992	
Core Source Journals and Their Distribution				
Rank	**Source Title**	**Number of Articles**	**Article Share (%)**	**Impact Factor**

1	Soil and Tillage Research	190	6.285	7.366
2	Field Crops Research	116	3.837	6.145
3	Agriculture, Ecosystems, and Environment	105	3.473	6.576
4	Sustainability	88	2.911	3.889
5	Agricultural Systems	76	2.514	6.765
6	Agronomy-Basel (MDPI)	59	1.952	3.949
7	Indian Journal of Agricultural Sciences	57	1.886	0.39
8	International Journal of Agricultural Sustainability	54	1.786	10.753
9	Agronomy for Sustainable Development	49	1.621	2.905
10	Science of the Total Environment	43	1.422	10.753
11	Land Use Policy	41	1.356	6.189
12	Geoderma	39	1.29	7.422
13	Experimental Agriculture	38	1.257	2.118
14	Land Degradation and Development	35	1.158	4.377
15	Journal of Cleaner Production	32	1.059	11.072

Figure 2 depicts the number of publications for the top five journals over time. The Soil and Tillage Journal has seen the most growth in publications. The trend also indicates that the higher preferences of the author side to publish in top journals over the years have increased.

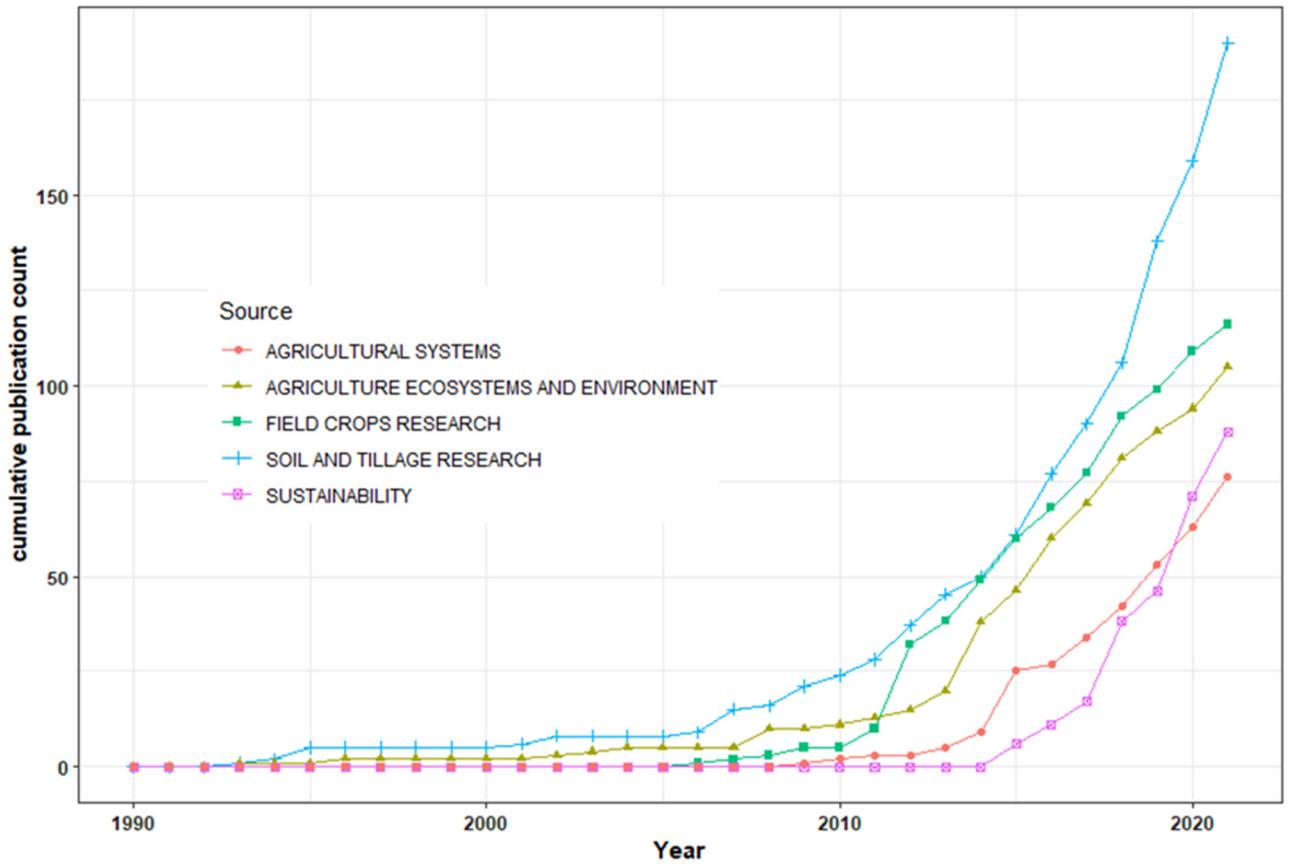

Figure 2. Cumulative publication trend of top 5 journals over the years.

The result of the co-citation analysis of sources is depicted in Table 3, and the network is visualized in figure below. Soil and tillage research is the top source based on total citations, which had received a total of 11,696 local citations (cited within the documents

included in our dataset). The total link strength of this journal indicates the total strength of co-citation of a given source with other sources, which is depicted as the size of the respective circles in Figure 3. It means the higher the number of sources citing a particular source, the higher the total link strength (size of the circle). The local citation of soil and tillage research is much higher than the agriculture ecosystem and environment.

