agronomy

MDPI

Article

A Bibliometric Analysis of Global Research on Climate Change and Agriculture from 1985 to 2023

Cheng Li [1,2,3,†], Hongda Yao [3,†], Zhaozhe Li [3], Fang Wu [4], Bo Liu [5], Yongping Wu [6], Kwok Pan Chun [7], Thanti Octavianti [7], Xuefeng Cui [4,*] and Yang Xu [1,2,*]

1 Jiangsu Key Laboratory of Crop Genetics and Physiology, Key Laboratory of Plant Functional Genomics of the Ministry of Education, Jiangsu Key Laboratory of Crop Genomics and Molecular Breeding, Yangzhou University, Yangzhou 225009, China; licheng@yzu.edu.cn
2 Jiangsu Co-Innovation Center for Modern Production Technology of Grain Crops, Yangzhou University, Yangzhou 225009, China
3 Department of Ecology, School of Plant Protection, Yangzhou University, Yangzhou 225009, China; 211801127@stu.yzu.edu.cn (H.Y.); 202331250023@mail.bnu.edu.cn (Z.L.)
4 School of Systems Science, Beijing Normal University, Beijing 100875, China; fangw@mail.bnu.edu.cn
5 College of Hydraulic Science and Engineering, Yangzhou University, Yangzhou 225009, China; boliu@yzu.edu.cn
6 College of Physical Science and Technology, Yangzhou University, Yangzhou 225002, China; ypwu@yzu.edu.cn
7 CATE School of Architecture and Environment, University of the West of England, Bristol BS16 1QY, UK; kwok.chun@uwe.ac.uk (K.P.C.); thanti.octavianti@uwe.ac.uk (T.O.)
* Correspondence: xuefeng.cui@bnu.edu.cn (X.C.); yangx@yzu.edu.cn (Y.X.)
† These authors contributed equally to this work.

Abstract: With increasing concentrations of atmospheric greenhouse gases, the interaction between climate change and agriculture is receiving widespread attention as part of food security and sustainable human development. However, a comprehensive summary of knowledge in the field of climate change and agriculture from a scientometric perspective is still lacking. Here, we selected 25,872 papers related to climate change and agriculture from the Web of Science Core Collection database for the period 1985 to 2023 and used VOSviewer software to reveal the research status and trends. The main results were as follows: (1) the number of papers in this field showed a rapidly increasing trend after 2007, with a clear interdisciplinary characteristic; (2) The United States was the most influential country in this field with 6819 papers and 363,109 citations. China had the second highest number of papers (3722 papers), but the Chinese Academy of Sciences was the most influential institution with the most papers. On an author level, Pete Smith was the most influential; (3) All keywords were divided into four different research topics, such as the impact of climate change on agriculture, climate change mitigation and adaptation in agriculture, and crop growth in response to climate change. Among them, some keywords related to climate change adaptation were the most recent topics of interest in this field. These findings provide effective scientific references for relevant scientists and practitioners to better conduct future theoretical and practical research on climate change and agriculture.

Keywords: climate change; agriculture; bibliometric analysis; visualization

check for updates

Citation: Li, C.; Yao, H.; Li, Z.; Wu, F.; Liu, B.; Wu, Y.; Chun, K.P.; Octavianti, T.; Cui, X.; Xu, Y. A Bibliometric Analysis of Global Research on Climate Change and Agriculture from 1985 to 2023. *Agronomy* **2024**, *14*, 2729. https://doi.org/10.3390/agronomy14112729

Academic Editor: Wenxu Dong

Received: 23 September 2024
Revised: 4 November 2024
Accepted: 14 November 2024
Published: 19 November 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

According to the latest data from the Intergovernmental Panel on Climate Change (IPCC), the global surface temperature during the period of 2011 to 2020 is 1.09 °C above the levels recorded between 1850 and 1900 [1]. Broadly speaking, climate change characterized by increasing temperature has altered the occurrence and severity of extreme weather and climate events [2], with widespread impacts on terrestrial ecosystems and human societies [3–5]. Agriculture, an essential foundation for sustainable economic and social

development, is not only considered one of the climate-impacted sectors but also an important source of greenhouse gas emissions [6–8]. In this context, research on climate change and agriculture has attracted great attention across regions, between countries, and among individuals [9,10].

Many scientists have conducted numerous theoretical and practical studies in the field of climate change and agriculture [11–14]. Some of these review papers, such as the traditional literature reviews and meta-analyses [15,16], reported from different perspectives in this field. They mainly focused on the relationship between weather, climate, and agricultural production [17]; climate change impact, mitigation, and adaptation in agriculture [18,19]; and quantitative methods to assess climate change impacts on agriculture [20]. However, most of these review papers had limited research scope and were easily influenced by scientists' personal preferences, resulting in a lack of quantitative analysis of the relevant scientific literature in this field from an objective perspective [21]. Bibliometric analysis is a widely used quantitative method for examining a large amount of the literature in terms of various aspects, including authors, documents, journals, keywords, and other indicators [22,23]. As the content and scope of research related to climate change and agriculture continue to deepen and expand, the knowledge structure and emerging trends of this field remain poorly understood using bibliometric analysis.

With the support of modern information technology, knowledge mapping has become an emerging technique that enables the visualization and analysis of complex bibliometric networks [24]. In addition, it can be viewed as an entry point for acquiring knowledge and new information in a specific field [25]. Currently, there are various commonly used knowledge mapping tools, such as VOSviewer 1.6.19, CiteSpace 6.3, Ucinet 6, and Bibexcel 2017 [26–30]. For example, VOSviewer is a typical knowledge mapping software developed by Leiden University based on the Java programming language [27]. Unlike other tools, its advantages lie in text mining capabilities that can identify co-occurrence networks of important terms and excellent visualization capabilities. In recent years, the VOSviewer software has been used to represent the knowledge structure and development of various research fields [31–33], especially several agriculture-related fields, such as agricultural drought [34], agricultural pollution [35], sustainable agriculture [36], and land use change and food security [37]. Despite the power and popularity of the VOSviewer software, there is still no research using this tool to investigate the growing publications on climate change and agriculture. Aiming to give a comprehensive summary of climate change and agriculture research, this study presents a bibliometric analysis to illustrate the knowledge structure and emerging trends in this field based on a trusted citation database and VOSviewer software. Therefore, the main research objectives are (1) to analyze the changes in the number of publications on climate change and agriculture, (2) to reveal research power (countries, institutions, and authors) through the visualization of collaboration networks, and (3) to identify the research trend using keyword co-occurrence analysis. The detailed result is of great importance for relevant researchers to understand the dynamics of this field and find new research directions.

2. Materials and Methods

2.1. Data

A scientific citation database is usually recognized as the data source for bibliometric analysis [38]. As the world's leading citation database, the Web of Science Core Collection (WoSCC) contains records of articles, conference proceedings, and books [39]. In this study, we used the WoSCC database to select the relevant publications for input data in bibliometric analysis. During the search process, we restricted the search period from 1985 to 2023 and set TS = (Climate Change AND Agriculture). In addition, the selected language was English, and the document types were articles and review articles. Finally, a total of 25,872 papers were selected for this study.

2.2. Methods

In this study, the software VOSviewer 1.6.19 (https://www.vosviewer.com/, accessed on 24 February 2024) was used to construct and visualize bibliometric networks. Users can select an item type in the VOSviewer software, such as authors, organizations, countries, and keywords, and set relevant parameters to generate analysis results and network graphs [40]. In a generated network graph, the dimension of the circle represents the importance of an item, while the width of the line between items indicates the intensity of the connections [41]. Guidelines for using VOSviewer software and data analysis steps can be found at https://www.vosviewer.com/. In addition, Origin 2021b software (https://www.originlab.com/, accessed on 24 February 2024) was also used to display data from the WoSCC database through graphs and charts.

