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Review

Bibliometric Analysis of Research Trends in Agricultural Soil Organic Carbon Mineralization from 2000 to 2022

Futao Zhang *, Yuedong Liu and Yueling Zhang

State Key Laboratory of Efficient Utilization of Arid and Semi-Arid Arable Land in Northern China, The Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China
* Correspondence: zhangfutao2017666@163.com

Abstract: The change in agricultural soil organic carbon (SOC) at a global scale has a great impact on the soil quality, crop yields, and greenhouse gas concentration in the atmosphere. Plant-derived C input into soil is an effective strategy to increase the SOC; meanwhile, it promotes SOC mineralization. The SOC dynamics after plant-derived C input have received widespread attention in the past 20 years. This bibliometric study was performed to identify the basic characteristics, research output, and knowledge base as well as to understand the research trends and key topics of agricultural SOC mineralization. We collected data from the Web of Science Core Collection databases, with dates ranging from 2000 to 2022. The parameter calculated from the default indicators of bibliometric software tools was used to indicate the contribution of the journal/author/institution/countries. The activity and attractive index were calculated separately to evaluate the relative effort and impact made by a country. The results showed that: (1) the number of articles increased gradually during 2000–2010 and thereafter sharply increased; (2) *Soil Biology & Biochemistry* was the most representative journal, and agriculture was the most popular subject category; (3) the most productive institution was the Chinese Academy of Sciences, which is based China and cooperates closely with other institutions; (4) although the number of articles from China was the largest, both the cited frequency and activity index were much lower for China than for the USA, which had the highest citation and centrality among countries; and (5) the studies involving agricultural SOC mineralization have primarily investigated the effect of exogenous C and nutrient addition, as well as biotic processes, especially the microbial process. We concluded that there was an increasing trend in research on agricultural SOC mineralization, with a focus on the interaction between SOC and nutrient/microbial communities. The physical processes, such as the association of minerals and occlusion of aggregate and pores, were paid less attention relative to biotic processes despite their importance in SOC mineralization. Through an in-depth analysis of agricultural SOC mineralization research, this study provides a better understanding of development trends that have emerged in this field over the past 22 years. In future studies, more attention should be paid to the physical processes to understand the physical protection mechanism of agricultural SOC mineralization.

Keywords: bibliometric analysis; priming effect; agriculture; temporal evolution; CiteSpace

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1. Introduction

Soil organic carbon (SOC) is the largest C pool in the terrestrial ecosystem [1]. It plays a critical role in soil quality, fertility, and greenhouse gas emissions [2,3]. A slight change in SOC turnover at a global scale would have the potential to influence food and climate security [4]. Labile organic C input (e.g., plant litter or exudates) into soil stimulates the decomposition of SOC, known as the priming effect [5]. The straw return is considered an effective way to increase the SOC; meanwhile, it can induce SOC decomposition in the agricultural ecosystem [6]. An agricultural SOC change has an important impact on the terrestrial carbon cycle [6]. Therefore, SOC mineralization in the agricultural ecosystem has been paid much attention by related researchers around the world [7,8].

The studies investigating SOC mineralization have been increasing since the priming effect was observed by Löhnis (1926), and 70% of priming effect studies have been performed over the last ten years [9]. These studies vary in experimental conditions, soil properties, and the quality and quantity of input C, leading to some inconsistent or incomparable results. Some reviews have been performed to integrate the results of the large body of SOC dynamic studies. For the priming effect, Kuzyakov et al. (2000) overviewed the different potential mechanisms, among which the changes in microbial activity and biomass were the most important [5]. Blagodatskaya et al. (2008) found that the magnitude of the priming effect depended on the quantity and quality of exogenous C, microbial biomass, community composition, enzyme activities, soil pH, and aggregate size [10]. The latest study underlined the abiotic mechanisms controlling SOC mineralization and proposed different scenarios to describe the influence of SOC decomposition on ecosystem services under climate change conditions [9]. Overall, the biotic activities and abiotic processes play an important role in agricultural SOC change [11,12]. Straw input can effectively promote the SOC content, improving the soil quality and crop yield in an agricultural ecosystem. High-throughput technology has been suggested for use in quantitatively estimating the microbial role in the soil C cycle [13]. These reviews can only synthesize the knowledge regarding SOC mineralization for some specific aspects. However, the studies investigating agricultural SOC mineralization are multi-disciplinary, including agricultural, environmental, ecological, and soil science, as well as geosciences, and its development among a large volume of publications has not been quantitatively analyzed.

Bibliometric analysis can qualitatively and quantitatively analyze the bibliometric data (e.g., units of publications and citations) based on mathematical statistics, revealing evolutionary nuances and emerging areas in a specific discipline or field [14]. Scientometrics citation analysis combined with information visualization technology provides researchers with an understanding of the knowledge within a field. A comprehensive overview of the studies involving a certain field can be created by describing the knowledge base, characteristics, and trends after bibliometric analysis. This technique has been widely used in recent years [15]. For example, Pan et al. (2021) conducted a study to investigate the research trends in soil nutrients, analyzing the leading journals, institutions, and countries, as well as identifying the hot topics in this field. Mao et al. (2018) investigated the research trends in contaminated soil remediation and identified the hotspots and developing trends, providing guidance for future research directions [16,17].

This study uses bibliometric analysis and visualization technology to (1) identify the basic characteristics of the literature, such as the number of articles and citations, research subject categories, and representative journals; (2) identify the research power of this field, such as representative countries, institutions, and authors; (3) uncover the research topics and changing trends in research hotspots over time; and (4) identify potential research directions for future research. The results provide a comprehensive insight into the agricultural SOC mineralization for researchers, which is important for the development of their study.

2. Materials and Methods

2.1. Data Collection

The literature was retrieved from the Web of Science Core Collection, which includes more than 12,000 influential academic journals and is widely considered an important database by global researchers. The Web of Science Core Collection is the world's leading interdisciplinary citation database and can provide the comprehensive data information required by bibliometrics analysis [18]. More importantly, the Web of Science Core Collection covers the authoritative international academic journals that publish literature involving the agricultural SOC dynamic. The indexed keywords and their combination in the title or abstract were "soil organic carbon or soil organic matter", "mineralization or decomposition or respiration or greenhouse gas", "input or addition or application", and "agriculture or cropland or farmland". The period considered was from January 2000 to

November 2022, during which agricultural SOC mineralization received attention from many researchers, and the involving studies were constantly expanding. Literature was included according to the following criteria: (1) the language was English; (2) the study had reported SOC mineralization in an agricultural ecosystem; (3) the literature type was an article; meetings, books and book chapters, online publications, reports, patents, thesis dissertations, abstracts, clinical trials, revisions, and other unspecified types of literature were excluded. A total of 3328 English articles were included from the Web of Science Core Collection and were exported as plain text files in the format of "full record and cited references" for bibliometric analysis (Figure 1).