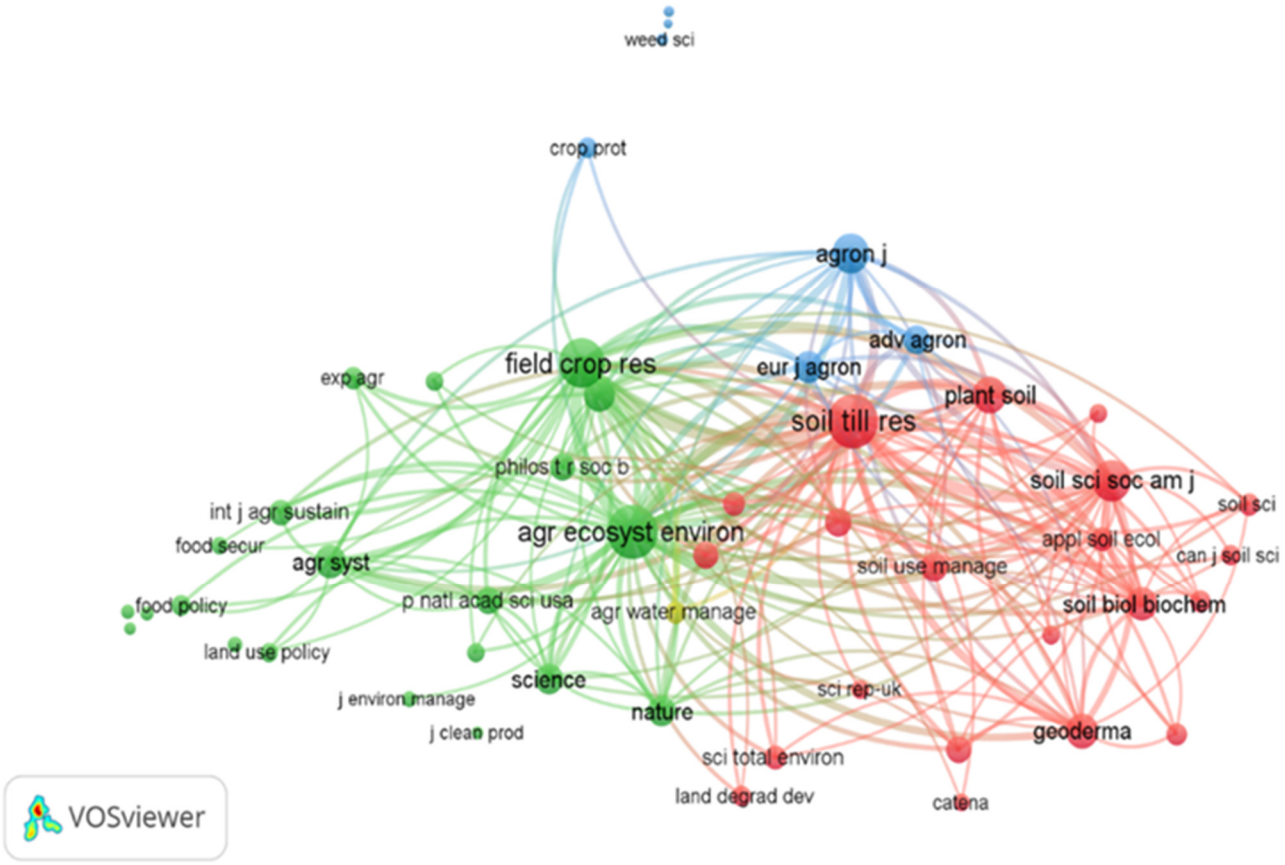

Figure 3. Visualization of sources networks.

Nevertheless, the total link strength is not much different, indicating that both of these sources have been cited in an equally large number of other sources, although soil and tillage research has benefited from a higher number of articles and each article receives more citations. The VOS viewer has partitioned all the sources into three clusters depicted in three different colors of the circles in Figure 3. Cluster 1 is depicted in red, cluster 2 in green, and cluster 3 in blue. The formation of the cluster is based on groups co-citing each other. The red cluster is a journal that publishes articles on different physical, chemical, and biological aspects of soil science. The second cluster is depicted in green; this group's journals are largely environmental science journals and multidisciplinary journals. The third cluster is blue, primarily agronomy and crop production science journals. It is also worth noting that cluster formation follows a decreasing trend, which means the maximum number of sources are enlisted in cluster 1, then cluster 2 and cluster 3. The largest number of sources hence focuses on soil science, while fewer sources focus on purely agronomic perspective. However, that does not mean that little research is conducted keeping crops in mind; rather, those journals which include crops also include other aspects such as soil or environment and are published in journals with multidisciplinary scopes.

Table 3. Top 10 sources by co-citation.

Sources	Local Citations	Total Link Strength	Cluster	Cluster Colour
Soil and Tillage Research	11696	17667840	1	Red
Agriculture Ecosystems and Environment	6396	17343386	2	Green
Field Crops Research	6037	13627374	2	Green
Soil Science Society of American Journal	4168	8668202	1	Red
Soil Biology and Biochemistry	3108	5197903	1	Red
Agronomy Journal	3034	7721948	3	Blue
Agricultural Systems	2650	5042288	2	Green
Geoderma	2411	5643750	1	Red
Plant and Soil	2329	6273118	1	Red
Agronomy for Sustainable Development	1734	4728959	2	Green

3.4. Analysis of Authors

Analysis of authors is a crucial section of bibliometric analysis. While the total number of authors on this topic counted as 8692, not all authors are equally productive. The productivity of authors is estimated using Lotka's law, a classical procedure in bibliometrics that describes the frequency of publication by an author in a given field [23]. Generally, only a few authors produce more documents and a large pool of authors with very few documents. The portrayal of Lotka's law in Figure 4 indicates that 76.8% of the authors have produced only one document, 1.2% of the authors have produced 5 documents, 0.2% of the authors have produced 10 documents, and 0.1% of authors have produced 15 documents. There are only four authors who have written more than 50 articles. Table 4 enlists the top ten most prominent authors who had significantly contributed to the publications on conservation agriculture. Jat M. L. of CIMMYT had made 78 publications, the highest on the topic, followed by Thierfelder, C. (67); Govaerts, B. (55); Lal, R. (56); Das, T.K. (42); Verhulst, N. (38); Jat, H.S. (37); Giller, K.E. (33); Corbeels, M. (32), and Parihar, C.M. (32). It can be seen from the Table 4 that an author with a higher number of publications does not necessarily mean a highly cited author or vice versa. The h-index, defined as the highest value of h for which the specified author or journal has published at least h papers, each of which has been referenced at least h times, is another crucial metric.

