Journal of
Water & Climate Change

IWA PUBLISHING

Journal of Water and Climate Change Vol 14 No 4, 1285 doi: 10.2166/wcc.2023.436

International literature characteristics and hotspots evolution of the impact of climate change on cotton: A bibliographic study

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ABSTRACT

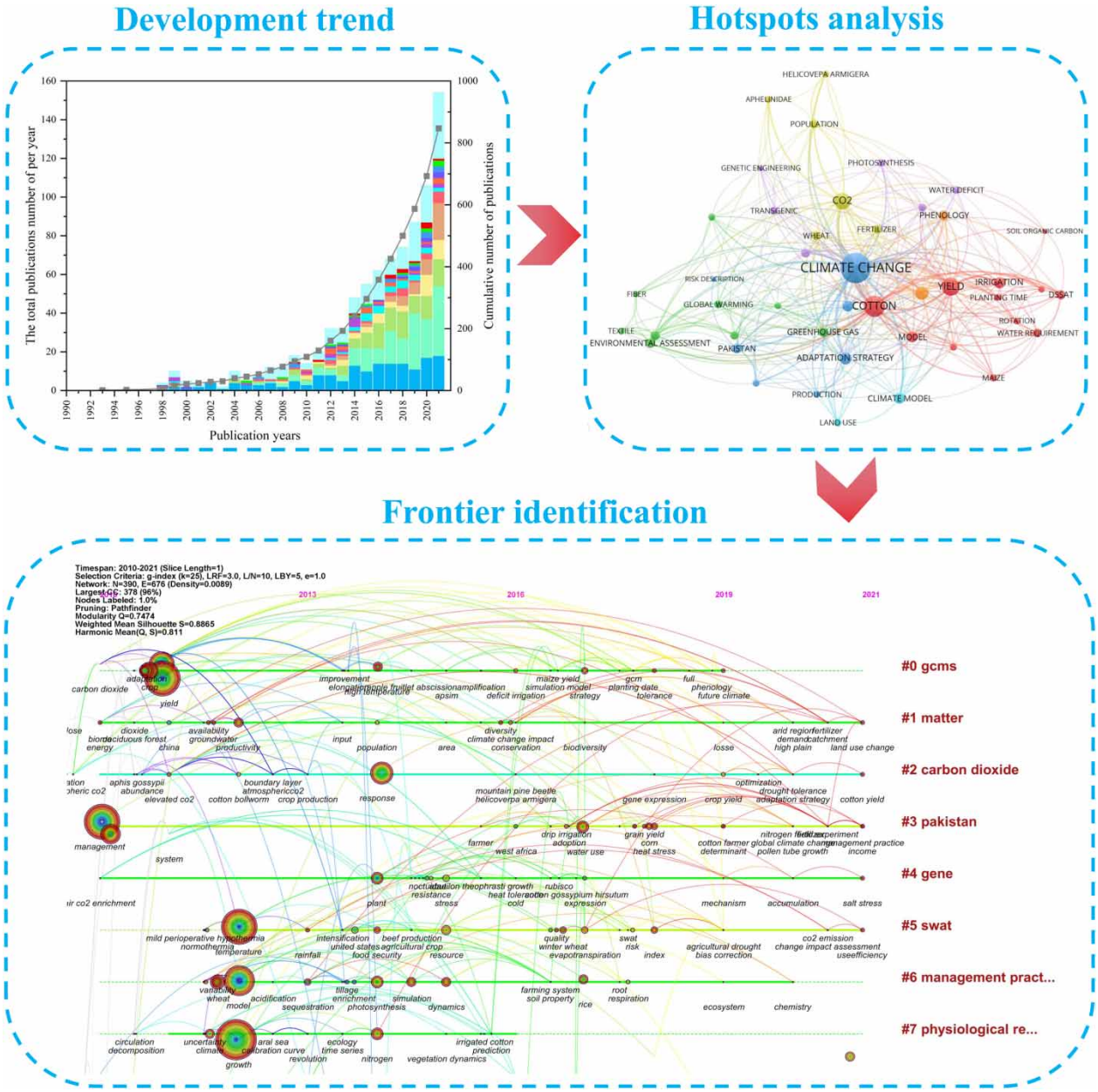
This study uses information visualization analysis software to quantitatively analyze the literature characteristics and hotspot evolution in the field of research on the impact of climate change on cotton. The results showed that the number of literature was on the rise, and environmental sciences, agronomy, plant sciences, water resources and agriculture were the main disciplines in this field. Countries and regions such as China, the U.S.A, Argentina, Pakistan and India pay great attention to the research field, and the cooperation between countries was relatively closed. Many well-known institutions such as the Chinese Academy of Sciences, University of Agriculture Faisalabad, Nanjing Agricultural University and United States Department of Agriculture-Agricultural Research Service were committed to research in this field. 'Yield', 'CO_2', 'Adaptation strategy', 'Irrigation', 'Model', etc., were the hot words in the research. Research hotspots had developed from the research on assessing the impact of climate change on future cotton production to focus on the impact of CO_2 concentration on cotton production, coping strategies for cotton industry development under climate change and climate-smart agriculture issues.

Key words: bibliographic, climate change, cotton, hotspot evolution, visualization

HIGHLIGHTS

- Quantitative analysis of the evolution of hotspots in research on the impact of climate change on cotton.
- Environmental sciences, agronomy, plant sciences, water resources and agriculture were the main disciplines in this field.
- 'Yield', 'CO_2', 'Adaptation strategy', 'Irrigation', 'Model', etc. were the hot words in the research.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Climate change is one of the great challenges facing mankind today and has become an important factor affecting and restricting the sustainable development of the social economy (Su *et al.* 2021). The sixth assessment report of the United Nations Intergovernmental Panel on Climate Change (IPCC) pointed out that the average global surface temperature in the last 10 years (2011–2020) was 1.09 °C (0.95–1.20 °C) higher than that in 1850–1900, and 0.19 °C (0.16–0.22 °C) higher than that in 2003–2012 (IPCC 2021). At the same time, the frequent occurrence of extreme climate events and the increasing difference in the spatial and seasonal distribution of precipitation are the obvious characteristics of climate change in recent decades. Agricultural production is highly dependent process on natural conditions, especially climatic conditions, and the change in climatic resources will inevitably have a significant impact on it (Cammarano & Tian 2018). Saini & Westgate (2000) and Appiah *et al.* (2018) pointed out that increasing temperature and drought affected agricultural productivity worldwide.

The research results of Lobell & Field (2007) also reported the significant negative impact of global temperature change on agricultural productivity. Under the climate background, agricultural climate resources, planting system, production layout, crop yield and quality will be greatly affected.