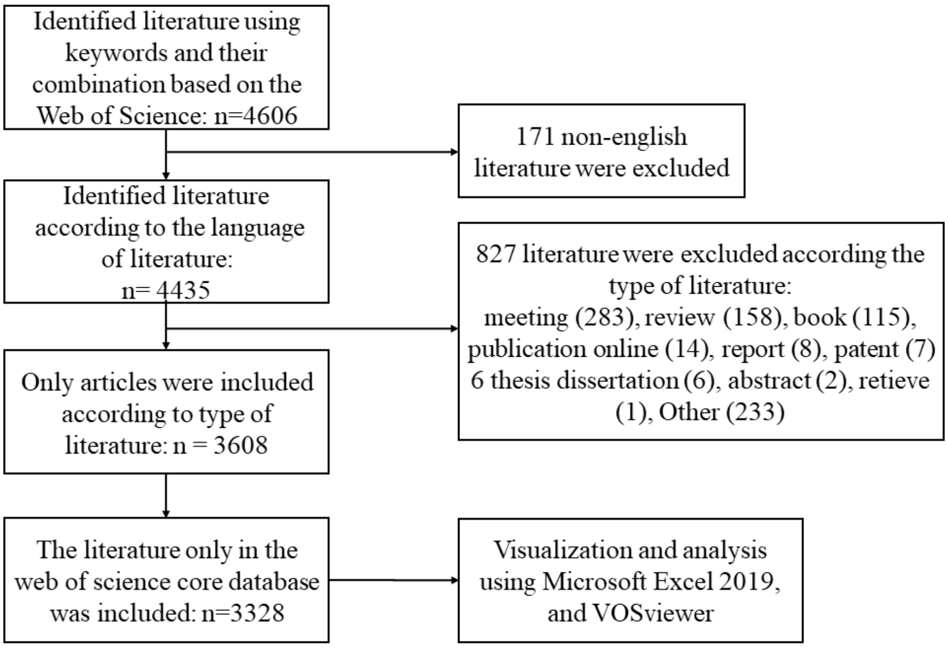

Figure 1. Flow chart of literature screening.

2.2. Data Analysis and Visualization

Academic cooperations play a critical role in the development of a research field. The network can show the cooperation relationship between countries/institutions/authors. The keyword analysis, including co-occurrence, cluster, and bursting analysis, can aid in identifying the hot topics and developments of a field. The cooccurrence network can show the relationships between topics and quantify the main research hotpots but may be complex and overlayed among nodes. Thus, clustering analysis was used to simplify the complex network into the relationship among several groups. Bursting keywords are those that show a sharp increase in frequency, indicating topics that were paid particular attention during a specific period and can be found using bursting detection. The bursting keywords can be used to identify research frontiers and predict research trends.

CiteSpace is free software and can be used to analyze the information within the literature, presenting the structure and distribution of the knowledge in a field via bibliometric maps [19]. We used CiteSpace (6.1 version) to remove the duplicates and then analyze the network of countries, institutions and authors, as well as the co-occurrence, cluster and burst analysis of keywords. The parameters in CiteSpace were set as follows: (1) time slicing from 1900 to 2022, years per slice = 1; (2) term source = title, abstract, author keywords; (3) node type = country or institution or author or keyword; (4) the selection uses a modified g-index in each slice. We can include or exclude some nodes through changing the proportional factor. In this study, the proportional factor was set as 5 in the collaboration or co-occurrence analysis to clarify the relationships between nodes in the network. Other parameters, such as links, were set to default. In the network, the size of the node reflects the frequencies of co-occurrence; and the links indicate the co-occurrence relationships between countries/institutions/author. The color of the node and line vary from gray to red as time passes from 2002 to 2021. The centrality was used as an indicator of the importance of countries/institutions/author in the studies of agricultural SOC mineralization. An institute or author is important and has a great influence on the development of a research field when the centrality is greater than 1.

VOSviewer is another free computer program widely used for bibliometric maps [20]. We used VOSviewer (1.6.18 version) to analyze the co-occurrence of Journal, which cannot be analyzed by the CiteSpace version we used. The parameters in the VOSviewer were set as follows: (1) citation: sources; (2) the counting method was set to full counting; (3) the minimum number of journals per document was set at 20 to ensure the clarity of nodes and links. The other parameters were set to default. In the network of journals, a bigger node represents a more important journal, the color represents the cluster of journals, and the lines indicate the link between journals. The total link strength indicates the co-occurrence frequency between one and another journal.

The cooperation and co-occurrence network of countries, institutions and authors, as well as the timeline of keywords, were plotted by CiteSpace. The cooccurrence network of journals was plotted by VOSviewer. Both software tools can present the amount of literature and number of citations from each country. We plotted the graph of the number of articles and the frequency of citations using Origin 2019 and listed the key information of the top 10 items (subject, journal, country, institute and author) in the tables.

To estimate the relative effort and influence made by a country in a given year, we calculated the activity index (AI) (Equation (1)) and the attractive index (AAI) (Equation (2)) [21]. A value of 1 for either index indicates that the research effort or academic influence of a particular country is equivalent to the global average level. An AI above or below 1 indicates that the research effort of a country is higher or lower than the global average research effort. An AAI above or below 1 indicates that the number of citations attracted by a country is higher or lower than the global average citation.

$$AI = \frac{P/\sum P}{TP/\sum TP} \tag{1}$$

$$AAI = \frac{C/\sum C}{TC/\sum TC} \tag{2}$$

where AI and AAI indicate the activity and attractive index of a country, respectively, in a given year. P and C represent the number of articles and citation frequency of a country in a year. TP and TC indicate the global number of articles and citation frequency in a year. $\sum P$ and $\sum C$ indicate the total number of articles and cited frequency in a country during 2000–2022. $\sum TP$ and $\sum TC$ indicate the global number of articles and citation frequency during 2000–2022.

3. Results and Discussion

3.1. Quantity of Articles and Citations

The number of English articles on agricultural SOC mineralization was 3328, with an average of 142 per year over the last 22 years based on the Web of Science Core collection (Figure 2). The number of articles increased steadily from 2000 to 2022, with a higher increase rate during 2000–2003 (the average rate = 34%) than during 2011–2021 (the average rate = 9%), while a slight change was observed during 2004–2012. These results suggest that studies investigating SOC mineralization in the agricultural ecosystem are currently in their development stage and have great potential. The number of articles exceeded 200 per year for the first time in 2018. A potential reason could be the pandemic because the pandemic began in 2019, particularly in China, which is one of the countries that contributes the most articles.