Table 4. Top 10 contributing authors.

Rank	Name of Author	Affiliation	Number of Publications	Local Citations	h-Index *
1	Jat, Mangi Lal	International Maize & Wheat Improvement Center (CIMMYT)	78	536	28
2	Thierfelder, Christian	International Maize & Wheat Improvement Center (CIMMYT)	65	790	27
3	Govaerts, Bram	International Maize & Wheat Improvement Center (CIMMYT)	55	653	26
4	Lal, Rattan	Ohio State University	56	276	25
5	Das, Tapas K.	ICAR-Indian Agricultural Research Institute	42	249	14
6	Verhulst, Nele	International Maize & Wheat Improvement Center (CIMMYT)	38	409	16
7	Jat, Hanuman Sahay	ICAR-Central Soil Salinity Research Institute	37	200	20
8	Giller, Ken E	Wageningen University & Research	33	1293	21
9	Corbeels, Marc	International Institute of Tropical Agriculture	32	1365	21
10	Parihar, Chiter Mai	ICAR-Indian Agricultural Research Institute	32	146	13

* h-index is based on local citations only.

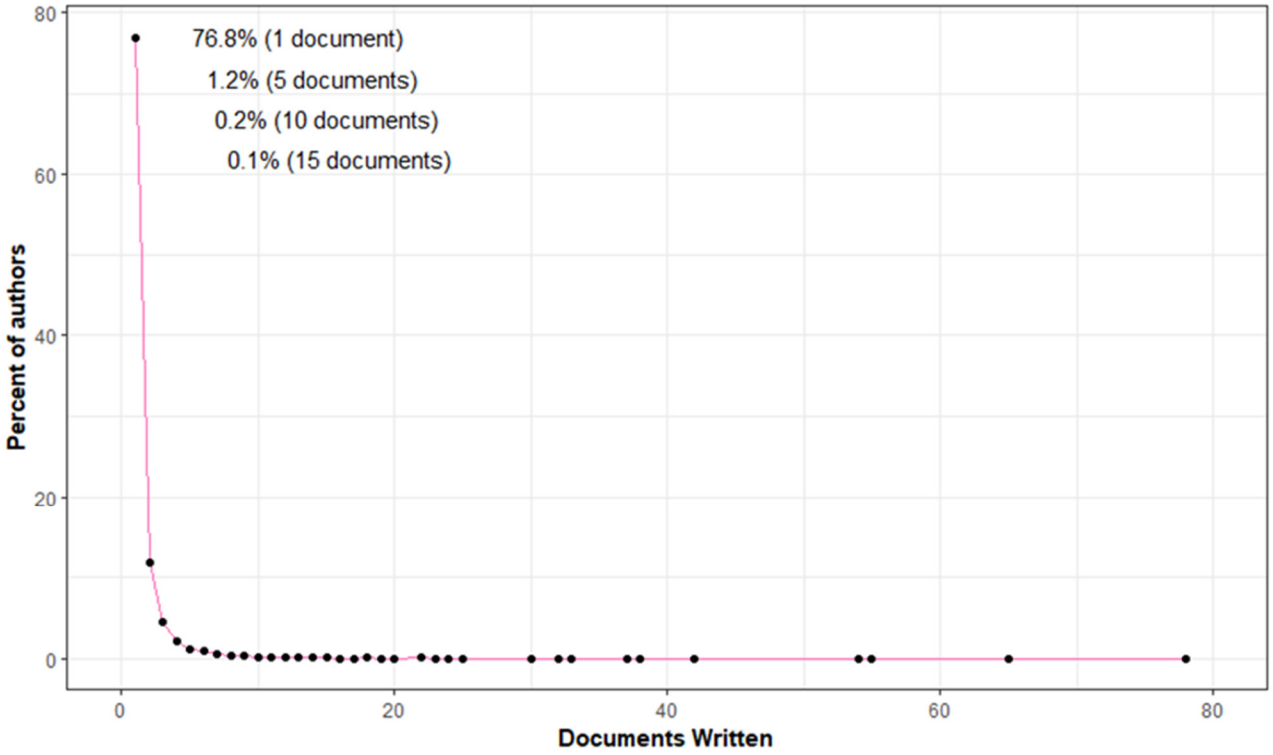

Figure 4. Productivity of authors as per Lotka's law.

There is disagreement in the literature on which metric—their h-index or their number of publications or citations—is more effective in determining how relevant a certain author is to a particular field of study. Hence, we have also represented the top 10 authors based on citations (Figure 5a) and h-index (Figure 5b). Based on citations, Corbeels, Marc has the highest citations of 1365, followed by Giller, Ken E (1293 citations) and Tittonell, Pablo (910 citations). The ranking of authors based on the h-index does not follow the ranking of the most productive authors or the authors with the highest citations. Corbeels, mark, although he has the highest citation count, does not have many publications, which is the reason for his less h-index.

On the other hand, Jat Mangi Lal has authored many documents on CA but received moderate citation counts; the balance of both factors made him the Author with the highest h-index. The quantity of citations, rather than the quantity of publications, is more important since it gauges a researcher's influence, according to [24]. In a nutshell, while the number of publications indicates the Author's productivity, the number of citations predicts the Author's influence [25]. However, considering the number of publications as a measure of an author's scientific influence in a particular field can be prone to error because, in some cases, the Author is in his early career whose scientific trajectory is still in the early growth stage [26].