Cotton is an important economic fiber crop and textile industrial raw material, which plays an important role in the development of the national economy (Adhikari *et al.* 2017). The reproductive process of cotton is sensitive to high temperatures. High temperature leads to the decrease of photosynthetic rate and the increase of respiratory intensity, resulting in the deficiency of photosynthetic products in plants, and the premature senescence of physiology, which in turn leads to the shedding of cotton buds and bolls and the decrease of yield and quality (Wang 2015). Hot weather increased the demand for cotton evaporation, resulting in more serious water stress (Hall 2000). The low temperature in the early growth stage of cotton led to delayed growth and development, and low temperature in flowering and boll formation caused a large number of buds and bolls to fall off (Wang *et al.* 2019). In addition, elevated CO_2 concentrations in the atmosphere were expected to have a positive impact on cotton production (Kimball 2016). Elevated CO_2 concentration resulted in partial stomatal closure, reduced transpiration and increased water use efficiency, resulting in increased biomass (Broughton 2015). Climate change leads to changes in the spatial and temporal distribution of water resources (Fan & Mao 2014), and water stress caused by unbalanced spatial and temporal distribution of precipitation had adverse effects on cotton yield and quality. The sensitivity coefficient of a cotton bud and boll abscission rate to soil moisture was different in different growth stages. Insufficient or excessive soil moisture could easily lead to increased bud and boll shedding and decreased quality (Wang 2015). Light is the only energy source for the photosynthesis of plants. The decreased light intensity during climate change reduced the photosynthetic yield of cotton, lacked organic nutrients in reproductive organs and increased the abscission rate, which affected cotton yield and fiber quality (Pettigrew 2008). In addition, the increased temperature lead to an increase in overwintering base of pests and diseases, which was not conducive to the high and stable yield of cotton (Zhang 2020). Therefore, exploring the impact of climate change on cotton production is of great significance for the high and stable yield and planting planning of cotton.

Bibliometrics is a method to describe, evaluate and predict the current situation and development trend of scientific literature by quantitative analysis of the external characteristics of scientific literature (Sharifi *et al.* 2020). Using bibliometrics can objectively and comprehensively excavate the discipline structure and the structure of the academic community, accurately identify the progress, hotspots and frontiers of discipline research, and thus reveal the development law of discipline (Chang 2022). Due to its remarkable research advantages of objectivity, quantification and modeling, it had been widely used in soil, agriculture, plant protection, ecosystem and resource utilization (Tan *et al.* 2021; Qin *et al.* 2022a). At present, there are many research reports on the impact of climate change on cotton, but there are few quantitative analysis on the hot trends and changes in research directions of the impact of climate change on cotton involved in the existing research. There is a lack of comprehensive and intuitive understanding of the overall development and change characteristics and the evolution of research hotspots. Therefore, based on the bibliometric method, this study used the information visualization analysis software Co-Occurance (COOC) 12.6, VOSviewer and CiteSpace V, and took the relevant literature on the impact of climate change on cotton in the Core Collection of Clarivate Analytics of Web of Science (WOS) from 1990 to 2021 as the research data to conducted network visualization analysis on the literature characteristics and hot research in this field. In order to reveal the hot spots and development trends of the research on the impact of climate change on cotton, and provide some reference for future research.

2. BIBLIOMETRIC ANALYSIS: DATA AND METHODS

2.1. Data sources

The data source for this study is the Core Collection of Clarivate Analytics of WOS. The retrieval method is advanced retrieval, with 'climate change', 'climate warming', 'warming', 'global warming' and 'cotton' as keywords for subject retrieval. The retrieval time was 24 May 2022, and the retrieval time period was set to 1990–2021. Articles published from 1 January 2022, were excluded because any collection after this period would include incomplete bibliometric data from that year. Types of literature include Articles and Reviews, and the record content of each literature was obtained through WOS, including titles, authors, institutions, keywords, publication years, journals, etc.

2.2. Research methods

Bibliometrics covers structural, dynamic, evaluative and predictive scientometrics (Tan *et al.* 2021). Several softwares, including Citespace, VOSviewer, COOC and HistCite had been used for bibliometric analysis. This study first preprocessed the literature data based on the relatively new bibliometric software Co-Occurance12.6 (COOC): (1) deleted the duplicate literature; (2) deleted meaningless literature; (3) merged synonyms. Then the preprocessed data were converted into a common format by COOC software, so as to import other visualization software for subsequent analysis. Finally, Endnote X9, Microsoft Office 2010 and Origin 2022 were used for statistical analysis of the publication time, journals and research field distribution of the literature; VOSviewer was used to draw the knowledge map of country, institution and keyword co-occurrence (Van Eck & Waltman 2010); Citespace was used to draw a keyword timeline view (Chen 2006).

3. RESULTS AND DISCUSSIONS

3.1. Output analysis of papers on the impact of climate change on cotton

In order to better understand the characteristics and evolution trends of research related to the impact of climate change on cotton, the annual quantitative change analysis of 847 literatures screened from the WOS core database was conducted first, and the results are shown in Figure 1. Since 1990, the number of papers related to the impact of climate change on cotton has shown a significant upward trend, with an average annual growth rate of 44.57%. The number of papers published in the past 5 years accounted for 57.73% of the total, indicating that research in this field has developed rapidly.

The whole development process in this field was roughly divided into three stages: the initial germination stage; primary growth stage; rapid development stage. (1) Initial germination stage (1990–2005): The research on the impact of climate change on cotton was in the early exploratory stage of development, and only a few scholars have conducted research. The total number of documents at this stage was 45 papers, accounting for 5.31%, with an average annual publication of 2.81 papers per year. 'The First Assessment Report' of the IPCC was published in 1990, which confirmed the scientific basis for climate change issues (McG Tegart *et al.* 1990). Under its influence, some scholars began to carry out relevant research in this field in 1993. After that, the number of published papers increased overall, but the increase was small and there was fluctuation. (2) Primary growth stage (2006–2013): This stage was the development stage of research on the

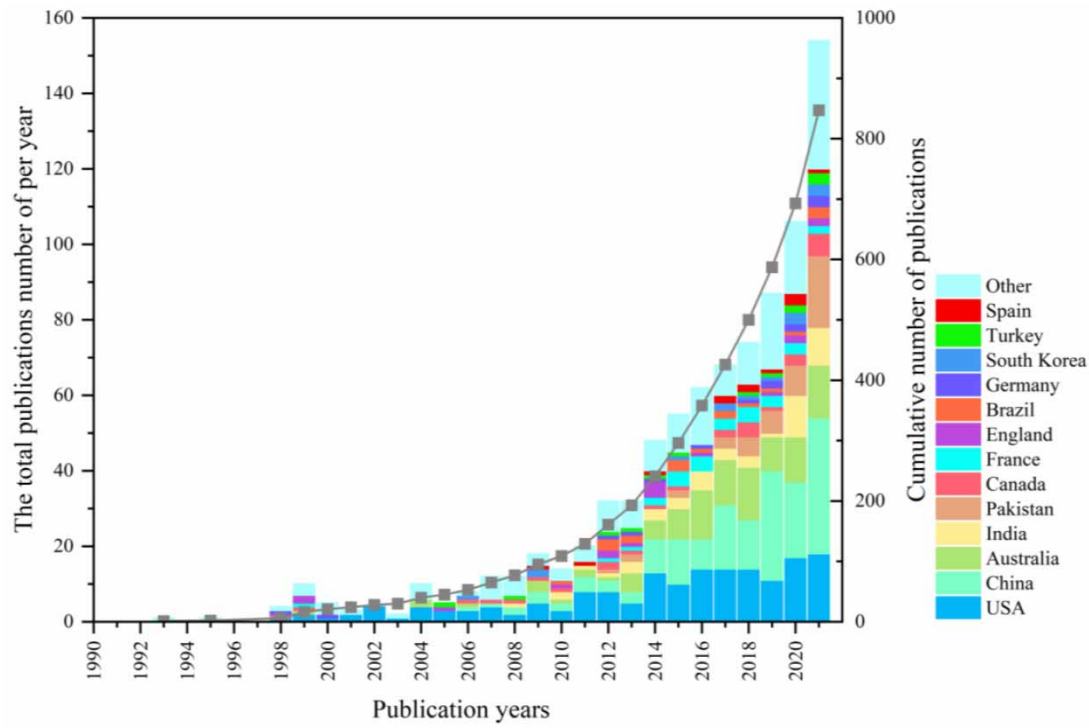


Figure 1 | Annual distribution of papers published in the field of impact of climate change on cotton.