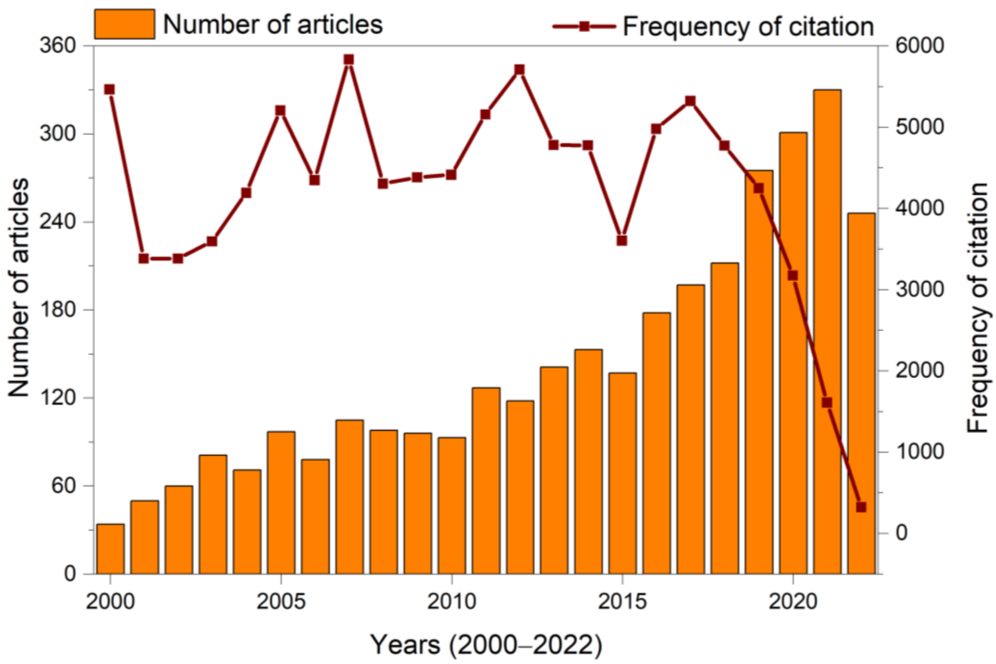

Figure 2. Trends in the number of articles and cited times identified by the Web of Science core dataset.

The frequency of citations per year changed to a different extent and the cumulative cited frequency was 97,002 over the last 22 years, with a maximum of 5836 (in 2007) and a minimum of 323 (in 2022) (Figure 2). The number of citations sharply decreased after 2017, although that of articles increased. The cited frequency of an article is related to its topic, the time of publication, and the influence of the journal. The decrease in citation frequency after 2017 was most likely attributed to two factors: (1) the delay in citation relative to publication and (2) an increased number of published articles during the COVID-19 pandemic between 2019–2022. These results suggest that the number of articles combined with their cited frequency can serve as a useful indicator of the development of a certain field.

3.2. Subject Categories Analysis

The top 10 subjects were screened and presented in Figure 3. During the selected period (2000–2022), the top three subjects were agriculture, environmental science ecology, and plant sciences, accounting for 23%, 20%, and 16% of the articles, respectively. The remaining seven subjects were chemistry, meteorology atmospheric sciences, biodiversity conservation, science technology other topics, business economics, public environmental occupational health, and biochemistry molecular biology. These results indicate that agricultural SOC mineralization has captured the attention of researchers from various disciplines and fields. Notably, the order of the subjects was not immutable. Agriculture, environmental science ecology, plant science, and chemistry were always among the top four, with the same order between subjects over the past two decades. Biochemistry molecular biology ranked 5th in the first ten years but 10th in the second ten years. Nutrition dietetics and forest only appeared from 2000 to 2010, and meteorology, atmospheric sciences, and business economics only from 2011 to 2022.

The number of articles related to a specific subject indicates the research trend involving agricultural SOC mineralization across different disciplines. Agriculture, environmental science ecology, and plant sciences have paid considerable attention to the research of agricultural SOC mineralization compared to other subjects in the top 10 because of the potential impacts of the SOC dynamic on environmental quality and plant growth [22]. Some new subjects, such as microbiology and business economics, have also focused on agricultural SOC mineralization, likely due to advancements in measuring microbial community. For example, DAN-based stable isotope probing and metagenome help to understand the microbial process involving in SOC dynamic [23]. These changes in subjects over the last 22 years underscore the need for interdisciplinary efforts to improve the research in agricultural SOC mineralization.

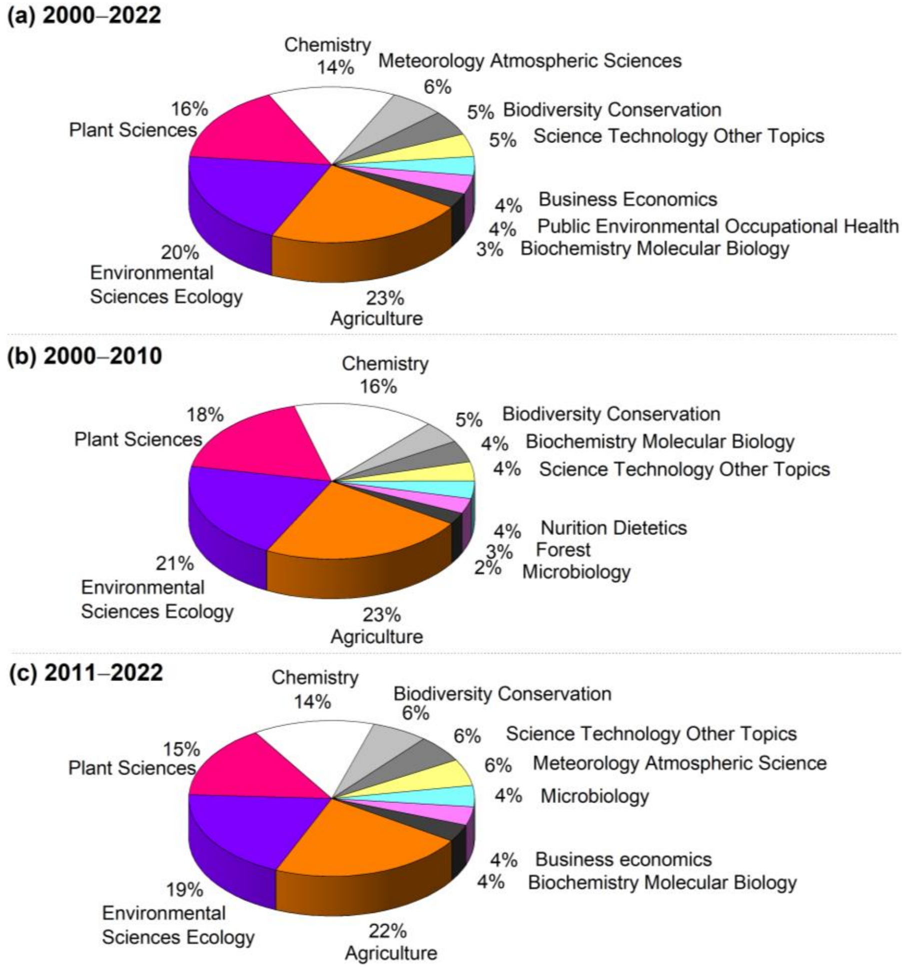

Figure 3. The percentage of the number of articles in a subject relative to the total amount of articles in the top 10 subjects during the last 22 years (**a**) and the first decade (**b**) and second decade (**c**).

3.3. The Related Journal Analysis

The articles related to agricultural SOC mineralization appeared in 411 journals, and the top 10 were listed in Table 1 based on the number of articles. *Soil Biology & Biochemistry* ranked first in the number of articles, total link strength and citations, while *Science of the Total Environment* ranked first in updated and average impact factor in five years and CiteScore. Taken together, considering the total link strength, citation, and impact factor, *Soil Biology & Biochemistry* plays an important role in scientific communication related to agricultural SOC mineralization.