Figure 6 illustrates the co-authorship network of the most prominent authors. The size of the letter and circle indicate the Author's total link strength (degree of co-authorship). The authors with the higher co-authorship have a larger circle and letter size. The distance between the authors (circle) indicates their relatedness based on the co-occurrence link. The top 10 authors have been included in the map who have authored at least 10 documents and have at least 50 citations. The authors have been grouped under 8 distinct clusters and connected by 153 links with a total link strength of 852. The top 10 authors with the highest collaboration are Jat, M.L. (156); Govaerts, B. (106), Parihar C.M. (82), Jat S.L. (73); Jat H.S. (65), Singh, A.K. (62); Choudhary M. (61); Dutta, A. (60); Therfelder, C. (59); and Deckers, J. (58).

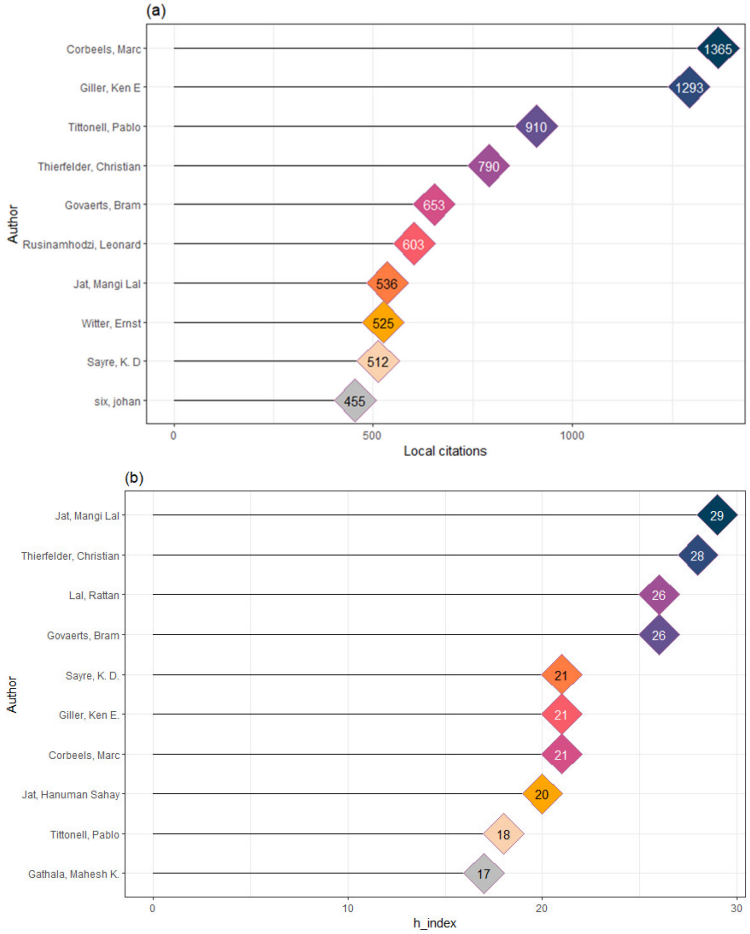

Figure 5. Top 10 authors based on (**a**) local citation and (**b**) h-index.