impact of climate change on cotton. The total number of papers was 148 papers, accounting for 17.47%. The number of published papers increased from 8 papers in 2006 to 32 papers in 2013. The average annual number of published papers was 18.5 papers per year, and the number of published papers increased significantly. (3) Rapid development stage (2014–2021): the number of published papers was 654, accounting for 77.21%. The annual average number of published papers was 81.75 per year, with an average growth rate of 22.56%, which was much higher than the overall growth level. This indicates that this field has been active in recent years.

3.2. Disciplinary distribution and main journals of papers on the impact of climate change on cotton

Figure 2 and Table 1 show the top 10 major disciplines and journals in terms of the number of published articles on the impact of climate change on cotton from 1990 to 2021. The data showed that the research on the impact of climate change on cotton involves many disciplines, among which the main disciplines involved were: environmental sciences, agronomy, plant sciences, water resources and agriculture, with a total of 624 papers published, accounting for 73.67% of the total published papers (Figure 2).

The papers on the impact of climate change on cotton were mainly published in 'Agricultural Water Management', 'Agricultural Systems', 'Journal of Cleaner Production', 'Climatic Change', 'Agronomy Journal' and other journals. A total of 165 articles were published in the top 10 journals, accounting for 19. 48% of the total published articles. The largest number of published papers was 'Agricultural Water Management' journals published in the Netherlands, with 32 papers, accounting for 3.78% of the total. Among the top 10 journals, 5 were published in the Netherlands and 2 were published in the U.S.A, indicating that these 5 journals published in the Netherlands played an important role in the study of the impact of climate change on cotton (Table 3).

3.3. Influential countries/regions analysis and global collaboration

The linkages between countries were analyzed and visualized in order to clarify the major countries/regions involved in the research field of the impact of climate change on cotton and their cooperation (Figure 3). The nodes in the figure represent different countries/regions, the sizes represent the number of published articles and the different colors represent diversified

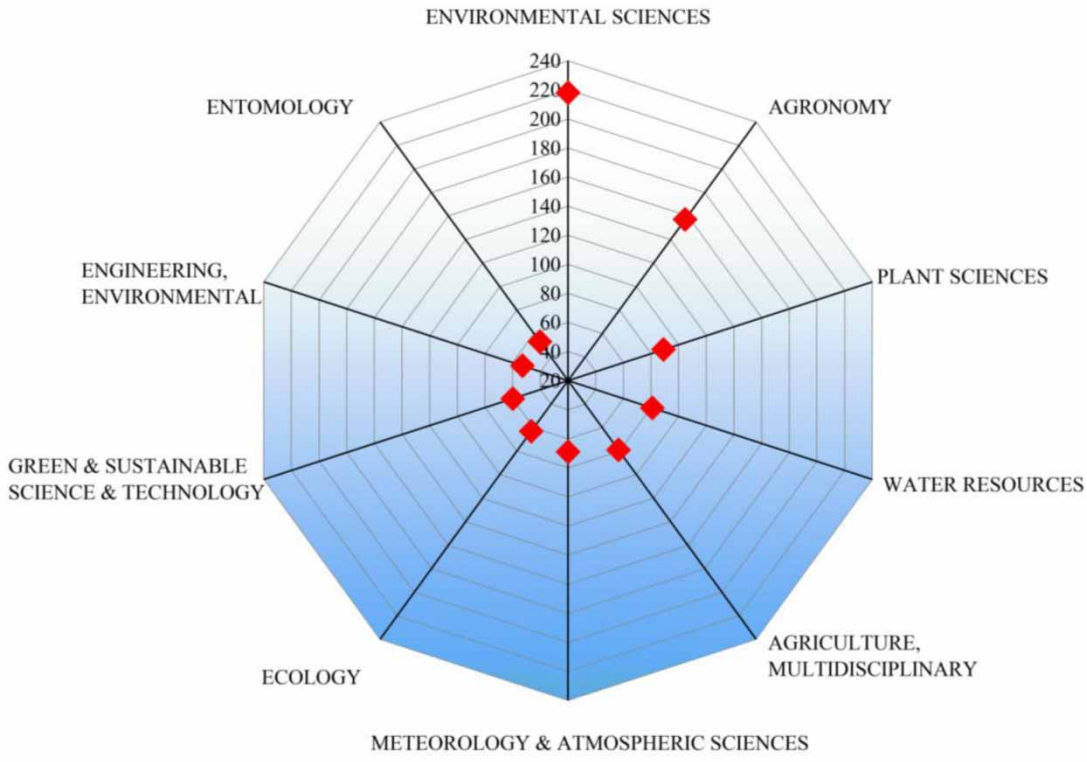


Figure 2 | The top 10 disciplinary fields of research on the impact of climate change on cotton.

Table 1 | Top 10 journals with published articles

Rank	Journal	Country	Number of publications	Impact factor (selected JCR year: 2021)	*h*-index
1	Agricultural Water Management	Netherlands	32	6.611	106
2	Agricultural Systems	Netherlands	21	6.765	95
3	Journal of Cleaner Production	United States	21	11.072	150
4	Climatic Change	Netherlands	14	5.174	162
5	Agronomy Journal	United States	14	2.65	113
6	Sustainability	Switzerland	14	3.889	53
7	Environmental Science and Pollution Research	Germany	13	5.19	82
8	Agricultural and Forest Meteorology	Netherlands	13	6.424	144
9	Science of the Total Environment	Netherlands	12	10.753	205
10	Scientific Reports	England	11	4.996	149