The citation-source network consists of 11 clusters and 37 notes (Figure 4). *Soil Biology & Biochemistry* acted as an intermediary that linked 10 journals such as *Soil Science Society of American*; *Soil & Tillage Research*, and *Agriculture, Ecosystems & Environment*. *Soil & Tillage Research* linked seven journals such as *Field Crops Research* and the *Journal of Environmental Management and Pedosphere*, with a primary focus on the effects of soil tillage on SOC dynamic in the field. The influential factor (IF) of a journal represents its role and status in certain scientific communication and were shown in Table 1. Thus, taken together, *Soil Biology & Biochemistry* is the most important journal in the field of agricultural SOC mineralization. The reason is that *Soil Biology & Biochemistry* published articles describing and elucidating biological processes occurring in the soil. In addition, it is an established journal that is widely recognized by experts in soil science worldwide.

Table 1. The top 10 journals related to the study of agricultural SOC mineralization, along with the number of articles and the key parameters used to estimate each journal.

Rank	Journal	Number of Articles	Total Link Strength	Cited Frequency	Average IF in Five Years	Citation Indicator in 2021
1	*Soil Biology & Biochemistry*	178	881	10,565	9.956	1.9
2	*Agriculture, Ecosystems & Environment*	155	670	6606	7.089	1.7
3	*Soil & Tillage Research*	123	531	5074	7.829	1.59
4	*Geoderma*	154	524	4042	7.444	1.66
5	*Biology and Fertility of Soils*	100	413	3800	7.116	1.5
6	*Applied Soil Ecology*	112	403	3451	5.678	1.16
7	*Plant and Soil*	109	397	3340	5.440	1.3
8	*Soil Science Society of America Journal*	99	390	4122	3.564	0.65
9	*Nutrient Cycling in Agroecosystems*	91	245	2074	4.504	0.8
10	*Science of the Total Environment*	98	245	1759	10.237	1.77

The total link strength indicates the co-occurrence frequency of one and another journal. IF, influential factor.

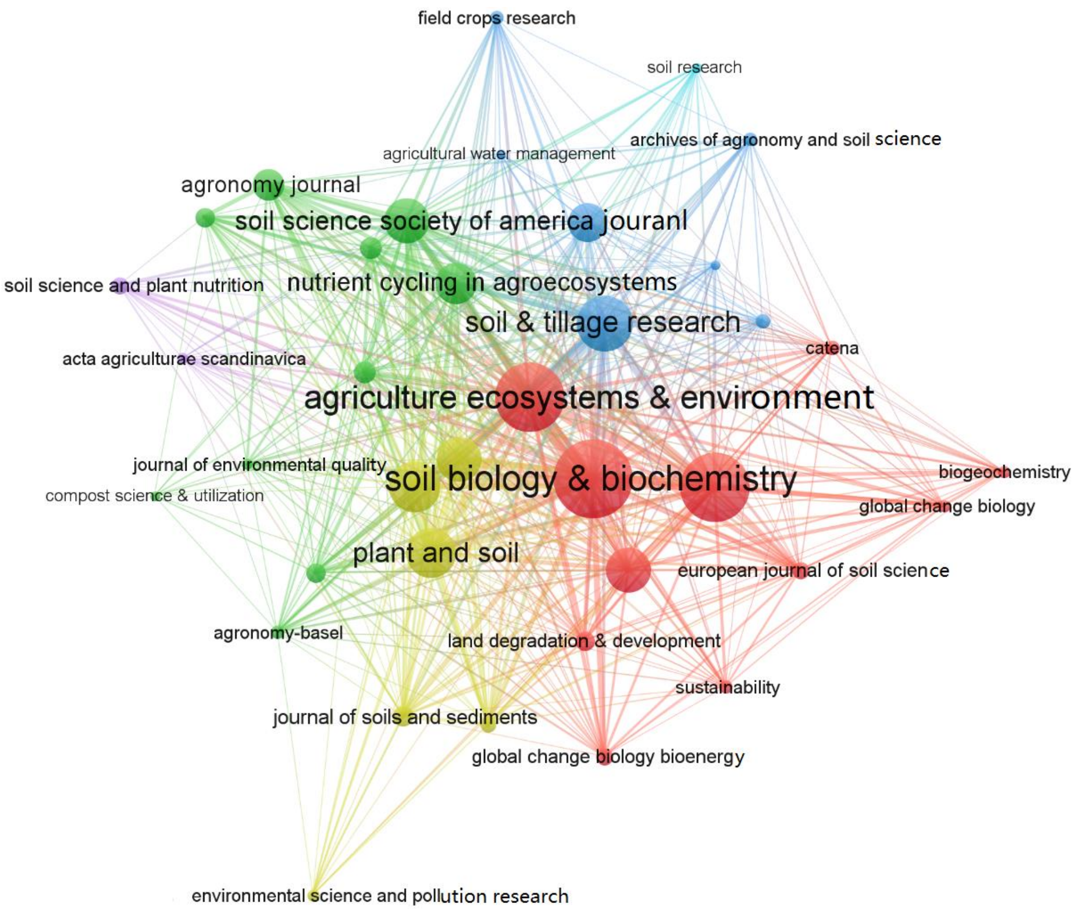

Figure 4. Network of journals including articles involving agricultural SOC mineralization. The bigger node represents that a journal is more important. The color indicates the cluster of journals. The lines indicate the link between journals.

3.4. The Development of Agricultural SOC Mineralization Research in the Top 10 Countries

There were 129 countries involved in the study involving agricultural SOC mineralization. The top 10 countries (the corresponding number of articles in the brackets) were China (820), the USA (659), Germany (311), Australia (226), India (209), Canada (205), Spain (160), France (151), Brazil (136) and Italy (131) (Figure 5a). The number of articles from China and the USA accounted for 45% of the number of total articles from all countries. China published more articles but had fewer citations than the USA, which had the highest average citation frequency per article in the last 22 years (Figure 5b). These results indicated the USA has a greater academic influence on the world due to its early development of soil science and its numerous high-level institutions and researchers. In contrast with the USA, China is a developing country, in which institutions and researchers face high economic and work pressure. The pressure may limit the investment of money or energy into research, leading to lower academic output and influence. These results also indicate that the studies involving agricultural SOC mineralization mainly concentrate in Asia, Europe, America, and Oceania.

The number of articles from the top 10 countries increased over time during the last 22 years (Figure 5c,d). The USA was always the largest source of articles before 2015, after which China was. The number of articles per year from China ranged from 2 to 18 before 2014, thereafter sharply increased, ranging from 32 to 137. China became the country that published the most articles at the fastest rate after 2015. The reasons for this are mainly as follows: (1) the greater financial and researcher's support in China, (2) the increased number of researchers and graduate students in China, (e.g., 326,687 Ph.D. in 2015 vs. 460,000 Ph.D. in 2020 in schools), (3) the creation of new international journals in the last 10 years. Meanwhile, the number of articles published by the remaining five countries in the top 10 fluctuated over time but showed and increasing trend overall.