3. Results and Discussion

3.1. Characteristics of Publications and Research Areas

According to the WoSCC database, a total of 25,872 papers on climate change and agriculture were identified from 1985 to 2023. Figure 1 shows the changes in publications on climate change and agriculture and the main subject categories from the WoSCC database. As shown in Figure 1a, the annual number of papers increased exponentially from 1985 to 2023 (R^2 = 0.96) and showed a rapid growth trend after 2007. A key reason was the publication of the IPCC Fourth Assessment Report in 2007, which provided an integrated perspective on the multifaceted nature and impacts of climate change and addressed a range of options and responses for adaptation and mitigation [42,43]. In addition, the IPCC was also awarded the Nobel Peace Prize that year [44], sparking greater interest in research on climate change and agriculture over the past decade [45,46]. As a result, 24,809 papers were published after 2007, accounting for 95.89% of all papers.

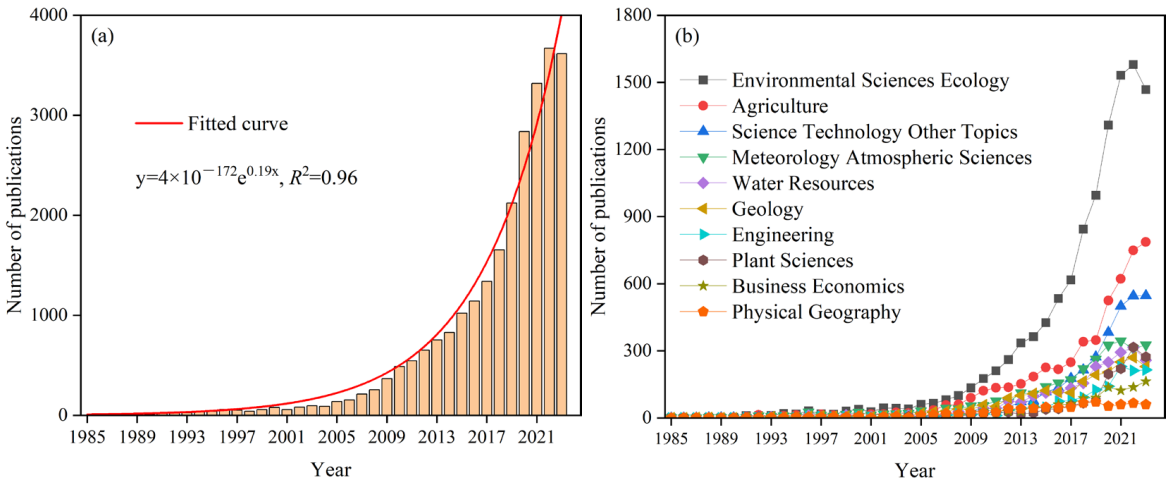

Figure 1. (**a**) Annual number of publications on climate change and agriculture from 1985 to 2023. (**b**) Annual publication output in the top ten research areas.

By analyzing the research areas from the WoSCC database (Figure 1b), the top ten research areas were Environmental Sciences Ecology (11,457 papers, 44.28% of 25,872 papers), Agriculture (5260 papers, 20.33%), Science Technology Other Topics (3254 papers, 12.58%), Meteorology Atmospheric Sciences (3050 papers, 11.79%), Water Resources (2349 papers, 9.08%), Geology (2306 papers, 8.91%), Engineering (1478 papers, 5.71%), Plant Sciences (1464 papers, 5.66%), Business Economics (1192 papers, 4.61%), Physical Geography (830 papers, 3.21%). Regarding changes in focus areas, Environmental Sciences Ecology, as the dominant research area, contributed more to this field after 2007, with Agriculture and Science Technology Other Topics increasing rapidly in recent years. The distribution of the above research areas also showed that climate change and agriculture research was

clearly interdisciplinary, which not only expanded our understanding of this field but also promoted its rapid and diverse development [47–49].

In order to identify principal journals on climate change and agriculture research, we set the minimum number of papers and the minimum number of citations to 50 and 100, respectively, in the VOSviewer software. A total of 97 of the 2991 source journals met the thresholds and were shown in the visualization network (Figure 2). As shown in Figure 2, the dimensions of different circles indicated the number of papers in different journals, and the source journals in the same color group were closely related to each other. Table 1 further shows the top ten journals published on climate change and agriculture research, each with more than 246 papers. As shown in Table 1, these ten journals published nearly 16% of all papers, suggesting that the papers in this field were not concentrated in a few journals [50]. Additionally, these ten journals were considered influential, with eight journals in Quartile 1 and two journals in Quartile 2. The top five journals were *Sustainability* (912 papers, 3.53%), *Science of the Total Environment* (589 papers, 2.28%), *Climatic Change* (445 papers, 1.72%), *Environmental Research Letters* (378 papers, 1.46%), *Water* (337 papers, 1.30%). Although the journal *Sustainability* published the largest number of papers in research on climate change and agriculture, its total number of citations was not very high. On the contrary, the top four journals with more than 17,500 citations were *Climatic Change*, *Agriculture Ecosystems and Environment*, *Science of the Total Environment*, and *Environmental Research Letters*, indicating that these four journals had a greater influence in this field.

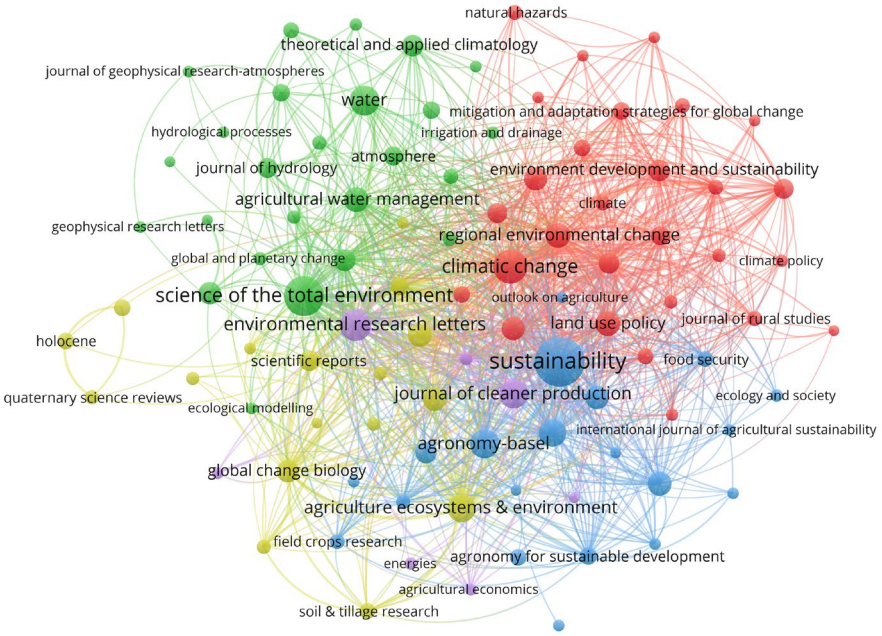

Figure 2. Visualization of principal journals on climate change and agriculture research.

Table 1. Top ten principal journals on climate change and agriculture research.