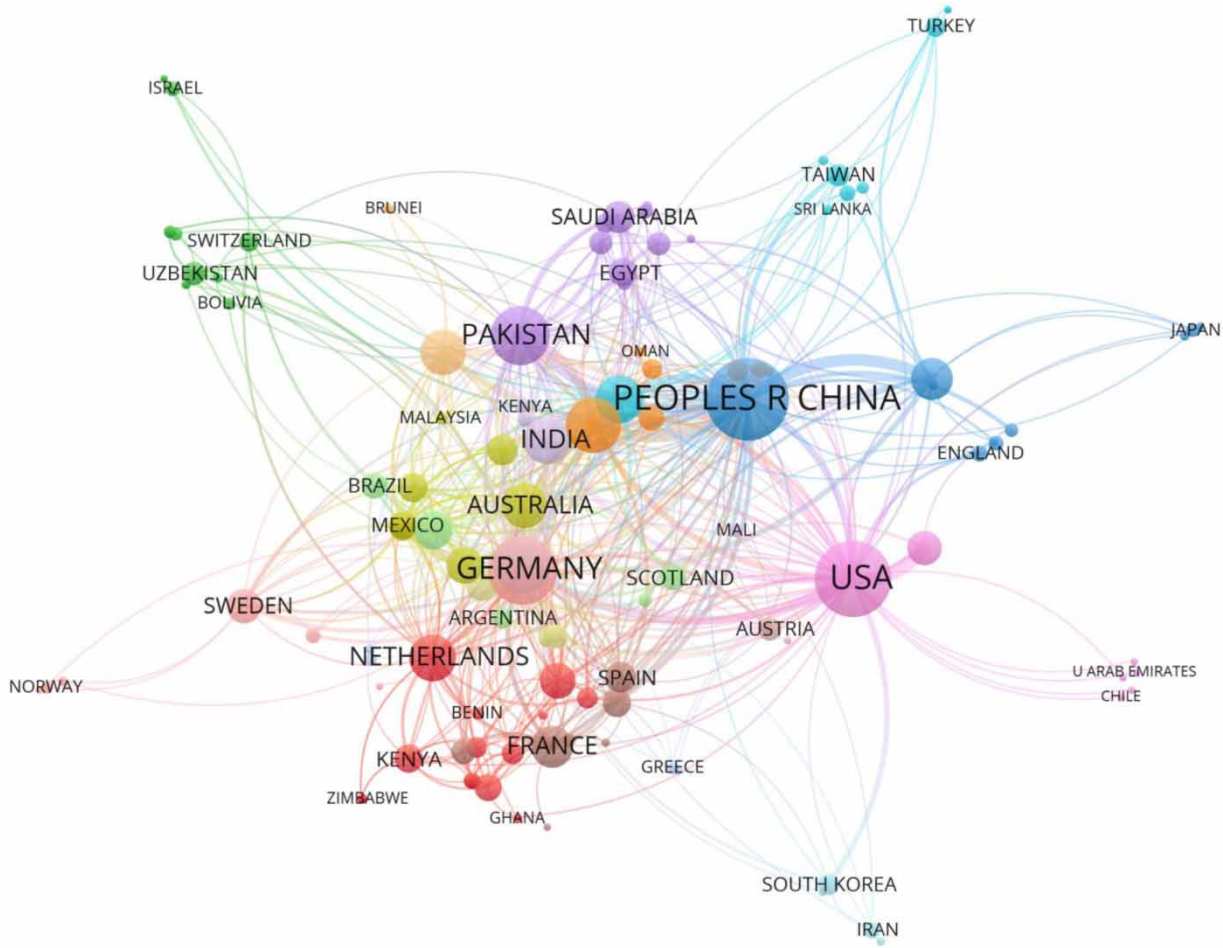


Figure 3 | Knowledge map of hotspot countries/regions for research on the impact of climate change on cotton.

clusters based on the cooperation matrix of corresponding countries/regions. The links between the two nodes represent their knowledge cooperation, and the thickness of the lines represents the degree of cooperation. Obviously, the closer the links between the two nodes, the deeper the links and cooperation between the two countries/regions. The study found that 92

countries/regions around the world were involved in research on the impact of climate change on cotton. The top five countries/regions were China, U.S.A, Argentina, Pakistan and India, with 269 (31.76%), 255 (30.11%), 120 (14.17%), 82 (9.68%) and 75 (8.85%) published articles, respectively. From the perspective of the extensiveness of the cooperative countries/regions, the U.S.A had the most extensive cooperation and had cooperative relations with 58 countries/regions. Secondly, Germany had cooperative relations with 52 countries/regions, and China and Pakistan had cooperative relations with 42 countries/regions. Based on the analysis of total link strength, the United States had the strongest international cooperation strength, followed by China. Of course, other countries/regions had also contributed a lot of efforts and cooperation in the progress of research on the impact of climate change on cotton, which showed that the future development trend in this field was the diversified development of multiple countries/regions.

3.4. Influential institutions analysis and global collaboration

The top five institutions with the number of published articles from 1990 to 2021 were Chinese Academy of Sciences, University of Agriculture Faisalabad, Nanjing Agricultural University, United States Department of Agriculture – Agricultural Research Service and Chinese Academy of Agricultural Sciences, accounting for 7.56, 3.78, 3.66, 3.19 and 2.83%, respectively (Table 2). Among the top 13 institutions, there were 7 institutions from China, 3 institutions from the United States, Pakistan, Germany, and Australia each had one institution. It can be seen that Chinese academia has paid attention to the research on the impact of climate change on cotton in recent years.

From the perspective of institutional cooperation, four scientific research institutions from the Chinese Academy of Sciences in China, the University of Queensland in Australia, the University of Agriculture Faisalabad in Pakistan and Nanjing Agricultural University in China were in a crucial position (Figure 4). Among them, the Chinese Academy of Sciences had the largest node and was closely related to other clusters, such as Nanjing Agricultural University, China Agricultural University, University of Chinese Academy of Sciences, the University of Queensland, Murdoch University, etc., indicating that the Chinese Academy of Sciences cooperates closely with these institutions. In addition, it was worth noting that China Meterological Administration, Central Asia Atmospheric Science Research Center, University of Maryland and the University of Melbourne, which were located on the edge, had a low degree of cooperation with other institutions and were not closely linked. Therefore, strengthening large-scale collaboration is the direction that needs efforts in the field of future research on the impact of climate change on cotton.

3.5. Literature citation analysis

The citation frequency of articles can show the degree to which scientific papers are used and valued in scientific research progress, as well as their role and status in the academic system. The total citation frequency of 847 articles on the impact of

Table 2 | Top 13 institutions in the number of articles published on the impact of climate change on cotton (the number of articles published $\geq$ 15)

Ranking	Number of articles	Institution abbreviation	Full name of institution	Country
1	64	CHINESE ACAD SCI	Chinese Academy of Sciences	China
2	32	UNIV AGR FAISALABAD	University of Agriculture Faisalabad	Pakistan
3	31	NANJING AGR UNIV	Nanjing Agricultural University	China
4	27	USDA ARS	United States Department of Agriculture-Agricultural Research Service	United States
5	24	CHINESE ACAD AGR SCI	Chinese Academy of Agricultural Sciences	China
6	23	TEXAS A&M UNIV	Texas A&M University	United States
7	21	CHINA AGR UNIV	China Agricultural University	China
8	21	UNIV BONN	University of Bonn	Germany
9	19	NORTHWEST A&F UNIV	Northwest Sci-Tech University of Agriculture and Forestry	China
10	17	HUAZHONG AGR UNIV	Huazhong Agricultural University	China
11	17	UNIV CHINESE ACAD SCI	University of Chinese Academy of Sciences	China
12	16	MISSISSIPPI STATE UNIV	Mississippi State University	United States
13	15	UNIV QUEENSLAND	The University of Queensland	Australia