The activity and attractive indexes changed over time and across countries, ranging from 0 to 2 except the attractive index of Braza in 2000 and 2001 year and of Canada in 2000 and 2001 year (Figure 6). Among the top 10 countries, the two indexes increased continuously over time only in China, with a similar rate between the two indexes, and were greater than 1 only after the 2016. The two indexes of the other nine countries changed to a different extent over time, ranging from 0 to 1. The activity index of China, Australia, Spain, and Italy was higher than their attractive indexes in most years (more than 11 years). Conversely, the activity index of India, France, and Brazil was higher than their attractive indexes in 11 years, while that of the USA, Germany, Canada was lower than their attractive indexes only in several years (less than 11 years). Moreover, the activity index of the USA fluctuated and was greater than 1 during 2000–2004 and in 2005, 2006, 2010, and 2011. The attractive index of the USA was always greater than 1 during 2001–2018 but less than 1 during 2018–2022.

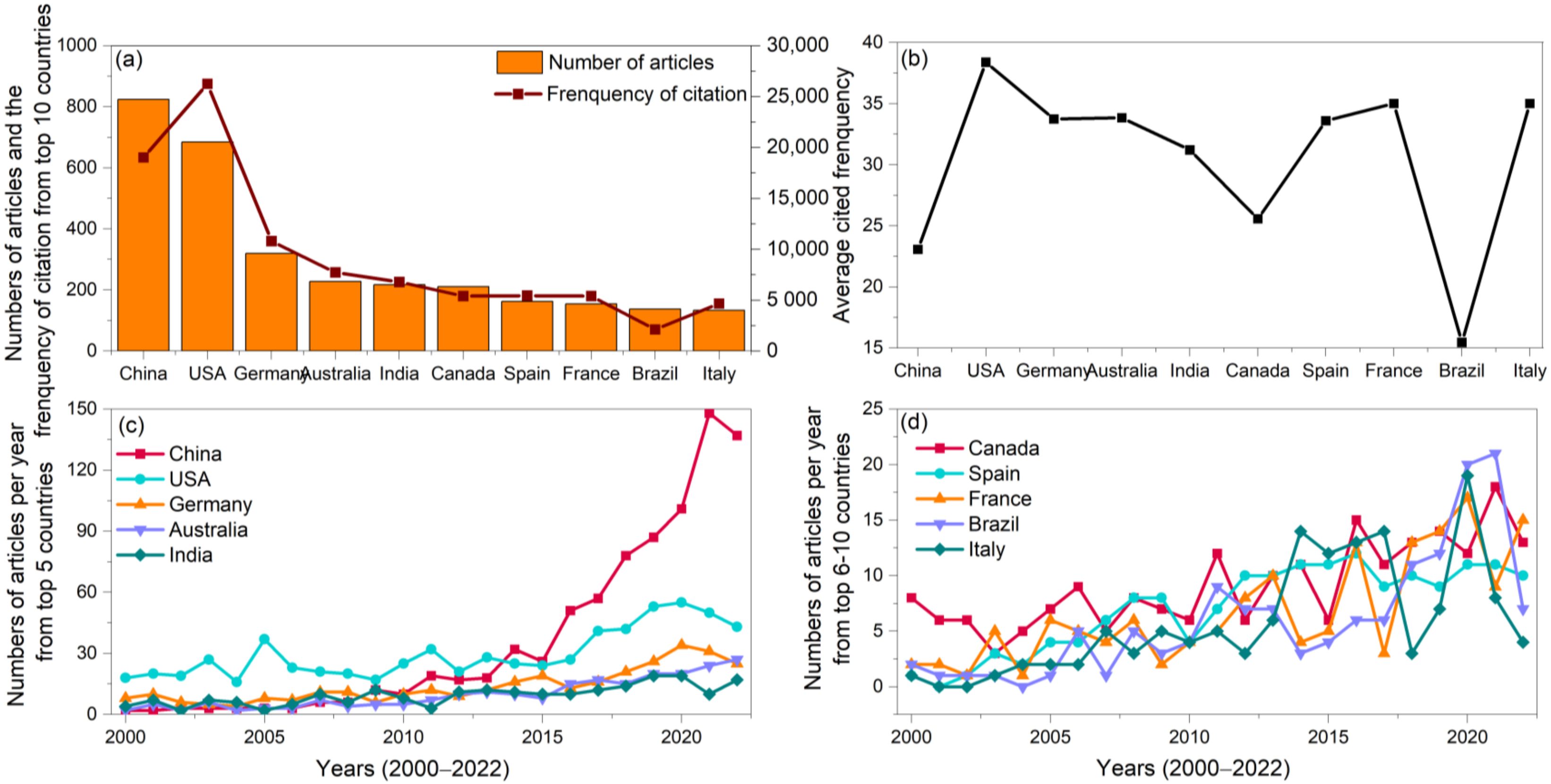

Figure 5. The number of articles and their cited frequency (**a**), the average citation frequency (**b**) from the top 10 countries, and the change in the number of articles per year from the top 5 and top 6–10 countries over time (**c**,**d**).