No.	Journal	No. of Papers	Ratio (%)	No. of Citations	Quartile in Category
1	*Sustainability*	912	3.53	14,061	Q2
2	*Science of the Total Environment*	589	2.28	21,451	Q1
3	*Climatic Change*	445	1.72	25,507	Q1
4	*Environmental Research Letters*	378	1.46	17,724	Q1
5	*Water*	337	1.30	5349	Q2
6	*Journal of Cleaner Production*	328	1.27	11,941	Q1
7	*Agronomy-Basel*	316	1.22	3878	Q1
8	*Agriculture Ecosystems and Environment*	301	1.16	22,037	Q1
9	*Agricultural Systems*	286	1.11	9974	Q1
10	*Regional Environmental Change*	246	0.95	7408	Q1

In order to identify influential papers on climate change and agriculture research, we set the minimum number of citations to 500 in the VOSviewer software. A total of 129 of the 25,872 papers met the thresholds and were shown in the visualization network (Figure 3). As shown in Figure 3, a larger circle indicates that the paper is more influential, while a thicker line indicates a stronger relationship between the two papers. Table 2 further shows the top ten influential papers published on climate change and agriculture research. As shown in Table 2, these ten papers were cited 25,107 times, with each of them cited more than 1260 times. However, the number of papers on climate change and agriculture research published in journals containing these most influential articles was not in the top ten, with the exception of *Environmental Research Letters*. An article published in the journal *Science* entitled "Food security: the challenge of feeding 9 billion people" took first place with 6990 citations [51]. In addition, "Global food demand and the sustainable intensification of agriculture" in the journal *Proceedings of the National Academy of Sciences of the United States of America* and "The impacts of climate change on water resources and agriculture in China" in the journal *Nature* took second to third place with 4518 and 2455 citations, respectively [52,53]. Interestingly, the three most cited papers were all published in multidisciplinary science journals with publishing histories spanning centuries. An important reason for this was that research papers published in high-quality journals were more likely to attract widespread attention and also promote more in-depth investigation of related hot topics in this field [54]. Regarding the timing of publication, nine of the ten most influential papers were published in the five-year period around 2012, suggesting that this period was important for the development of knowledge systems on climate change and agriculture research.

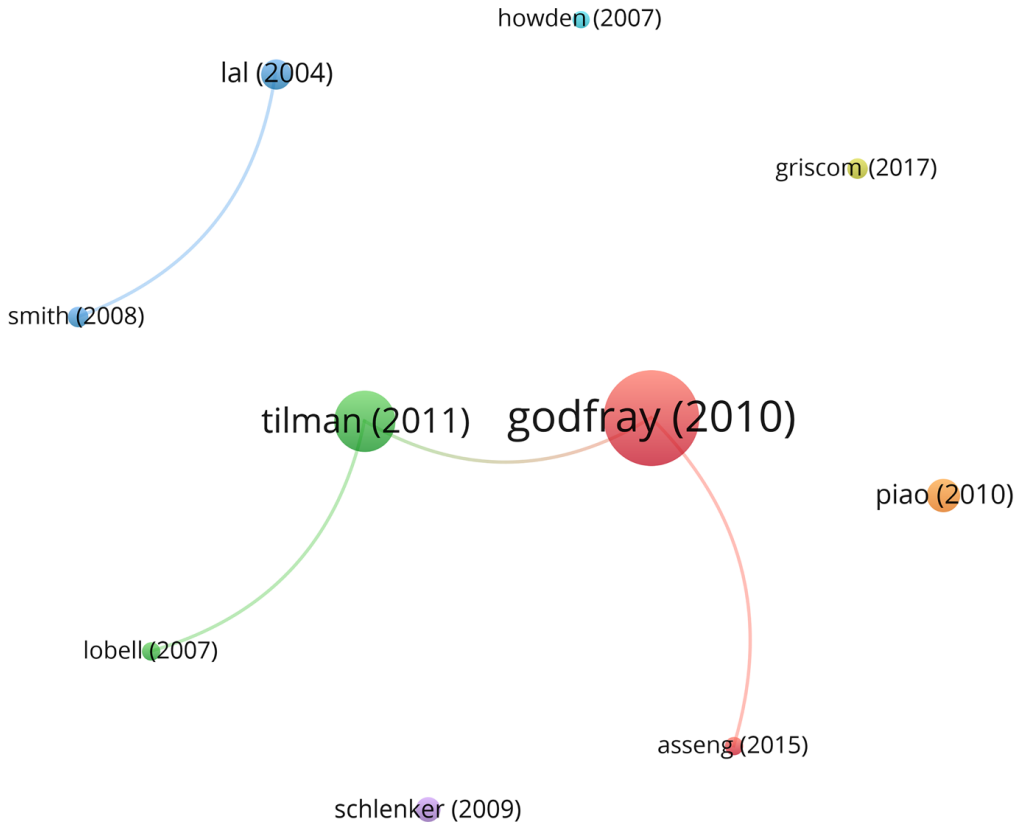

Figure 3. Visualization of influential papers on climate change and agriculture research [51–53,55–61].

Table 2. Top ten influential papers on climate change and agriculture research.

No.	Document	Title	Source	No. of Citations
1	[51]	Food security: The challenge of feeding 9 billion people	*Science*	6990
2	[52]	Global food demand and the sustainable intensification of agriculture	*Proceedings of the National Academy of Sciences of the United States of America* (*PNAS*)	4518
3	[53]	The impacts of climate change on water resources and agriculture in China	*Nature*	2455
4	[55]	Soil carbon sequestration to mitigate climate change	*Geoderma*	2201
5	[56]	Nonlinear temperature effects indicate severe damages to US crop yields under climate change	*PNAS*	1880
6	[57]	Greenhouse gas mitigation in agriculture	*Philosophical Transactions of the Royal Society B*	1550
7	[58]	Natural climate solutions	*PNAS*	1516
8	[59]	Rising temperatures reduce global wheat production	*Nature Climate Change*	1371
9	[60]	Global scale climate–crop yield relationships and the impacts of recent warming	*Environmental Research Letters*	1358
10	[61]	Adapting agriculture to climate change	*PNAS*	1268

3.2. Cooperation Networks of Climate Change and Agriculture Research

3.2.1. Country Co-Authorship

According to the WoSCC database, 190 countries participated in climate change and agriculture research. We set the minimum number of papers and the minimum number of citations in the VOSviewer software to 100 and 200, respectively [33,40]. A total of 62 of the 190 countries met the thresholds and were divided into six different color groups in the cooperation network (Figure 4). As shown in Figure 4, the larger the circle, the greater the collaboration between countries and researchers from different countries in this field.

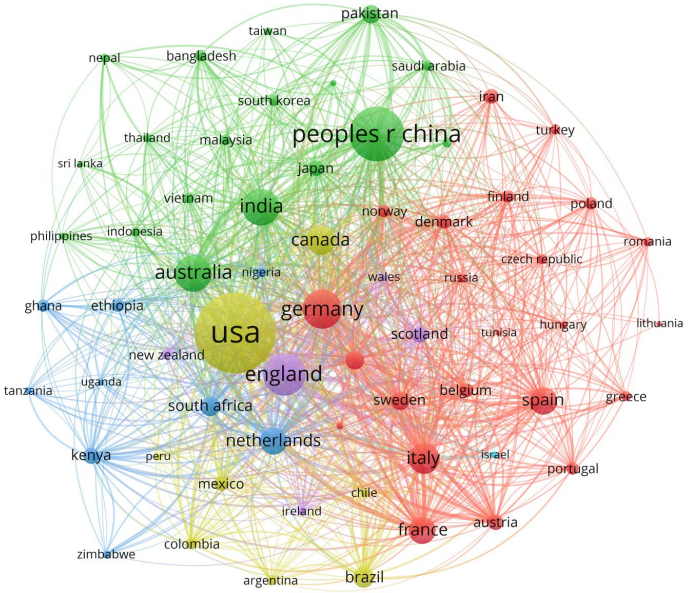

Figure 4. Visualization of the cooperation network of countries published on climate change and agriculture research.