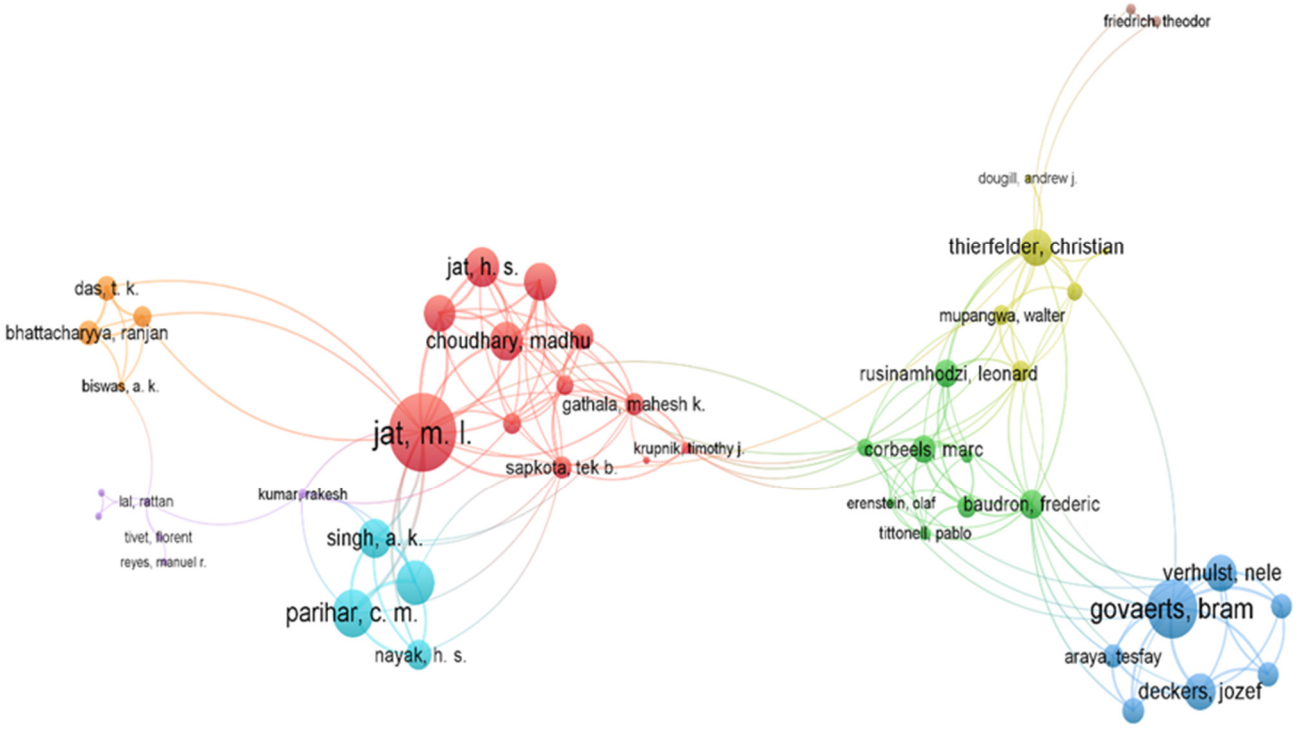

Figure 6. Co-authorship network among the 50 top authors based on total link strength who have at least 10 documents and 50 citations.

While the topic of CA has 8692 authors, only 50 have been included in the network, which shows a greater opportunity for a higher degree of collaboration in the future.

From the 7034 authors (Table 1), a network containing only 60 authors shows that the field can be enlarged. The international co-authorship percentage of 46.87% indicates a good number of authors collaborating internationally, which can be improved further. The network analysis identified eight different clusters based on co-authorship. Cluster 1 has the highest number of authors, 13, followed by cluster 2 with 8 authors, cluster 3 with 7 authors, cluster 4 with 6 authors, cluster 5 with 6 authors, Clusters 6 and 7 each with 4 authors, and finally, cluster 8 with only two authors.

Cluster 1 (red color) comprises authors from India and neighboring Asian countries, and most of their documents are related to the field of Agronomy, followed by Soil science and Environmental science, respectively, as per the Web of Science subject category. The most prominent topic of this cluster revolves around conservation agriculture practices in Indo-Gangetic plains with a predominantly Rice-Wheat cropping system. The most frequent aspects being studied in general are the effect of CA on crop yield under intensive cropping systems and the soil's physical, chemical, and biological properties, especially soil organic carbon. Although the aim of the bibliometric analysis is only the quantitative evaluation of the scientific literature based on the top number of documents, top sources, authors, country, document, etcetera; however, a short overview of documents by the authors clustered in a single group helps to understand why they have been clustered together better. The conclusions from cluster one indicate that, for resource-poor farmers of IGP, CA provides better economic return as well as resource use efficiency in the rice-wheat cropping system; the wheat shows economic benefit faster compared to rice, where it takes 4–5 years to attain the monetary advantage of CA [27–30]. The wide adoption of CA could also help India to lower the crop residue burning issue [31]. The improvement of soil physical, chemical, and biological properties after the adoption of CA is also evaluated by the authors of this cluster [32,33].

Cluster 2 (green color) includes authors who have largely conducted their research in African nations, and documents are mostly from agronomy, multidisciplinary and agricultural policy. The major topics in this group are sustainable intensification and adoption among small-holding farmers. The documents by this cluster of authors contradict cluster 1; they argue that CA is unsuitable for resource-constrained small-holding farmers as it does not provide substantial benefits [34]. The reason is primarily that the adoption of CA generally requires high inputs, especially fertilizer; even then, the yield stability is not guaranteed, especially under a rainfed scenario where drought or high-intensity rainfall is frequent [35,36]. Other prominent challenges observed in Sub-Saharan Africa (SSA) are lack of crop rotation and residue retention [37]. Therefore, the contrasting outcome in IGP with SSA is probably due to the adoption of CA under irrigated IGP and rainfed conditions in SSA.

The authors of cluster 3 (blue color) researched the effect of CA on soil properties regarding crop production, climate change, and carbon sequestration. This cluster includes authors from around the World but primarily from Mexico. Their research outcome concludes that CA is largely beneficial for soil health. However, farmers' profit is questionable because most experiments are holistic up to the farm level, which needs to be extended to larger areas to gather data on a global level for better clarity of outcome [38–40]. Cluster 4 (yellow color) is also based in Africa, especially Zimbabwe, has authors from other countries, and focuses on topics ranging from agronomy to environmental aspects of policy-making, although agronomy is the major subject. Among topics, these group reports individual components of CA and its advantages [41–43]. Other remaining clusters have only a few authors as well as citations.

3.5. Analysis of Documents

The top 15 most cited documents are depicted in Table 5, which had a great role in the development of the evolution of the topic over the years. The highest cited document

in CA is titled "Farmers' adoption of conservation agriculture: A review and synthesis of recent research", which points out that despite several modest benefits of CA over conventional practices especially considering soil health, the adoption is rather limited because of financial viability and lack of knowledge and technology to the marginal farmers [44].

Table 5. Top 15 most cited documents.

Title	Document	DOI	Total Citations	TC per Year
Farmers' adoption of conservation agriculture: A review and synthesis of recent research	[44]	10.1016/j.foodpol.2006.01.003	918	57.38
Soil carbon 4 per mile	[45]	10.1016/j.geoderma.2017.01.002	804	134.00
The role of conservation agriculture in sustainable agriculture	[16]	10.1098/rstb.2007.2169	777	51.80
Conservation agriculture and smallholder farming in Africa: The heretics' view	[34]	10.1016/j.fcr.2009.06.017	758	54.14
Productivity limits and potentials of the principles of conservation agriculture	[46]	10.1038/nature13809	707	88.38
Sustainable intensification in African agriculture	[47]	10.3763/ijas.2010.0583	569	47.42
Restoring Soil Quality to Mitigate Soil Degradation	[48]	10.3390/su7055875	527	65.88
When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture	[49]	10.1016/j.fcr.2012.10.007	510	51.00
The spread of Conservation Agriculture: justification, sustainability, and uptake	[50]	10.3763/ijas.2009.0477	452	32.29
Limited potential of no-till agriculture for climate change mitigation	[51]	10.1038/NCLIMATE2292	447	49.67
Conservation agriculture and ecosystem services: An overview	[52]	10.1016/j.agee.2013.10.010	439	48.78
Climate change: Can wheat beat the heat?	[53]	10.1016/j.agee.2008.01.019	411	27.4
Direct Seeding of Rice: Recent Developments and Future Research Needs	[54]	10.1016/B978-0-12-387689-8.00001-1	396	33
When does no-till yield more? A global meta-analysis	[55]	10.1016/j.fcr.2015.07.020	381	47.63
Sustainable intensification in agricultural systems	[56]	10.1093/aob/mcu205	373	41.44