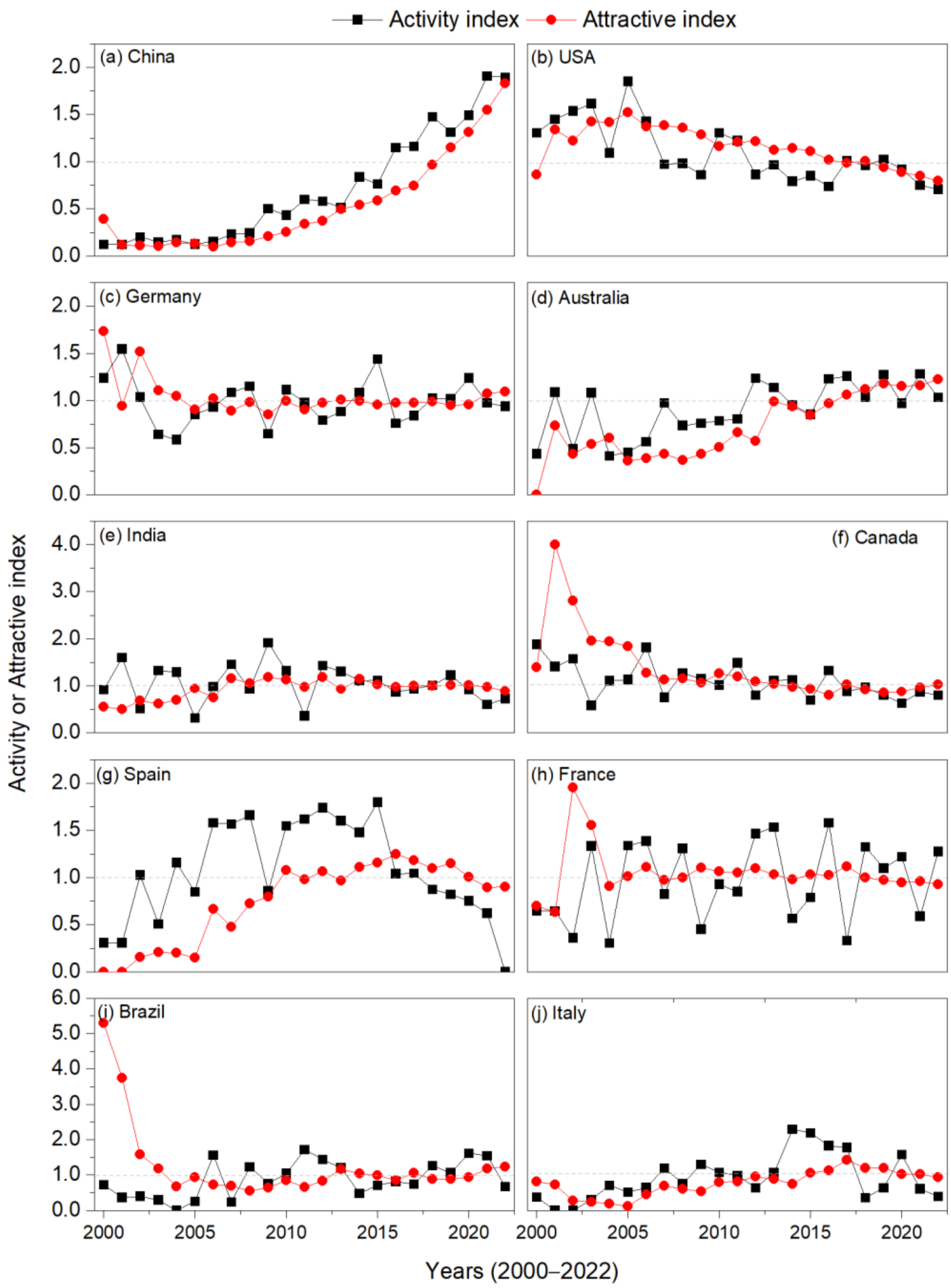

Figure 6. The activity and attractive index of the top 10 countries. The dotted line y = 1 represented that the research effort and academic influence of a country are the same as that of the global average.

3.5. The Academic Cooperation Relationship between Countries or Institutes

The cooperation network of countries consisted of 92 nodes and 612 links (Figure 7a). Among all countries, the USA and Germany had the highest centrality (0.24); followed by China (0.19); Australia (0.14); England (0.12); Switzerland (0.10); Italy, the Netherlands and Japan (0.08); and Belgium (0.07). China, which was the largest source of articles, had cooperated with 41 countries and had the closest relationship with Japan. The USA had established close cooperation with almost all the countries such as China, Germany, India, the Netherlands, and Russia. These results indicated that China contributed the most to the number of articles but had less influence in collaborative networks.

For the institutions, the Chinese Academy of Sciences published the most articles (395), accounting for 12.0% of the total amount of articles (Table 2). The other institutions in the top 10 were listed in Table 2. Five institutions in the top 10 were from China and published

19.7% of the number of articles, while three institutions were from the USA, publishing 4.7% of the number of articles. The remaining institution was from Spain, only publishing 1.2% of the number of articles.

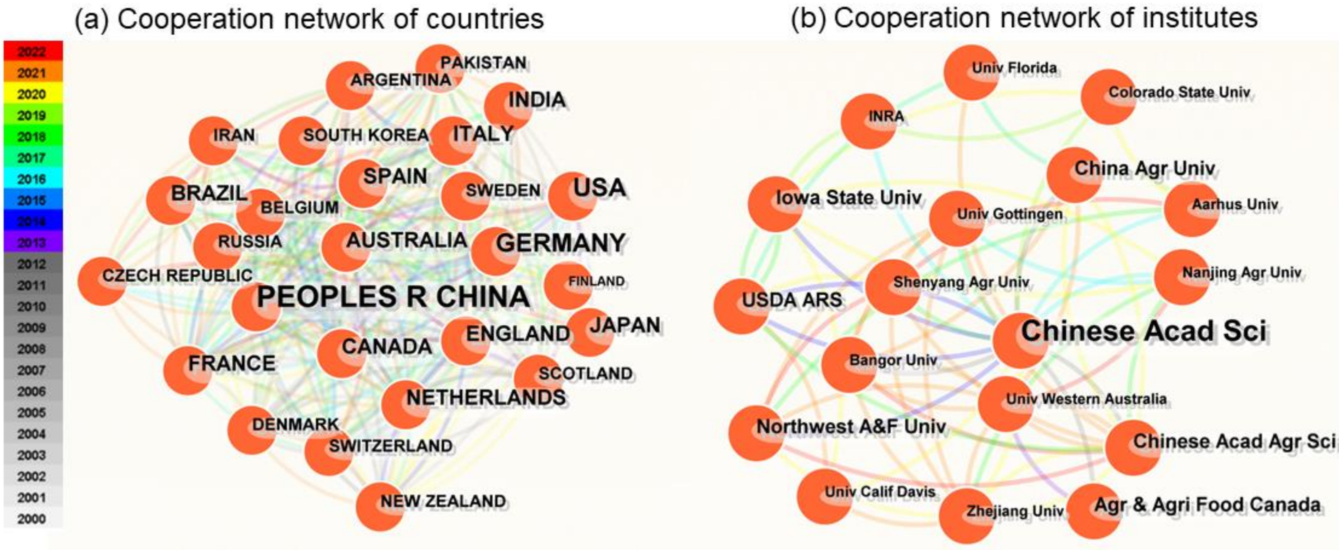

Figure 7. The network of countries (**a**) and institutions (**b**). The size of the country's/institution's name reflects the co-occurrence frequencies. The links indicate the co-occurrence relationships of countries/institutions. The color of the nodes and lines varied from gray to red as shown in the legend, from 2000 to 2022. The wider lines represent stronger cooperation of authors.

Table 2. The top 10 institutes related to the study of agricultural SOC mineralization and their key information.

Rank	Institute	Articles	Percentage	Centrality †	Country
1	Chinese Academy of Sciences	395	12.0%	0.43	China
2	Chinese Academy of Agricultural Sciences	88	2.6%	0.04	China
3	USDA-agricultural research service	79	2.4%	0.07	USA
4	Northwest A&F University of China	75	2.2%	0.04	China
5	Agriculture & Agri-Food Canada	72	2.1%	0.09	Canada
6	China Agricultural University	62	1.8%	0.07	China
7	Iowa State University	41	1.2%	0.02	USA
8	Spanish National Research Council (CSIC)	40	1.2%	0.04	Spain
9	University of California Davis	39	1.1%	0.04	USA
10	Zhejiang University	38	1.1%	0.01	China

† The centrality is an indicator representing the importance of an institute in a research field. An institute is important and has a great influence on the development of a research field when the centrality is greater than 1.

The network of institutions consisted of 195 nodes and 416 links (Figure 7b). The first principal institution was led by the Chinese Academy of Sciences, with the highest centrality (0.43) among the top 10 productive institutions. The top 10 institutions in terms of centrality were the Chinese Academy of Sciences, Agriculture & Agri-Food Canada, INRA, Colorado State University, China Agricultural University, Rothamsted Research, Bangor University, Aberdeen University, and Katholieke University Leuven. Zhejiang University ranked in the top 10 in the number of articles, but its centrality was lower than some institutes that produced more articles such as Colorado State University. The Chinese Academy of Sciences cooperated with many institutions, such as the University of California Davis and Colorado in the USA, the University of Adelaide and Queensland in Australia, the University of Paris Saclay in Paris, and Peaking University in China.