Table 3 further shows the top ten influential countries published on climate change and agriculture research. At least 1212 papers were published in each of these ten influential countries, eight of which were developed Western countries, and only China and India were developing countries [62]. In particular, the USA ranked first in the total number of papers and citations. Moreover, the USA (63 links and 7172 total link strength) had the largest circle and densest lines in the cooperation network, indicating that it held a crucial position in this field and carried out extensive cooperation with other countries

(Figure 4). China had the second highest number of papers (3722 papers), but its total number of citations and total link strength was much lower than that of the USA (Table 3). Although India also published a large number of papers, its average number of citations per paper was much lower than that of other countries, and its collaboration with other countries was limited (Table 3 and Figure 4). In addition to these ten influential countries, it was undeniable that other countries had also made positive contributions to this field (Figure 4). In the future, more attention should be paid to cross-country cooperation in order to sustain the rapid development in this field [49]. In particular, cooperation could be established with countries where the literature was less available (e.g., Africa, which is highly vulnerable to climate change) in order to enhance their local knowledge [63].

Table 3. Top ten influential countries published on climate change and agriculture research.

No.	Country	No. of Papers	No. of Citations	Total Link Strength
1	USA	6819	363,109	7172
2	P. R. China	3722	124,376	3860
3	England	2450	152,233	4929
4	Germany	2207	116,180	4485
5	India	2017	60,024	1934
6	Australia	2000	101,704	3284
7	Italy	1469	69,516	2575
8	Canada	1363	65,962	1943
9	Spain	1244	46,324	2128
10	France	1212	70,259	2684

3.2.2. Institution Co-Authorship

According to the WoSCC database, 15,460 institutions participated in climate change and agriculture research. We set the minimum number of papers and the minimum number of citations in the VOSviewer software to 100 and 200, respectively [33,40]. A total of 80 of the 15,460 institutions met the thresholds and were divided into five different color groups in the cooperation network (Figure 5). As shown in Figure 5, a larger circle indicates that the institution is more influential, while a thicker line indicates a higher degree of cooperation between institutions.

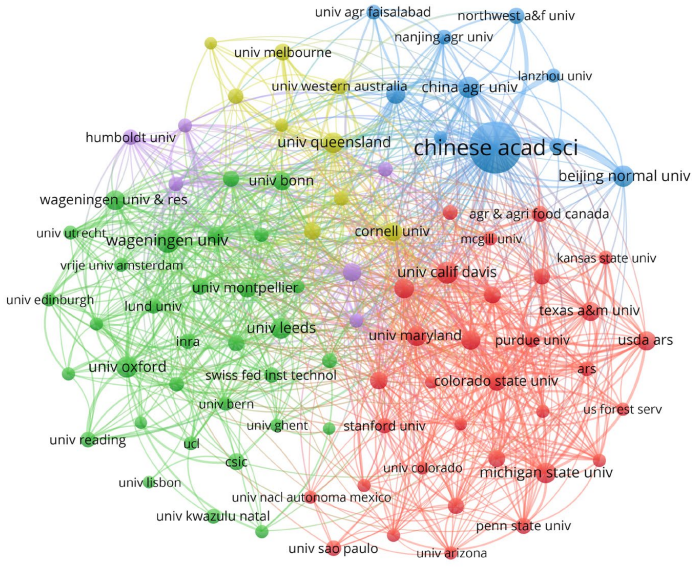

Figure 5. Visualization of the cooperation network of institutions published on climate change and agriculture research.

Table 4 further presents the top ten influential institutions published on climate change and agriculture research. Of these ten influential institutions, there were three each in the

USA and China, two in England, and one each in the Netherlands and Australia. Moreover, each of these institutions published at least 222 papers. The Chinese Academy of Sciences ranked first in the total number of papers and citations and also showed extensive cooperation with other institutions in different countries (Figure 5). In addition, some institutions in the USA (e.g., the University of Florida and the University of California, Davis) also cooperated more with other institutions (Figure 5). The average number of citations per paper in Chinese institutions was less than 40 times, although they published a large number of papers. In comparison, institutions in Western countries had a higher average number of citations per paper, ranging from 47.49 to 86.90 times (Table 4). Interestingly, institutions from the same country were more closely linked to each other than to institutions from different countries in the cooperation network (Figure 5), which suggested that future research should strengthen cooperation with institutions from different countries in order to realize high-level scientific outputs in this field [64].

Table 4. Top ten influential institutions published on climate change and agriculture research.

No.	Institution	No. of Papers	No. of Citations	Total Link Strength	Country
1	Chinese Academy of Sciences	1121	42,066	624	China
2	Wageningen University	505	30,558	481	Netherlands
3	University of California, Davis	261	15,371	276	USA
4	Beijing Normal University	254	8971	190	China
5	China Agricultural University	254	9266	250	China
6	University of Oxford	254	22,073	269	England
7	Michigan State University	231	12,617	235	USA
8	University of Queensland	231	10,971	211	Australia
9	University of Leeds	229	14,247	176	England
10	University of Florida	222	14,381	298	USA

3.2.3. Author Co-Authorship

According to the WoSCC database, there were 87,743 authors who published on climate change and agricultural research. In order to identify principal authors in this field, we set the minimum number of papers and the minimum number of citations in the VOSviewer software to 20 and 100, respectively [33,40]. A total of 65 of the 87,743 authors met the thresholds and were divided into 22 different color groups in the cooperation network (Figure 6). As shown in Figure 6, the larger the circle, the more papers the author published, and authors with the same circle color cooperated closely with each other.

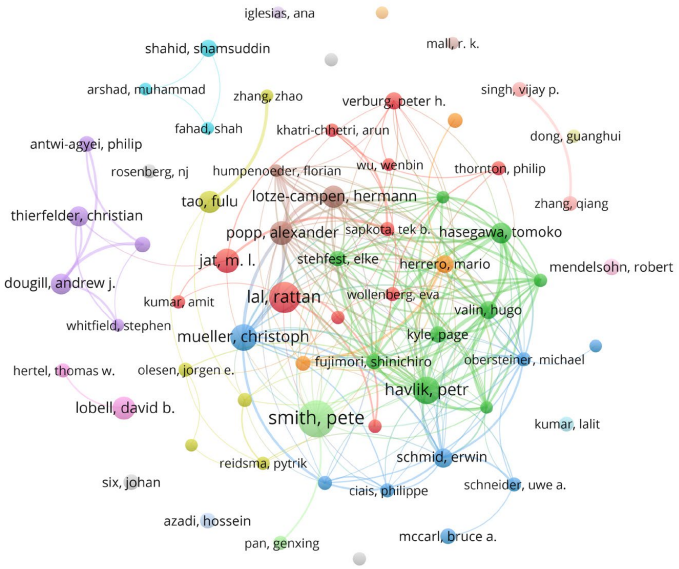

Figure 6. Visualization of the cooperation network of authors published on climate change and agriculture research.

Table 5 further presents the top ten influential authors published on climate change and agriculture research. As shown in Table 5, each of these ten influential authors published at least 37 papers. Notably, authors who published at least 50 papers with more than 5000 citations included Pete Smith, Rattan Lal, Petr Havlik, and Christoph Müller. Taking author Pete Smith as an example shows that he not only belonged to the same group as Genxing Pan but also carried out extensive cooperation with Rattan Lal, Petr Havlik, M. L. Jat, and Philip K. Thornton from other color groups (Figure 6). In contrast to Pete Smith, the authors David B. Lobell, with the highest average citations per paper (189.52 times), and Thomas W. Hertel were part of a group, but their cooperation with other authors was limited (Figure 6). Overall, most influential authors had strong tiers within their respective groups, and cooperation between different groups should be strengthened, which could serve as an important reference for newcomers, as well as those seeking potential cooperators in this field [65].

Table 5. Top ten influential authors published on climate change and agriculture research.