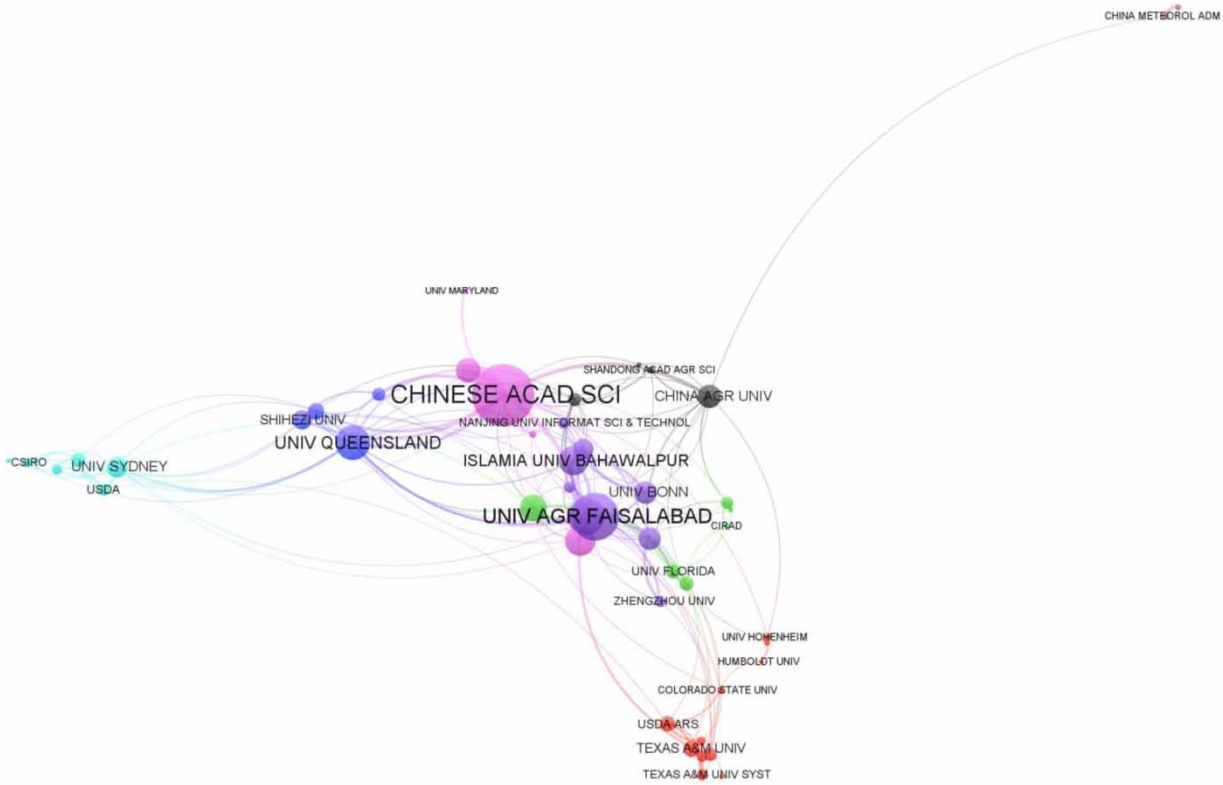


Figure 4 | Knowledge map of hotspot institutions for research on the impact of climate change on cotton.

climate change on cotton was 20,010 times, and the average citation frequency of each article was 23.62 times. Table 3 summarizes the five articles with the highest total citation frequency. The most cited article was published in 'Proceedings of the National Academy of Sciences (PNAS)' in 2009 by Meerburg *et al.*, entitled 'Do nonlinear temperature effects indicate severe damages to US crop yields under climate change?', which was cited 1,445 times. This paper mainly studies the nonlinear response of maize, soybean and cotton to increased temperature. The remaining four highly cited papers mainly studied how to adopt reasonable and effective policies and management strategies to protect pollinators affected by land use, climate change, genetically modified pathogens and maintain pollinating services; the role of climate change, water scarcity, energy crisis and human growth in global food security; effects of combined drought and pathogen combined stress caused by climate change on crop productivity; responses of plants to solar ultraviolet radiation and other climatic factors. And these topics should be hotspots in the current climate change research field.

3.6. Keywords co-occurrence analysis

Keywords are a high degree of generalization of the theme of the article. They are keywords that can reflect the theme or thought of the article. They can reveal the research hotspots in the field of the impact of climate change on cotton. 'Climate change', 'cotton', 'and temperature' were the most frequent occurrences in the research literature, which were also the basic conditions for the literature to obtain data sources (Figure 5). Therefore, the above keywords were not analyzed in the hotspot analysis.

The larger the weight of keywords, the larger the corresponding font and node. As can be seen in Figure 5, keywords such as 'Yield', 'CO_2', 'Adaptation strategy' and 'Irrigation' are hotspots in the research field related to the impact of climate change on cotton. (1) Yield: The impact of climate change on cotton yield was mainly reflected in the impact of climate factors simulated by crop model and the exploration of adaptive measures (such as sowing date, variety, irrigation, rotation mode, etc.) to cope with climate change. In addition, variation characteristics of cotton water productivity under the influence of climate change were discussed, in order to provide guidance for cotton production planning and water resources management. (2) CO_2: Elevated CO_2 concentration is one of the main characteristics of climate change (IPCC 2021). CO_2 is an important

Table 3 | Five papers with the highest citation frequency

Order	Title	Journal	Author	Publishing time	Institution	Country	Citation frequency
1	Do nonlinear temperature effects indicate severe damages to US crop yields under climate change?	Proceedings of the National Academy of Sciences	Meerburg, B. G., Verhagen, A., Jongschaap, R. E. E., *et al.*	2009	N CAROLINA STATE UNIV; COLUMBIA UNIV	United States	1,445
2	Safeguarding pollinators and their values to human well-being	Nature	Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., *et al.*	2016	VALE INST TECHNOL SUSTAINABLE DEV; GERMAN CTR INTEGRAT BIODIVERS RES IDIV; NERC CTR ECOL & HYDROL; *et al.*	Argentina; Germany; Brazil; Australia; England; Scotland; Netherlands	638
3	Global water crisis and future food security in an era of climate change	Food Policy	Hanjra, M. A., Qureshi, M. E.	2010	CHARLES STURT UNIV; CSIRO SUSTAINABLE ECOSYST; AUSTRALIAN NATL UNIV	Australia	601
4	Impact of Combined Abiotic and Biotic Stresses on Plant Growth and Avenues for Crop Improvement by Exploiting Physio-morphological Traits	Frontiers in Plant Science	Prachi, P., Vadivelmurugan, I., Bagavathiannan, M. V., Muthappa, S. K.	2017	NATL INST PLANT GENOME RES; TEXAS A&M UNIV	United States; India	301
5	Terrestrial ecosystems, increased solar ultraviolet radiation, and interactions with other climate change factors	Photochemical & Photobiological Sciences	Caldwell, M. M., Bornman, J. F., C. L. Ballaré, *et al.*	2007	NATL SCI FDN; UNIV WAIKATO; UNIV BUENOS AIRES; UTAH STATE UNIV; CONSEJO NACL INVEST CIENT & TECN; RES CTR FLAKKEBJERG; MADURAI KAMARAJ UNIV	Aegentina; United States; New Zealand; Denmark; India	300