3.6. Authors Analysis and Their Academic Cooperation

A total of 12,977 authors participated in the study involving agricultural SOC mineralization. The top 10 authors in the number of articles were listed in Table 3. Ge Tida, Wu Jingshui, and Zhu Zhenke were from China, with Ge Tida working at the University of Ningbo and the latter two authors at the University of Chinese Academy of Sciences. Kuzyakov Yakov and Joergensen Rainer Georg came from the University of Göttingen and Kassel in Germany. Six John and Castellano Michael J. were from the University of Colorado State and Iowa State in the USA. OK Yong Silk and Jones Davey L. were from the University of Sejong in South Korea and the University of Western Australia in Australia, respectively.

The network of authors consisted of 245 nodes and 168 collaborative links. Among the top 10 most productive authors (Table 3), Yuzyakov Yakov and Chang Scott X. ranked in the top two in terms of centrality. The main cooperation of authors was mainly after 2015 (Figure 8). Kuzyakov Yakov had the strongest cooperation relationship with 20 authors such as Gunina Anna, Blagodatskaya Evgenia, and Wu Jingshui. Their cooperating work mainly focused on the effect of cropping systems and land use and C input on SOC stock [24,25], the processes of SOC formation and transformation, and the decomposition of SOC following organic C input [10,26,27]. Both Ge Tida and Wu Jinshui cooperated with Zhu Zhenke, Guggenberger Georg, and Kuzyakov Yakov, mainly focusing on the SOC mineralization and sequestration in the paddy and the microbial and abiotic mechanisms [28–30]. Chang Scott X. showed no links in the network, focusing on the soil N mineralization and its relationship with SOC change and the effect of biochar amendment on SOC storage [31–33].

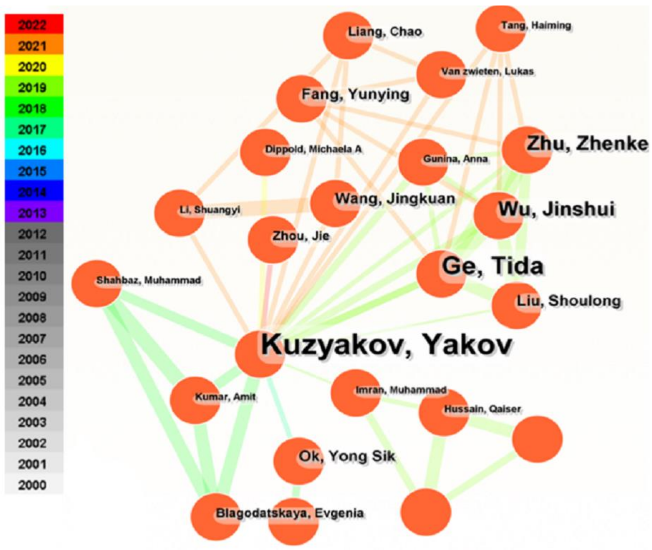

Figure 8. The cooperation network of authors. The size of the author's name reflects the co-occurrence frequencies. The links indicate the co-occurrence relationships of authors. The color of the node and line varied from gray to red as time passes from 2000 to 2022. The wider lines represent stronger cooperation of authors.

Table 3. The top 10 authors in terms of related studies and their key information.

Rank	Author	Institution	Country	Articles	Centrality †
1	Kuzyakov Yakov	University of Göttingen	Germany	36	0.01
2	Ge Tida	Ningbo University	China	21	0.00
3	Wu Jinshui	Institute of Subtropical Agriculture, Chinese Academy of Sciences	China	12	0.00
4	Joergensen Rainer Georg	University of Kassel	Germany	8	0.00
5	Zhu Zhenke	Institute of Subtropical Agriculture, Chinese Academy of Sciences	China	8	0.00

Table 3. *Cont.*

Rank	Author	Institution	Country	Articles	Centrality †
6	Chang Scott X.	University of Alberta	Canada	8	0.01
7	Ok Yong Sik	University of Sejong	South Korea	8	0.00
8	Six John	University of Colorado State	USA	8	0.00
9	Castellano Michael J.	Iowa State University	USA	7	0.00
10	Jones Davey L.	University of Western Australia	Australia	7	0.00

† The centrality is an indicator representing the importance of an author in a research field. An author is important and has a great influence on the development of a research field when the centrality is greater than 1.

3.7. Keywords Co-Occurrence, Clusters, and Evolution Analysis

There are 10,677 keywords occurring in the articles involving agricultural SOC mineralization, among which 112 keywords had a frequency of more than 16. The top 10 keywords in terms of the occurrence frequency were organic matter (760), nitrogen (689), decomposition (671), carbon (607), microbial biome (587), mineralization (538), dynamics (492), management (473), matter (330), and sequestration (300).

The top five clusters in terms of size are listed in Table 4. The main keywords included in the cluster of "Carbon sequestration" were organic matter, soil enzyme activity, nitrogen use efficiency, mineralization rate, and soil fertility. In this cluster, researchers mainly focused on the effect of nutrition and C addition on SOC mineralization and microbial activity. Nutrition addition has been demonstrated to increase the SOC during long-term field experiments [34]. Moreover, split N and P application has been demonstrated to decrease SOC mineralization compared with full N and P application using an incubation experiment [35]. The effect of nutrient addition on SOC mineralization was related to the increased microbial biomass, enzyme activity, and microbial use efficiency [36,37]. The main keywords in the "soil organic carbon" cluster were organic carbon, microbial biomass, carbon isotopes, soil constraints, and N uptake. In this cluster, researchers mainly investigated how soil stoichiometry influences SOC change through a changing microbial biomass and N limitation using the stable isotope method [38,39]. The SOC concentration and pH were the key constraining factors of SOC turnover [40] because pH may regulate the soil microbial community composition and the SOC was an important C and nutrient resource of microbes [41,42]. The main keywords in the cluster of "system" were organic carbon, dynamics, system, total nitrogen, and cover change straw. The researchers mainly investigated the effect of straw return or cover on SOC and N dynamics, depending on returning modes and soils [43,44]. For example, straw returning increased more straw-derived C sequestration in the subsurface soil than in surface soil [45]. The main keywords in the cluster of "enzyme activity" and "microbial biomass" were microbial biomass, growth-promoting rhizobacteria, plant yield, soil food web and ecological significance, microbial biomass, soil quality, conservation agriculture, microbial respiration, and free-living nematode. The researchers in the two clusters mainly focused on the biotic processes in soil, especially the role of microbes and nematodes, and other small animals in SOC mineralization [46,47]. The microbial community composition and their C use efficiency and growth rate were the drivers of SOC change [48]. Compared with bacteria, fungi have an advantage in utilizing recalcitrant SOC due to its high C:N and mycelia [49]. The microbes with high C use efficiency and growth rate may produce more enzymes and necromass, influencing SOC decomposition and formation [50,51].