No.	Author	No. of Papers	No. of Citations	Total Link Strength	Affiliations
1	Smith, Pete	77	10,920	46	University of Aberdeen
2	Lal, Rattan	63	5537	20	The Ohio State University
3	Havlik, Petr	52	5932	206	International Institute for Applied Systems Analysis
4	Müller, Christoph	51	5805	92	Potsdam Institute for Climate Impact Research (PIK)
5	Jat, M. L.	45	2860	17	International Maize and Wheat Improvement Center
6	Popp, Alexander	43	4245	140	PIK
7	Lobell, David B.	42	7960	4	Stanford University
8	Tao, Fulu	41	2680	21	Chinese Academy of Sciences
9	Lotze-Campen, Hermann	40	4571	125	PIK
10	Dougill, Andrew J.	37	1849	45	University of Leeds

3.3. Keywords Co-Occurrence Analysis

All keywords, including author keywords and keywords plus, are usually considered an important aspect of presenting the core content of papers, which can reflect the dynamics and trends of research in a certain field [66,67]. In this study, we selected all keywords to analyze the co-occurrence of keywords related to climate change and agriculture research.

After analyzing the co-occurrence of all keywords using the full counting method, there were a total of 55,861 keywords, of which 169 met the threshold of 200 and were divided into four different color groups in the visualization network (Figure 7). As shown in Figure 7, a keyword with a larger circle indicated that it occurred more frequently, whereas a thicker connecting line indicated a higher intensity of co-occurrence between keywords. Meanwhile, Table 6 shows the top 10 keywords with the highest frequency of co-occurrence in each color group resulting from the co-occurrence analysis of keywords (Figure 7). The top 17 co-occurrences of all keywords were “climate change”, “agriculture”, “impact”, “adaption”, “management”, “food security”, “variability”, “land use”, “temperature”, “drought”, “model”, “yield”, “vulnerability”, “sustainability”, “precipitation”, “water”, and “growth”, each appearing more than 1000 times (Table 6). Of the two search terms in this field, “climate change” and “agriculture” were the most common, and both were strongly related to other keywords.

As shown in Figure 7, four color groups presented different research topics. The red group represented the climate change impacts on agriculture, with two key terms being “climate change” and “impact”. Some keywords related to climate change mainly included “temperature”, “drought”, “precipitation”, “water resources”, “variability”, and “trends”. A number of keywords related to impact assessment were “model”, “simulation”, “scenarios”, “remote sensing”, “gis”, and “prediction”. The representative research regions were mainly in China, the USA, India, and European countries.

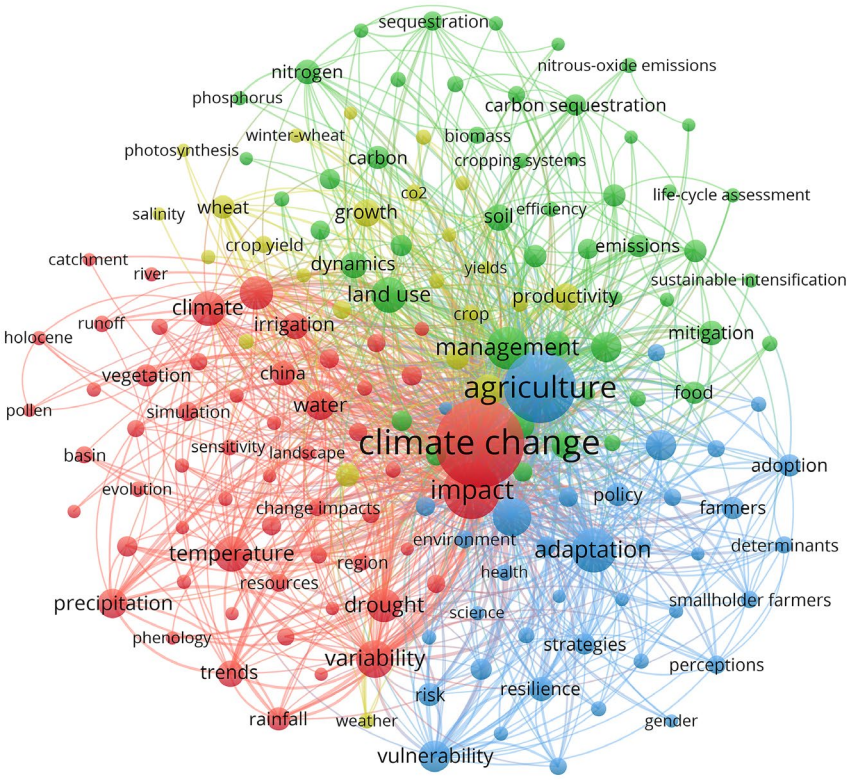

Figure 7. Visualization of the co-occurrence network of most frequent keywords published on climate change and agriculture research.

Table 6. The top 10 keywords with the highest frequency of co-occurrence in each color group in Figure 7.

No.	Red Group		Green Group		Blue Group		Yellow Group	
	K	O	K	O	K	O	K	O
1	Climate change	11,648	Management	2469	Agriculture	7464	Yield	1339
2	Impact	4581	Land use	1722	Adaptation	2755	Growth	1000
3	Variability	1871	Biodiversity	984	Food security	1964	Productivity	974
4	Temperature	1647	Soil	909	Vulnerability	1295	Responses	709
5	Drought	1490	Conservation	899	Sustainability	1174	Wheat	688
6	Model	1484	Dynamics	865	Resilience	745	Maize	634
7	Precipitation	1136	Nitrogen	766	Policy	692	Rice	412
8	Water	1111	Mitigation	733	Risk	667	Crop yield	388
9	Irrigation	931	Carbon	677	Farmers	649	Crop production	374
10	Trends	918	Greenhouse-gas emissions	659	Adoption	612	CO_2	363

The green group represented climate change mitigation in agriculture, focusing primarily on the following two aspects: agricultural management as well as greenhouse gas emissions and mitigation potential (Figure 7). The keywords related to agricultural management were "land use", "conservation agriculture", "sustainable agriculture", "deforestation", "tillage", "cropping systems", and "sustainable intensification". Some keywords related to greenhouse gas emissions and mitigation mainly included "carbon", "nitrogen", "methane", "soil", "biomass", "organic matter", "carbon sequestration", "biodiversity", and "life-cycle assessment".

The blue group represented climate change adaptation in agriculture, which mainly focused on conceptual studies and climate adaptation strategies (Figure 7). The former mainly included the keywords "adaptation", "food security", and "adaptive capacity", while the latter mainly included keywords "adaptation strategies", "climate-smart agriculture", and "smallholder farmers". In addition, Africa, particularly Sub-Saharan Africa and Southeast Asia, were important hotspots for research on agricultural adaptation to climate change.

The yellow group represented crop growth in response to climate change, which had a high degree of overlap with the red group and the green group (Figure 7). Agronomic keywords related to crop growth included "yield", "productivity", "photosynthesis", "stress", and "water use efficiency". Several keywords related to crop types were "wheat", "maize", and "rice". Additionally, other commonly used keywords such as "responses", "CO_2", "weather", and "global warming" also appeared in this group.

Note: K represents keywords, while O represents co-occurrences (frequency of keywords). Four color groups presented different research topics.

Figure 8 shows an overlay map by year in which papers were published to reflect the evolution of climate change and agriculture research. In Figure 8, blue keywords represent earlier research topics, while yellow keywords represent more recent research topics [68]. In particular, most yellow keywords were found in the right part of Figure 8, suggesting that attention has recently shifted to climate change adaptation in agriculture. Keywords such as "adaptation strategies", "adoption", "perceptions", "gender", "smallholder farmers", and "climate-smart agriculture" have been the latest research hotspots that appeared to have gained more attention in recent years.