"Soil carbon 4 per mille", the second most cited document, has 804 citations, although it has the highest total citation per year of 134 among all the top documents. The article focuses on the ambitious global research initiative launched during the climate change conference held in Paris, 2015, which calls for an initiative to increase soil organic matter by 0.4% each year as an immediate measure to limit climate change; in which among several strategies, one such is the adoption of CA wherever possible [45]. One of the most frequently cited documents on positive aspects of CA, especially regarding sustainable agriculture, is by Hobbs [33], which holds the third place with 777 citations. The article provides a detailed account of the advantages of CA over conventional agriculture or even conservation tillage. Coming to challenges faced by the adoption of CA among smallholding farmers; Gillers and co-authors [34] pointed out the decline of yield in initial years, increased requirement for labor when herbicides are not used, and shifting of gender roles; all of which need to be evaluated under diverse ecological and socioeconomic condition. Selectively adopting individual principles, especially only zero-tillage, usually yields less than conventional.

In contrast, the assured yield advantage can only be possible when all the principles are adequately applied, the feasibility of which is once again questionable, especially considering marginal farmers [46]. Other positive aspects include intensifying the cropping system sustainably [47], maintaining soil quality, and mitigating soil degradation [48,50].

The major bottleneck of CA, although it performs best in rainfed dry areas, most farmers of those areas find it hard to adopt because of its resource-intensive nature [55]. The top 15 documents (the majority of the articles are review article) hence provide good insight into CA from both positive and negative aspects and indisputably emphasizes conducting research in diverse agroecological and socioeconomic condition to attain a global perspective. In this regard, collaboration among researchers across the globe could be a better option, as indicated in the network analysis of the author section of this article.

3.6. Analysis of Countries

As mentioned in Table 6, the country with the maximum number of publications is the USA (n = 658), making up a significant 21.92 percent of the total publications included in the study. The USA also holds the top position in the list regarding total citations from any region on conservation agriculture publications. India (n = 491), Australia (n = 276) and France (n = 247) ranked second, third and fourth with 16.35%, 9.19%, and 8.23% of the publications, respectively. A list of the top 20 countries based on the number of publications is a blending of developed and developing countries. The list consists of developed countries such as the USA, Australia, France, and China and, at the same time, includes developing regions such as India, Zimbabwe, Bangladesh, etc. This is a clear indication of the acceptability and implementation of the research topic, i.e., conservation agriculture in all parts of the World, and based on dynamics, it can be labeled a topic with increasing popularity and growth.

Much like a list of the top 20 countries based on several publications, similar attributes were found for the list of top 20 countries based on the number of total citations. As mentioned earlier, the USA has the highest number of total citations (n= 12771) and is almost double that of the second country on the list, i.e., India (n = 6714). United Kingdom (n = 5029) and France (n = 4833) stand third and fourth on the list, respectively. However, in the context of average article citations per year, the Netherlands is the highest, with 55.98 citations per year. Mexico ranks second with 46 average article citations per year, and the United Kingdom ranks third with 37.25 average article citations per year.

Table 6. Top 20 countries with the highest productivity and citations.

Top 20 Countries Based on the Number of Documents				Top 20 Countries Based on the Number of Citations		
Rank	**Country**	**Total Number of Documents**	**Proportion (%)**	**Country**	**Total Citations**	**Average Document Citations per Year**
1	USA	658	21.92	USA	12771	30.33
2	India	491	16.35	India	6714	15.16
3	Australia	276	9.19	UK	5029	37.25
4	France	247	8.23	France	4833	30.40
5	Zimbabwe	202	6.72	Australia	4315	27.14
6	Italy	200	6.66	Mexico	3818	46
7	Germany	197	6.56	Zimbabwe	3518	31.41
8	Mexico	195	6.5	Netherlands	3471	55.98
9	UK	193	6.43	Italy	2592	16.83
10	China	190	6.33	China	2449	13.76
11	Kenya	186	6.20	Germany	2162	20.59
12	Brazil	179	5.96	Kenya	2064	29.07
13	South Africa	178	5.93	Spain	1928	16.91
14	Spain	153	5.09	Brazil	1884	12.56
15	Netherlands	146	4.86	Ethiopia	1471	24.52
16	Ethiopia	108	3.60	Canada	1386	33
17	Belgium	96	3.19	South Africa	1306	9.89
18	Bangladesh	86	2.87	Belgium	1001	32.29
19	Switzerland	82	2.73	Switzerland	959	23.39
20	Canada	68	2.27	Norway	799	25.77

Conservation agriculture is a potential topic with a strong collaboration network among the countries (Figure 7). Network analysis of the database for the study classifies the countries into six clusters (classified based on colors in Figure 6). The USA is the most important node in the network and links with other important countries such as India, China, Brazil, France, Mexico, etc. Other important nodes in the network having a good number of publications and string linkage with other countries are India, Australia, Mexico, Zimbabwe, Kenya, France, etc. This network indicates strong research collaboration across the World and signifies good research potential on the topic.