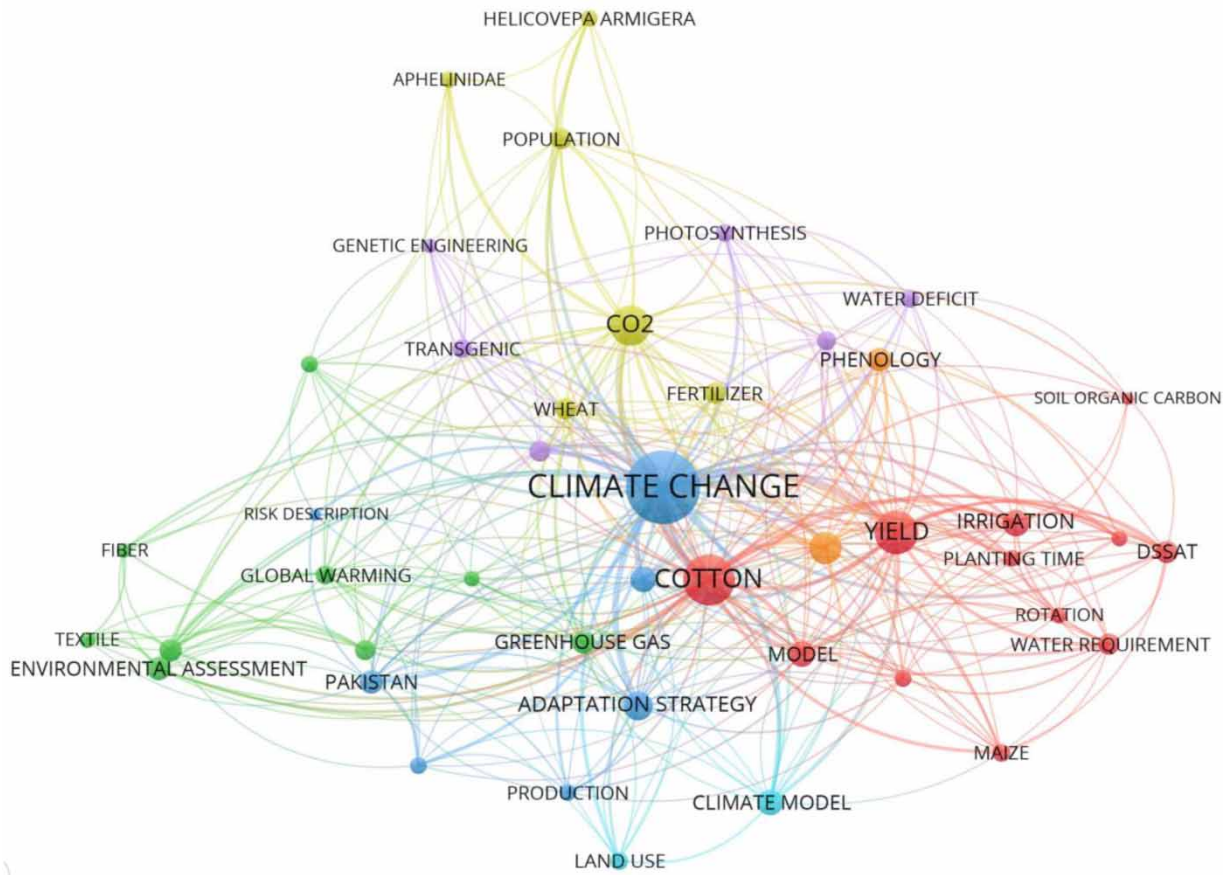


Figure 5 | Knowledge map of high-frequency keywords co-occurrence in the field of the impact of climate change on cotton.

photosynthesis substrate for crops, and elevated CO_2 concentration will affect crop growth and development, nutrient absorption and utilization and physiological and biochemical indicators (Li *et al.* 2021). At present, whether the impact of elevated CO_2 concentration was considered in climate change impact assessment often plays a decisive role in the research results. At present, the effects of CO_2 concentration changes on cotton physiological ecology and yield were mainly explored through FACE (Free-air-carbon dioxide enrichment) and model simulation. (3) Adaptation strategy: Taking appropriate adaptive measures in agricultural production has great potential to pursue advantages and avoid disadvantages. Whether climate change had a serious impact on agricultural production depends not only on the degree of climate change but also on the adaptation of agricultural production systems to climate change. (4) Irrigation: Water is an important factor limiting crop growth, and lack of soil moisture can affect crop growth and final yield formation. Therefore, especially dry farming, irrigation was considered as an effective measure to cope with climate change (Mainuddin *et al.* 2013). Through scientific and reasonable adjustment of the irrigation system, the limited water was allocated to the critical period of crop water demand, which could save water resources to the maximum extent and improved water use efficiency under the premise of ensuring crop growth (Ishaque *et al.* 2017).

3.7. Clustering analyses based on two-mode matrix

In this study, based on Co-Occurrence12.6 (COOC) software, two-mode matrix construction and systematic clustering analysis of high-frequency keywords and journals were carried out. Figure 6 shows the bidirectional clustering results for publications on the impact of climate change on cotton. The horizontal clustering tree represents the clustering results of high-frequency keywords, and the vertical clustering tree represents the clustering results of high-frequency journals. The right side of the figure lists 12 high-frequency keywords, and the bottom of the figure lists 9 high-frequency journals. Each box