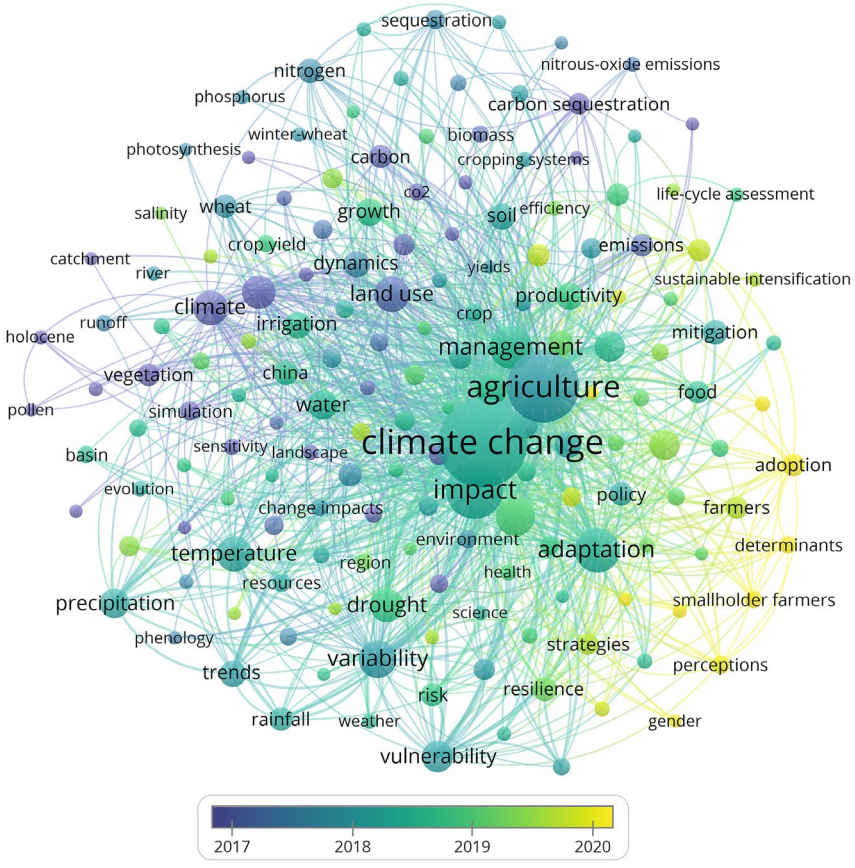

Figure 8. Visualization of the co-occurrence overlay of most frequent keywords published on climate change and agriculture research. The years in which specific keywords frequently occur are shown by different colors.

Taking agricultural greenhouse gas emissions in relation to political efforts as an example, major economies around the world proposed a variety of plans to reduce emissions, including international commitments, policy measures, technological innovations, market mechanisms, and environmental protection strategies [69]. However, the effectiveness of these political efforts was easily influenced by various factors, such as the complex international environment, side effects of emission reduction measures, the involvement of a large number of stakeholders, and the unfamiliarity of farmers with climate change [70].

As an important starting point for the discussion, identifying political efforts conducive to incentivizing emissions reductions and promoting sustainable agriculture requires a concerted effort from policymakers, economic actors, farmers, and researchers [71].

3.4. Limitations

The limitations of our study arise mainly from two aspects. First, the literature data used for the analysis were only from the WoSCC database, ignoring the literature from other databases [72]. This was primarily attributed to the fact that the existing VOSviewer software is prone to formatting errors when merging the literature data from different databases [73]. Therefore, a small number of relevant papers from other databases may not be included in this study. Second, different parameter settings in the VOSviewer software may generate different results, which may contain some synonyms that need to be replaced due to differences in the presentation of relevant information [64]. Both two aspects may affect the reliability of the bibliometric results. As the WoSCC database is constantly updated, we will collect more literature data on climate change and agriculture and invite more scientists with expertise to further summarize research progress in relevant sub-fields by incorporating a systematic review or a scoping review.

4. Conclusions

Using the WOSCC database and the VOSviewer software, this study analyzed 25,872 papers on climate change and agriculture research from 1985 to 2023 in terms of the number of publications, research power, and keywords. The main results were as follows:

(1) The annual number of papers increased exponentially from 1985 to 2023 and showed a rapid growth trend after 2007, with 95.89% of the total number of papers being published during this period. Furthermore, climate change and agriculture research was characterized by interdisciplinarity and diversity in terms of research areas and journals;
(2) The USA had the leading position in this field, with the highest number of papers and total citations, and cooperated closely with other countries. In addition to the USA, China and some European countries also have great influence in this field. Furthermore, the most influential institutions and authors were mainly distributed in these countries;
(3) The most prominent keywords were “climate change”, “agriculture”, “impact”, “adaptation”, and “management”. Although four distinct research topics have been identified over the decades, in recent years, the research focus has shifted toward climate change adaptation in agriculture.

Overall, this bibliometric analysis presents a distinct and intriguing snapshot of climate change and agriculture research, allowing relevant researchers to understand the knowledge structure, emerging trends, and how progress is being made in this field. As a starting point for future research, some valuable suggestions could be given to scientists/countries that claim to have less literature to improve their local knowledge.