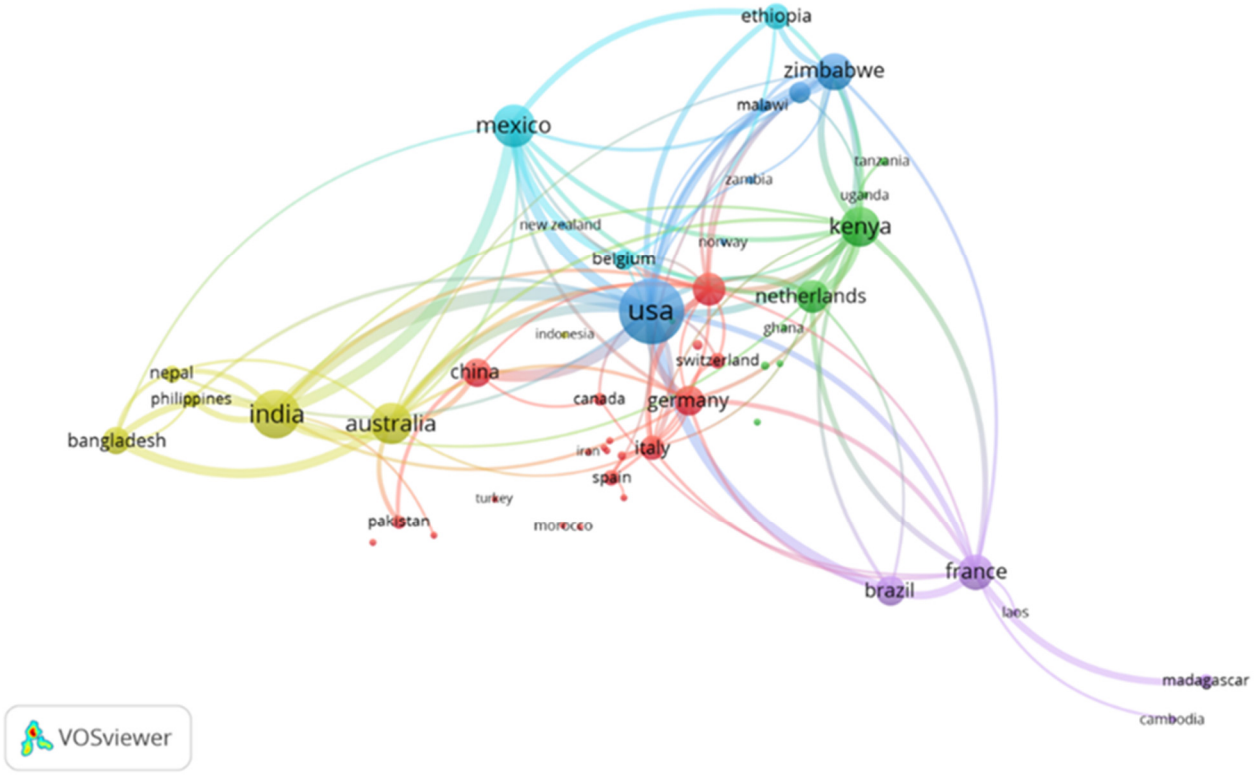

Figure 7. Collaboration among countries.

3.7. Analysis of Keywords

Table 7 shows the most relevant keywords related to conservation agriculture. It can be seen that conservation agriculture has the maximum (845) number of occurrences, followed by zero-tillage (302) and agriculture (187).

The presence of keywords such as climate change, carbon sequestration, and sustainable agriculture provides a clear indication of how research on conservation agriculture has a strong association with the topic of climate change and is gaining momentum in this field. Keywords such as soil, no-tillage, and soil quality reveal how the publications have tried to focus on the environmental aspects and try to implement conservation agriculture safely and sustainably. Conservation agriculture is also highly related to social issues; thus, including keywords such as sustainable intensification and food security is imperative.

Table 7. Most relevant Author's keywords and keywords plus.

Author's Keyword	Occurrences	Keyword Plus/Index Words	Occurrences
conservation agriculture	845	conservation agriculture	1134
no-tillage	302	management	747
agriculture	187	systems	514
tillage	179	no-tillage	479
climate change	149	tillage	467
soil	140	soil	356
conservation	110	yield	345
conservation tillage	95	productivity	333
adoption	91	organic-matter	267
carbon sequestration	84	adoption	259
soil organic carbon	80	climate-change	248
crop rotation	77	nitrogen	243
sustainable agriculture	73	carbon	220
maize	72	quality	217
wheat	72	agriculture	212
cover crops	70	maize	207
soil quality	70	cropping systems	197
sustainability	66	wheat	195
sustainable intensification	65	conservation	181
food security	64	dynamics	178

The network analysis provides a clearer view of top keywords and their association (Figure 8). The network analysis identified eight clusters. In the largest cluster (in red), CA is the most highly used core keyword and is often used with carbon sequestration, no-tillage, conventional tillage, soil organic matter, cover crop, conservation tillage, crop residue, and soil health. Among these keywords, no-tillage/conservation tillage and cover crop/crop residue cooccured because of core principles of CA. The second largest cluster represents green, climate change, adoption, adaptation, climate-smart agriculture, Sub-Sahara, or Sub-Saharan African Nations. The adoption of CA in Sub-Saharan African countries was hard; as Giller et al. (2009) [34] pointed out in their widely cited review paper, the adoption of CA in those countries is a matter of debate, as opposed to the higher adoption claimed by many organizations; the seemingly higher adoption rate is probably due to the temporal effect of the project or due to lucrative offers of input from the government side as the majority of the farmers reverts to conventional farming practice once the project/input supply is over. However, despite all odds, more and more countries in Sub-Saharan Africa are adopting CA, sometimes in small pockets [50,57]. However, increasing the adoption is necessary for the fight against climate change and reducing climate change vulnerability which can be achieved by increasing soil carbon stock [58,59]. The third cluster, visualized in purple, demonstrates the relationship between sustainable and conservation agriculture. In the coming days, achieving sustainability in agriculture will be a major issue, as the land resource is continuously decreasing while the demand for food is increasing, which needs to be addressed using CA, especially in India and Sub-Saharan Africa.