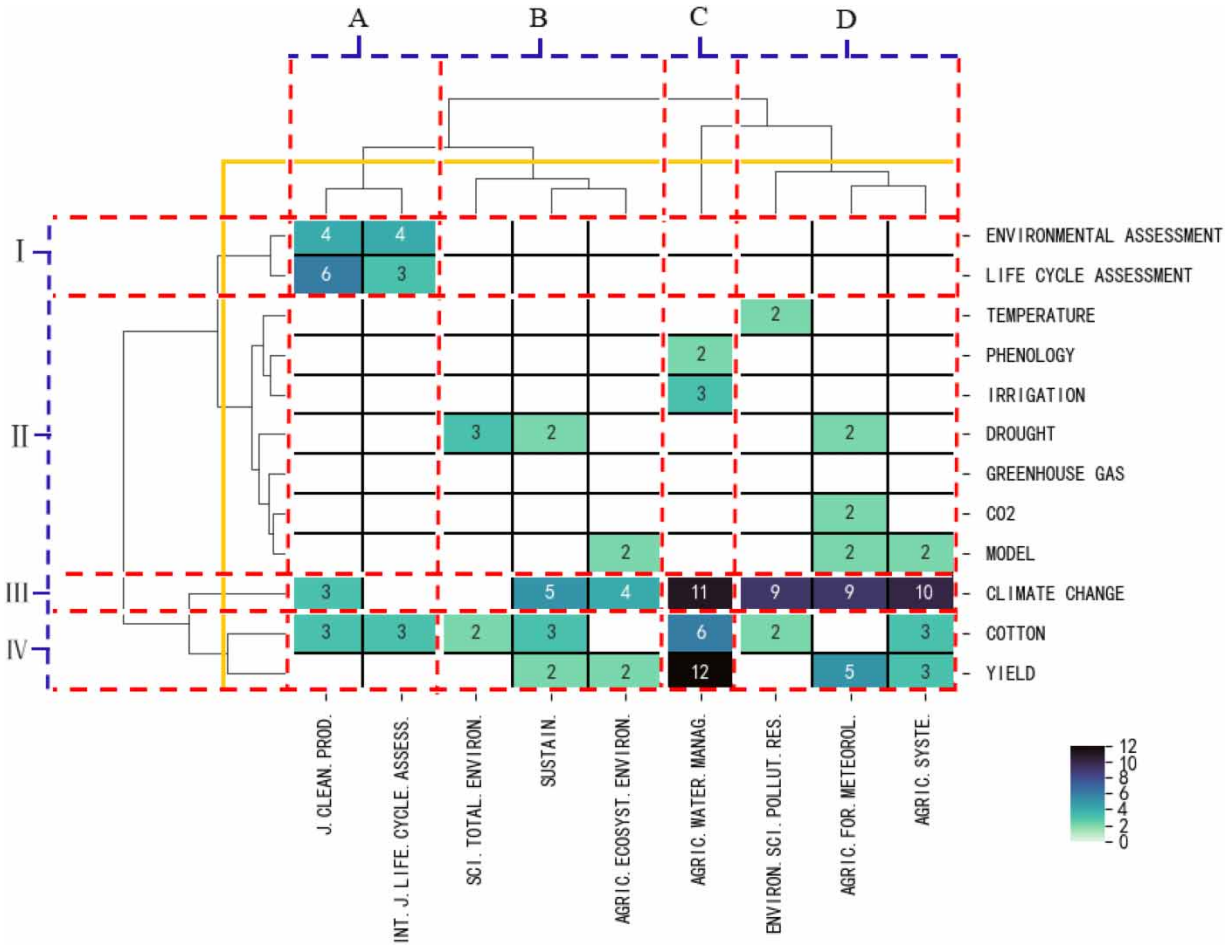


Figure 6 | Mapping knowledge domain of system clustering pedigree tree based on two-module matrix of keywords and journals.

represents the high-frequency keyword-journal units corresponding to row-column, and the color depth corresponds to the co-occurrence frequency in the publications.

The hot spots were concentrated in four aspects: (I) Environmental impact assessment research, mainly including 'Environment assessment' and 'Life cycle assessment'; (II) Effects of temperature rise, drought, greenhouse gas emissions and management measures on crop growth and simulation studies, including 'Temperature', 'Phenology', 'Drought', 'Greenhouse gas', 'CO_2' and 'Model'; (III) Climate change impacts, mainly including 'Climate change'; (IV) Cotton yield response research, mainly including 'Cotton' and 'Yield'. Similarly, the popular journal groups can be divided into four fields according to unit correlation: (A) Cleaner production and environmental impact research; (B) Research on sustainable development of ecosystem environment; (C) Agricultural water management research; (D) Environmental ecology and agricultural systems research. Through further correlation matching, A and B, C and D can also be classified into one category, indicating 'environmental sustainable development' and 'agricultural ecosystem research' journal groups. It was worth noting that III and IV were the most popular research directions in this field, while C and D were the most popular journals, especially C-III, C-IV and D-III, indicating that more and more research had begun to focus on the agricultural systems and environmental effects of climate change impacts.

3.8. Evolution of research hotspots

Figure 7 shows eight high-frequency clustering words for the 2010–2013 study on the impact of climate change on cotton, including General Circulation Models (GCMs) (#0), Matter (#1), Carbon dioxide (#2), Pakistan (#3), Gene (#4), SWAT (#5), Management practices (#6) and Physiological research (#7).

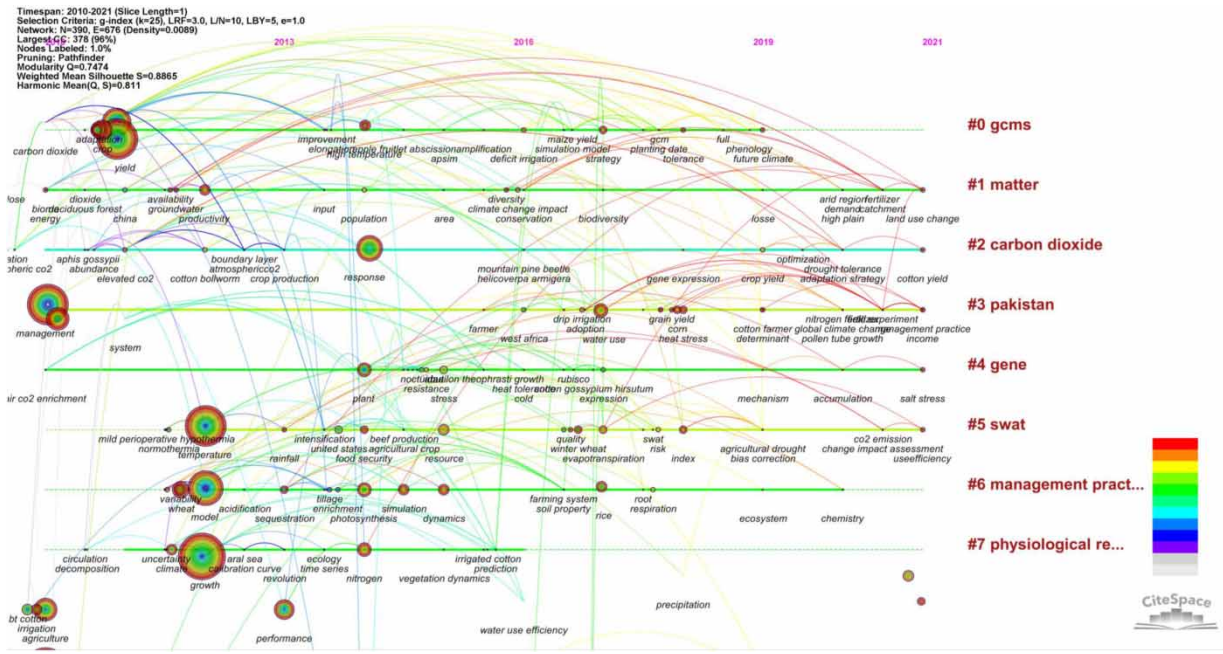


Figure 7 | Keyword timeline view of publications on the impact of climate change on cotton from 2010 to 2021.

Cluster #0 (GCMs) contains keywords such as carbon dioxide, adaptation, yield, simulation model, deficit irrigation, planting date, etc. It is of great significance for cotton production practice to predict the response of cotton to future climate change and the adaptive measures that can be taken. At present, the widely used method was to input the future meteorological data simulated by the global climate model into the crop model, so as to drive the model to simulate the impact of future climate change on cotton growth and yield, and explored possible measures to deal with climate change (such as irrigation and sowing date).

The high-frequency keywords in Cluster #1 (Matter) included availability, groundwater, productivity, diversity, land use change, etc. It involves research on biodiversity, land use and water productivity in the impact of climate change.