Author Contributions: Conceptualization, C.L., X.C. and Y.X.; methodology, C.L. and H.Y.; software, H.Y.; formal analysis, H.Y., Z.L. and F.W.; data curation, F.W. and B.L.; writing—original draft preparation, C.L. and H.Y.; writing—review and editing, Z.L., F.W., B.L., Y.W., K.P.C., T.O., X.C. and Y.X.; funding acquisition, C.L., Y.W., K.P.C., X.C. and Y.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Program of China (2023YFF1303702), the Key Research and Development Program of Jiangsu Province (BE2022343), the Young Scientific and Technological Talents Support Project of Jiangsu Association for Science and Technology (TJ-2023-032), the National Natural Science Foundation of China (42275029, 41801013), the Royal Society International Exchanges 2022 (IEC\NSFC\223132), the Qinglan Project of Jiangsu Province, and the Qinglan Project of Yangzhou University.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. IPCC. Climate Change 2021: The Physical Science Basis. In *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK, 2021.
2. Rawat, A.; Kumar, D.; Khati, B.S. A review on climate change impacts, models, and its consequences on different sectors: A systematic approach. *J. Water Clim. Change* **2024**, *15*, 104–126. [CrossRef]
3. Malhi, Y.; Franklin, J.; Seddon, N.; Solan, M.; Turner, M.G.; Field, C.B.; Knowlton, N. Climate Change and Ecosystems: Threats, Opportunities and Solutions. *Philos. Trans. R. Soc. B* **2020**, *375*, 20190104. [CrossRef] [PubMed]
4. Piao, S.; Wang, X.; Park, T.; Chen, C.; Lian, X.; He, Y.; Bjerke, J.W.; Chen, A.; Ciais, P.; Tømmervik, H.; et al. Characteristics, drivers and feedbacks of global greening. *Nat. Rev. Earth Environ.* **2020**, *1*, 14–27. [CrossRef]
5. Dietz, T.; Shwom, R.L.; Whitley, C.T. Climate Change and Society. *Annu. Rev. Sociol.* **2020**, *46*, 135–158. [CrossRef]
6. Ray, D.; Gerber, J.; MacDonald, G.; West, P.C. Climate variation explains a third of global crop yield variability. *Nat. Commun.* **2015**, *6*, 5989. [CrossRef]
7. Crippa, M.; Solazzo, E.; Guizzardi, D.; Monforti-Ferrario, F.; Tubiello, F.N.; Leip, A. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat. Food* **2021**, *2*, 198–209. [CrossRef]
8. Li, C.; Jia, J.; Wu, F.; Zuo, L.; Cui, X. County-level intensity of carbon emissions from crop farming in China during 2000–2019. *Sci. Data* **2024**, *11*, 457. [CrossRef]
9. Abbass, K.; Qasim, M.Z.; Song, H.; Murshed, M.; Mahmood, H.; Younis, I. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ. Sci. Pollut. Res.* **2022**, *29*, 42539–42559. [CrossRef]
10. Rivera-Ferre, M.G. From agriculture to food systems in the IPCC. *Glob. Change Biol.* **2020**, *26*, 2731–2733. [CrossRef]
11. Yuan, X.; Li, S.; Chen, J.; Yu, H.; Yang, T.; Wang, C.; Huang, S.; Chen, H.; Ao, X. Impacts of Global Climate Change on Agricultural Production: A Comprehensive Review. *Agronomy* **2024**, *14*, 1360. [CrossRef]
12. Azadi, H.; Moghaddam, S.M.; Burkart, S.; Mahmoudi, H.; Passel, S.V.; Kurban, A.; Lopez-Carr, D. Rethinking resilient agriculture: From Climate-Smart Agriculture to Vulnerable-Smart Agriculture. *J. Clean. Prod.* **2021**, *319*, 128602. [CrossRef]
13. McLeman, R.; Mayo, D.; Strebeck, E.; Smit, B. Drought adaptation in rural eastern Oklahoma in the 1930s: Lessons for climate change adaptation research. *Mitig. Adapt. Strateg. Glob. Change* **2008**, *13*, 379–400. [CrossRef]
14. Lee, C.C.; Zeng, M.; Luo, K. How does climate change affect food security? Evidence from China. *Environ. Impact Assess. Rev.* **2024**, *104*, 107324. [CrossRef]
15. Gaugler, T.; Stoeckl, S.; Rathgeber, A.W. Global climate impacts of agriculture: A meta-regression analysis of food production. *J. Clean. Prod.* **2020**, *276*, 122575. [CrossRef]
16. Mizik, T. Climate-Smart Agriculture on Small-Scale Farms: A Systematic Literature Review. *Agronomy* **2021**, *11*, 1096. [CrossRef]
17. Parolini, G. Weather, climate, and agriculture: Historical contributions and perspectives from agricultural meteorology. *Wiley Interdiscip. Rev. Clim. Change* **2022**, *13*, e766. [CrossRef]
18. Malhi, G.S.; Kaur, M.; Kaushik, P. Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability* **2021**, *13*, 1318. [CrossRef]
19. Grigorieva, E.; Livenets, A.; Stelmakh, E. Adaptation of Agriculture to Climate Change: A Scoping Review. *Climate* **2023**, *11*, 202. [CrossRef]
20. Crane-Droesch, A. Machine learning methods for crop yield prediction and climate change impact assessment in agriculture. *Environ. Res. Lett.* **2018**, *13*, 114003. [CrossRef]
21. Totin, E.; Segnon, A.C.; Schut, M.; Affognon, H.; Zougmoré, R.B.; Rosenstock, T.; Thornton, P.K. Institutional Perspectives of Climate-Smart Agriculture: A Systematic Literature Review. *Sustainability* **2018**, *10*, 1990. [CrossRef]
22. Wang, Z.; Zhao, Y.; Wang, B. A bibliometric analysis of climate change adaptation based on massive research literature Data. *J. Clean. Prod.* **2018**, *199*, 1072–1082. [CrossRef]
23. Chen, G.; Bai, J.; Bi, C.; Wang, Y.; Cui, B. Global greenhouse gas emissions from aquaculture: A bibliometric analysis. *Agric. Ecosyst. Environ.* **2023**, *348*, 108405. [CrossRef]
24. Shiffrin, R.M.; Börner, K. Mapping knowledge domains. *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 5183–5185. [CrossRef] [PubMed]
25. Huang, Y.; Glänzel, W.; Zhang, L. Tracing the development of mapping knowledge domains. *Scientometrics* **2021**, *126*, 6201–6224. [CrossRef]
26. Xu, Y.; Yang, Y.; Chen, X.; Liu, Y. Bibliometric Analysis of Global NDVI Research Trends from 1985 to 2021. *Remote Sens.* **2022**, *14*, 3967. [CrossRef]
27. Van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
28. Chen, C. Citespace ii: Detecting and visualizing emerging trends and transient patterns in scientific literature. *J. Am. Soc. Inf. Sci. Technol.* **2006**, *57*, 359–377. [CrossRef]