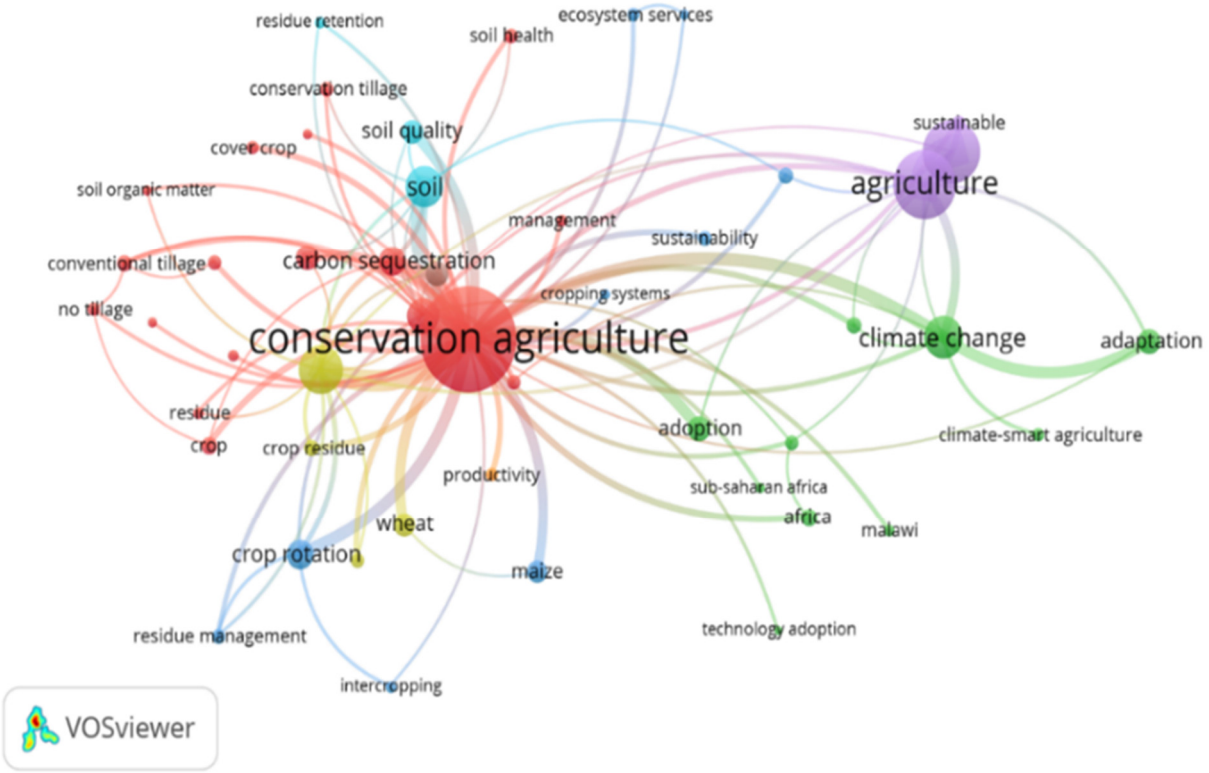

Figure 8. Visualization of Author's keyword network.

4. Implication

The current analysis of CA agriculture identifies several research gaps. First, more research is needed to identify whether CA is equally advantageous to different cropping systems and patterns. The majority of experiments on CA have experimented on cereal grains and legumes. However, vegetable crops, forage, fiber, and commercial crops are often given more monetary returns, especially in resource-poor countries. In such scenarios, is it possible to adopt CA?

There are debates on CA's carbon sequestration capability compared to the conventional system. Whether the magnitude of SOC storage is high irrespective of agro-climatic scenarios?

The advantage of CA is largely demonstrated on a quantitative basis and little based on quality attributes; hence, more research is required to understand if CA is equally advantageous to quality attributes too or not.

Lastly, in many countries where farmers are resource-poor when the input incentives supply from the government is being stopped, the farmers revert to the conventional farming system. Are the phenomena true for all resource-poor nations, or is it country specific? What is the reason behind this phenomenon? Can the development of cost-effective tools and methods bring more farmers under the umbrella of CA?

5. Conclusions

Although there has been increasing research attention to the topic of conservation agriculture, there is hardly any bibliometric analysis that has analysed the literature quantitatively and provided a bird's eye view of the current state of research. In this article, we have identified the trend of research, most productive journals, productive authors and their collaboration, collaborative research among countries, most influential and cited literature on this field and their content, and lastly, the most frequently used keywords are interrelation through networking. Several conclusions can be made drawn from the results. First, the research on conservation agriculture has tremendously grown over the

year. However, a sudden fall was recorded in 2021. Among 670 sources, the Soil and Tillage Research journal has published the highest number of articles, accounting for 6.285% of the total published literature. The same journal has also received the highest number of citations. All the sources/journals were not equally productive, as only 15 lie within Bradford's core zone, producing 27.52% document share. Jat, M.L. from International Maize and Wheat Improvement Center is the most productive author in this field, followed by Thierfelder, C. The USA is the leading country in conservation agriculture, as the maximum number of publications and citations are associated with the country. Tillage, climate change, conservation, adoption, carbon sequestration, crop rotation, and sustainable agriculture are a few of the most commonly used keywords in this field. The potential of conservation agriculture is enormous and global, but it needs more site-specific experiments to conclude.

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