Cluster #2 (Carbon dioxide) was the focus of climate change research. CO_2 is an important photosynthesis substrate for crops. Whether or not elevated CO_2 was considered in climate change impact assessments plays a decisive role in the findings. At present, the effects of elevated CO_2 concentration on cotton physiology and ecology were mainly studied through FACE experiments and crop model simulations.

As can be seen from Cluster #3 (Pakistan), Pakistan was a hot research country in the field of climate change impact on cotton. And it also ranked in the top 10 high-frequency keywords. Basic high-frequency keywords include management, drip irrigation, water use, cotton farmer determinant, etc. Through the time evolution line, it could be seen that Pakistan's research had shifted from focusing on farmers' decision-making response to climate change to focusing on the impact of climate change on cotton physiological processes and management measures.

Cluster #4 (Gene) had entered a rapid development period since 2014. It was emphasized that crop breeding through genetic engineering to enhance crop resistance to habitat stress and crop adaptability. Keywords mainly include plant, resistance, stress, expression, and salt stress.

Based on the future climate predicted by the climate model, the Soil and Water Assessment Tool (Cluster #5 (SWAT)) model had been widely used to study the impact of future climate change on the utilization of water resources for agricultural production. Keywords mainly include temperature, food security, resource, evapotranspiration, use efficiency, etc. SWAT model was mainly used to study the impact of climate change on cotton evapotranspiration and water use efficiency.

Cluster #6 (Management practices): It was of great significance for the stable development of agricultural production to develop adaptation measures aimed at improving the level of agricultural production and limiting the adverse effects on crop production by assessing the potential impact of climate change (Modala 2014). It was found that compared with the

negative impact of climate change, technological improvement seems to have a greater effect on increasing yield (Aggarwal *et al.* 2019).

It could be seen from the evolution timeline of Cluster #7 (Physiological research) that the number of keywords was decreasing. Cotton physiology research was an early hotspot, and no such keywords had appeared since 2016. It indicated that the research enthusiasm for climate change on cotton physiology was fading, and the prelude of diversified research had been opened.

In summary, the relevant literature on the impact of climate change on cotton not only focuses on the future changes in cotton growth and yield affected by climate change but also pays more attention to how to adapt to climate change in the future. And current research hotspots focussed more attention on genetic engineering crop improvement. The research methods mainly focus on the use of climate model and crop model simulation, and the enthusiasm of early FACE experiment to study the effects of environmental factors on cotton physiology was gradually fading. In addition, Pakistan had paid more and more attention to the impact of climate change on cotton in recent years.

4. CONCLUSIONS AND RESEARCH OUTLOOKS

This study conducted a bibliometric analysis based on publications in the field of research on the impact of climate change on cotton. The research hotspots and development trends of the impact of climate change on cotton were revealed. The study found that the number of articles published on the impact of climate change on cotton showed a steady growth trend. It could be roughly divided into three development stages, the initial germination stage between 1990 and 2005, the primary growth stage between 2006 and 2013 and the rapid development stage between 2014 and 2021, the number of published articles accounted for 5.31, 17.47 and 77.21% of the total, respectively. There were many disciplines involved in the research paper, among which the main disciplines involved were environmental sciences, agronomy, plant sciences, water resources and agriculture.

China is the most active country in the study of the impact of climate change on cotton, while the publications of the Netherlands, the United States, Switzerland, Germany, Britain and other countries contribute the most. Chinese Academy of Sciences, Nanjing Agricultural University, Chinese Agricultural University, Northwest A & F University and Huazhong Agricultural University from China, University of Agriculture Faisalabad from Pakistan, United States Department of Agriculture-Agricultural Research Service, Texas A&M University, Mississippi State University from America, Bonn University from Germany and other institutions play a key role in research in this field.

'Yield', 'CO_2', 'Adaptation strategies' and 'irrigation' are hot topics in the study of the impact of climate change on cotton. The phased characteristics of hot spots evolution in the research field of the impact of climate change on cotton have shown a shift from the simulation of future yield changes, results exploration and attribution analysis to the research on agricultural adaptability, management measures and climate-smart agriculture. The research content is more comprehensive, and the research hotspots tend to be concentrated. The research directions mainly including climate-smart agriculture and agricultural adaptability will be the future key development direction of the research field on the impact of climate change on cotton.

The research on the impact of climate change on cotton had attracted more and more researchers' attention to the increased CO_2 and the technical measures that could be taken. Adaptation measures had a positive impact on reducing climate change risks to ecosystems (Qin *et al.* 2022b). The impact of technology was three to four times greater than the impact of climate signals (Lobell & Gourdji 2012; Najafi *et al.* 2018). The current adaptation of agricultural production to climate change was mainly through the adaptation of existing systems to reduced climate change risks (Li *et al.* 2021). Changing irrigation and fertilization systems, sowing dates and varieties were effective measures for cotton production to cope with climate change (Chen *et al.* 2019; Mraa *et al.* 2020). Rahman *et al.* (2018) study found that early planting, increased nitrogen fertilization, increased sowing density and variety changes offset 17% of the negative impact of climate change on cotton production. Adaptation measures must consider regional differences, and measures suitable for regional climate characteristics and technological development should be selected according to local conditions. At the same time, due to the high cost of environmental control experiments in the field, this study also found in the hotspot analysis that there were more studies using models to study the effects of climate change on cotton, resulting in a lack of field validation of the effects of climate change on cotton.

In addition, the limited literature available for bibliometric analysis due to the search format setting and the time span limitation increased the limitations of the analysis results of this study. And the current bibliometric software (COOC, CiteSpace and VOSviewer) also has some shortcomings: (1) The method of data preprocessing is not perfect, and the accuracy needs to

be further improved. The process of manual screening and merging literature can be reduced by improving software functions to include artificial intelligence algorithms, etc.; (2) Clustering method does not consider the applicability of the data, resulting in limited and homogeneous results; (3) In terms of visualization, it is also essential to improve the esthetics of the knowledge graph and the flexibility of parameter settings.' The data used in the bibliometric analysis are important for an accurate and comprehensive understanding of developments in the target field. However, there is no high-precision database with complete and reliable data at present. The data used in this study were obtained from the WOS database, focusing on basic research in the field around the world. The study may be limited in the source of data due to the selection of literature from the WOS database only, and the interpretation of climate change on cotton production was not comprehensive. In the future, the field of literature research can be further expanded, and the source of literature data acquisition can be broadened. The related research of China National Knowledge Infrastructure (CNKI), Chinese Social Sciences Citation Index (CSSCI) and other basic databases can be included in the scope of research for comparative study, so as to more comprehensively grasp the macroscopic research status of climate change on cotton production.

AUTHOR CONTRIBUTIONS

Na Li conducted data curation and wrote the original draft preparation; Jiaping Liang conceptualized the whole article and developed the methodology, Qiliang Yang visualized the article, Tianmu Du wrote the review and edited the article.

FUNDING

This research was supported by the National Natural Science Foundation of China (5197913451779113) and Key Laboratory Project of High-efficiency Water Use and Green Production for Characteristic Crops in Universities of Yunnan Province (KKPS201923009).

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 26 October 2022; accepted in revised form 3 March 2023. Available online 14 March 2023