29. Borgatti, S.; Everett, M.; Freeman, L. *UCINET 6 for Windows: Software for Social Network Analysis*; Analytic Technology: Harvard, MA, USA, 2002.
30. Persson, O.; Danell, R.; Schneider, J.W. How to use Bibexcel for various types of bibliometric analysis. In *Celebrating Scholarly Communication Studies: A Festschrift for Olle Persson at his 60th Birthday*; Umeå University Library: Umeå, Sweden, 2009; pp. 9–24.
31. McAllister, J.T.; Lennertz, L.; Atencio Mojica, Z. Mapping a Discipline: A Guide to Using VOSviewer for Bibliometric and Visual Analysis. *Sci. Technol. Libr.* **2022**, *41*, 319–348. [CrossRef]
32. Bukar, U.A.; Sayeed, M.S.; Razak, S.F.A.; Yogarayan, S.; Amodu, O.A.; Mahmood, R.A.R. A Method for Analyzing Text Using VOSviewer. *MethodsX* **2023**, *11*, 102339. [CrossRef]
33. Sweileh, W.M. Bibliometric analysis of peer-reviewed literature on food security in the context of climate change from 1980 to 2019. *Agric. Food Secur.* **2020**, *9*, 11. [CrossRef]
34. Xiao, F.; Liu, Q.; Qin, Y.; Huang, D.; Liao, Y. Agricultural drought research knowledge graph reasoning by using VOSviewer. *Heliyon* **2024**, *10*, e27696. [CrossRef] [PubMed]
35. Li, B.; Hu, K.; Lysenko, V.; Khan, K.Y.; Wang, Y.K.; Jiang, Y.N.; Guo, Y. A scientometric analysis of agricultural pollution by using bibliometric software VoSViewer and Histcite (TM). *Environ. Sci. Pollut. Res.* **2022**, *29*, 37882–37893. [CrossRef] [PubMed]
36. Sarkar, A.; Wang, H.; Rahman, A.; Memon, W.H.; Qian, L. A bibliometric analysis of sustainable agriculture: Based on the Web of Science (WOS) platform. *Environ. Sci. Pollut. Res.* **2022**, *29*, 38928–38949. [CrossRef] [PubMed]
37. Cheng, P.; Tang, H.; Dong, Y.; Liu, K.; Jiang, P.; Liu, Y. Knowledge Mapping of Research on Land Use Change and Food Security: A Visual Analysis Using CiteSpace and VOSviewer. *Int. J. Environ. Res. Public Health* **2021**, *18*, 13065. [CrossRef]
38. Baraj, B.; Mishra, M.; Sudarsan, D.; da Silva, R.M.; Santos, C.A.G. Climate change and resilience, adaptation, and sustainability of agriculture in India: A bibliometric review. *Heliyon* **2024**, *10*, e29586. [CrossRef]
39. van Leeuwen, T. The application of bibliometric analyses in the evaluation of social science research. Who benefits from it, and why it is still feasible. *Scientometrics* **2006**, *66*, 133–154. [CrossRef]
40. Li, M.; Wang, Y.; Li, N.; Chou, S. Knowledge mapping on the sun-induced chlorophyll fluorescence technology research: A scientometric and visualization analysis. *Environ. Sci. Pollut. Res.* **2024**, *31*, 9150–9166. [CrossRef]
41. Yuan, B.Z.; Sun, J. Research trend of rice and greenhouse gases based on Web of Science: A bibliometric analysis. *All. Earth* **2023**, *35*, 16–30. [CrossRef]
42. Solomon, S.; Qin, D.; Manning, M.; Averyt, K.; Marquis, M. (Eds.) *Climate Change 2007—The Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC*; Cambridge University Press: Cambridge, UK, 2007.
43. Fussel, H.M. An updated assessment of the risks from climate change based on research published since the IPCC Fourth Assessment Report. *Clim. Change* **2009**, *97*, 469–482. [CrossRef]
44. Ravishankara, A.R.; Randall, D.A.; Hurrell, J.W. Complex and yet predictable: The message of the 2021 Nobel Prize in Physics. *Proc. Natl. Acad. Sci. USA* **2022**, *119*, e2120669119. [CrossRef]
45. Hertel, T.W.; de Lima, C.Z. Climate impacts on agriculture: Searching for keys under the streetlight. *Food Policy* **2020**, *95*, 101954. [CrossRef]
46. Shahzad, A.; Ullah, S.; Dar, A.A.; Sardar, M.F.; Mehmood, T.; Tufail, M.A.; Shakoor, A.; Haris, M. Nexus on climate change: Agriculture and possible solution to cope future climate change stresses. *Environ. Sci. Pollut. Res.* **2021**, *7*, 1–22. [CrossRef] [PubMed]
47. Yu, Q.; Wu, W.; Yang, P.; Li, Z.; Xiong, W.; Tang, H. Proposing an interdisciplinary and cross-scale framework for global change and food security researches. *Agric. Ecosyst. Environ.* **2012**, *156*, 57–71. [CrossRef]
48. El Bilali, H.; Strassner, C.; Ben Hassen, T. Sustainable Agri-Food Systems: Environment, Economy, Society, and Policy. *Sustainability* **2021**, *13*, 6260. [CrossRef]
49. Yang, Q.; Du, T.; Li, N.; Liang, J.; Javed, T.; Wang, H.; Guo, J.; Liu, Y. Bibliometric Analysis on the Impact of Climate Change on Crop Pest and Disease. *Agronomy* **2023**, *13*, 920. [CrossRef]
50. Sawirdin, S.; Tian, A.; Shi, L.; Fu, W.; Cheng, S.; Halik, Ü.; Liang, J. A Bibliometric Analysis of the Research Progress and Trends during 2002–2022 on the Carbon Stocks in Terrestrial Ecosystems. *Forests* **2023**, *14*, 2051. [CrossRef]
51. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food security: The challenge of feeding 9 billion people. *Science* **2010**, *327*, 812–818. [CrossRef]
52. Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 20260–20264. [CrossRef]
53. Piao, S.; Ciais, P.; Huang, Y.; Shen, Z.; Peng, S.; Li, J.; Zhou, L.; Liu, H.; Ma, Y.; Ding, Y. The impacts of climate change on water resources and agriculture in China. *Nature* **2010**, *467*, 43. [CrossRef]
54. Van Dalen, H.P.; Henkens, K. Signals in science—On the importance of signaling in gaining attention in science. *Scientometrics* **2005**, *64*, 209–233. [CrossRef]
55. Lal, R. Soil carbon sequestration to mitigate climate change. *Geoderma* **2004**, *123*, 1–22. [CrossRef]
56. Schlenker, W.; Roberts, M.J. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 15594–15598. [CrossRef] [PubMed]
57. Smith, P.; Martino, D.; Cai, Z.; Gwary, D.; Janzen, H.; Kumar, P.; McCarl, B.; Ogle, S.; O'Mara, F.; Rice, C.; et al. Greenhouse gas mitigation in agriculture. *Phil. Trans. R. Soc. B* **2008**, *363*, 789–813. [CrossRef] [PubMed]

58. Griscom, B.W.; Adams, J.; Ellis, P.W.; Houghton, R.A.; Lomax, G.; Miteva, D.A.; Schlesinger, W.H.; Shoch, D.; Siikamäki, J.V.; Smith, P.; et al. Natural climate solutions. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 11645–11650. [CrossRef]
59. Asseng, S.; Ewert, F.; Martre, P.; Rötter, R.P.; Lobell, D.; Cammarano, D.; Kimball, B.; Ottman, M.; Wall, G.; White, J.W. Rising temperatures reduce global wheat production. *Nat. Clim. Change* **2015**, *5*, 143. [CrossRef]
60. Lobell, D.B.; Field, C.B. Global scale climate–crop yield relationships and the impacts of recent warming. *Environ. Res. Lett.* **2007**, *2*, 014002. [CrossRef]
61. Howden, S.M.; Soussana, J.F.; Tubiello, F.N.; Chhetri, N.; Dunlop, M.; Meinke, H. Adapting agriculture to climate change. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19691–19696. [CrossRef]
62. Leng, S.; Gao, X.; Pei, T.; Zhang, G.; Chen, L.; Chen, X.; He, C.; He, D.; Li, X.; Lin, C.; et al. *The Geographical Sciences During 1986–2015*; Springer: Berlin/Heidelberg, Germany, 2017.
63. Ogisi, O.D.; Begho, T. Adoption of climate-smart agricultural practices in sub-Saharan Africa: A review of the progress, barriers, gender differences and recommendations. *Farming Syst.* **2023**, *1*, 100019. [CrossRef]
64. Jiang, B.; Deng, X.; Chen, H.; Cui, L.; Tang, W. Research trends and hotspots in climate adaptation of the agricultural system: A bibliometric analysis. *Front. Sustain. Food Syst.* **2023**, *7*, 1158904. [CrossRef]
65. Aleixandre-Benavent, R.; Aleixandre-Tudó, J.; Castelló-Cogollos, L.; Aleixandre, J. Trends in scientific research on climate change in agriculture and forestry subject areas (2005–2014). *J. Clean. Prod.* **2017**, *147*, 406–418. [CrossRef]
66. Velasco-Muñoz, J.F.; Aznar-Sánchez, J.A.; Belmonte-Ureña, L.J.; López-Serrano, M.J. Advances in Water Use Efficiency in Agriculture: A Bibliometric Analysis. *Water* **2018**, *10*, 377. [CrossRef]
67. Yuan, B.; Sun, J. Trend and status of Food Science and Technology category based on the Essential Science Indicators during 2011–2021. *Food Sci. Technol.* **2022**, *42*, e91321. [CrossRef]
68. Lin, W.; De, K.; Wei, X.; Wang, W.; Zhang, L.; Xiang, X.; Li, F. Visual analysis of alpine meadow research trends and hotspots based on VOS viewer. *Front. Environ. Sci.* **2023**, *11*, 1095299. [CrossRef]
69. Nsabiyeze, A.; Ma, R.; Li, J.; Luo, H.; Zhao, Q.; Tomka, J.; Zhang, M. Tackling climate change in agriculture: A global evaluation of the effectiveness of carbon emission reduction policies. *J. Clean. Prod.* **2024**, *468*, 142973. [CrossRef]
70. Oenema, O.; Velthof, G.; Kuikman, P. Technical and policy aspects of strategies to decrease greenhouse gas emissions from agriculture. *Nutr. Cycl. Agroecosyst.* **2001**, *60*, 301–315. [CrossRef]
71. Liu, M.; Chen, X.; Jiao, Y. Sustainable Agriculture: Theories, Methods, Practices and Policies. *Agriculture* **2024**, *14*, 473. [CrossRef]
72. Ochoa-Noriega, C.A.; Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; Álvarez-Bejar, A. The Use of Water in Agriculture in Mexico and Its Sustainable Management: A Bibliometric Review. *Agronomy* **2020**, *10*, 1957. [CrossRef]
73. Shi, S.; Yin, J. Global research on carbon footprint: A scientometric review. *Environ. Impact Assess. Rev.* **2021**, *89*, 106571. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.