The timeline of keywords showed that sequestration, dynamics, mineralization, decomposition, and organic C were predominant topics of agricultural SOC mineralization during 2000–2005 (Figure 9). Additionally, the researchers focused on the SOC dynamic and sequestration under different methods of soil management and tillage and identified microbial regulations. In the last 7 years, more attention was paid to the decomposition of SOC and its mechanisms, such as the effect of nutrition on microbial decomposition of SOC.

Table 4. The top 5 clusters of the keywords and the included keywords of the top 5.

ID	Cluster Name	Size	Main Keywords (Top 5)
0	Carbon sequestration	46	organic matter; soil enzyme activity; nitrogen use efficiency; mineralization rates; soil fertility;
1	Soil organic carbon	41	organic carbon; microbial biomass; carbon isotopes; soil constraints; N uptake
2	System	38	organic carbon; dynamics; system; total nitrogen; cover change straw;
3	Enzyme activity	29	microbial biomass; growth-promoting rhizobacteria; plant yield; soil food web; ecological significance
4	Microbial biomass	20	microbial biomass; soil quality; conservation agriculture; microbial respiration; free-living nematodes

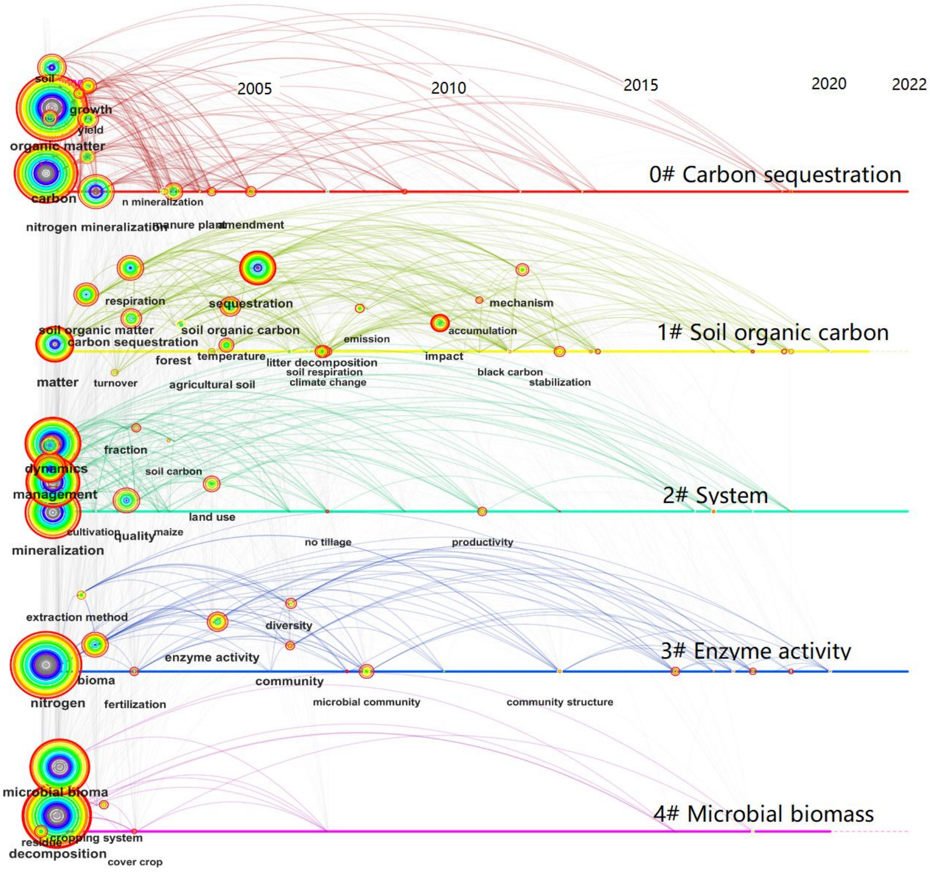

Figure 9. The timelines of keywords involving the study of agricultural SOC mineralization in five clusters. The size of the node reflects the co-occurrence frequencies. The links indicate the co-occurrence relationships between keywords, with a color representing a cluster of keywords. The keywords on or above straight lines listed from left to right according to time (from 2000 to 2022).

The bursting keywords in the last five years (2018–2022) along with their strength and occurrence timespan were shown in Table 5. The studies involving CO_2 efflux, China, C sequestration and storage, addition, black C, soil moisture, sensitivity, manure application, and straw incorporation emerged as active topics in recent five years. The increased CO_2 concentration in the atmosphere enhanced the primary production of plants and accelerated the SOC cycle through the input of plant-derived C into soils [52,53]. Straw is often used as the simulation of exogenous C to investigate the effect of plant-derived C on SOC change [54]. The studies investigating CO_2 flux within the plant–atmosphere–soil system benefit the understanding of SOC change and its feedback on the climate. China has developed quickly in economics, culture, and technology, attended the Paris climate agreement in 2016, and paid more attention to the research on SOC mineralization in recent years [55]. The sequestration of atmospheric CO_2 into SOC is an effective strategy to reduce the CO_2 concentration in the atmosphere, with the potential to mitigate climate change [4].

Table 5. Top 10 keywords with the strongest citation bursts and their key information.

ID	Keywords	Year	Strength	Begin	End	2018	2019	2020	2021	2022
1	CO_2 efflux	2018	3.13	2018	2019					
2	China	2018	2.78	2018	2019					
3	Carbon sequestration	2018	2.43	2018	2019					
4	Carbon storage	2018	2.43	2018	2019					
5	Addition	2018	2.43	2018	2019					
6	Black carbon	2018	2.10	2018	2019					
7	Soil moisture	2019	2.68	2019	2020					
8	Sensitivity	2019	2.41	2019	2020					
9	Manure application	2019	2.15	2019	2020					
10	Straw incorporation	2020	2.26	2020	2022					

Blue and red lines indicate the time interval and the period of a bursting keyword from beginning to end.

3.8. Articles Analysis with High Cited Frequency

Of the top 5 articles in terms of the average cited frequency per year (Table 6), three were published in *Soil Biology & Biochemistry*, and the other two were published in *Plant and Soil* and *Agriculture, Ecosystem & Environment*. The result was consistent with the results of a network of journals, indicating that *Soil Biology & Biochemistry* is the representative journal in the field of agricultural SOC mineralization research. The top five articles were from five different developed countries, indicating that the developed countries have a greater impact effect.

Table 6. The top 10 articles related to the study of agricultural SOC mineralization.

Rank	Average Cited Frequency per Year	Title	Authors (Year)	Country	Journal
1	89	Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils	Zimmerman et al. (2011)	France	*Soil Biology & Biochemistry*
2	65	Biochar-mediated changes in soil quality and plant growth in a three-year field trial	Jones et al. (2012)	UK	*Soil Biology & Biochemistry*
3	41	Decreased soil microbial biomass and nitrogen mineralization with Eucalyptus biochar addition to a coarse textured soil	Dempster et al. (2012)	Australia	*Plant and Soil*
4	38	Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments	Luo et al. (2010)	China	*Agriculture, Ecosystems & Environment*
5	36	Life in the 'charosphere'—Does biochar in agricultural soil provide a significant habitat for microorganisms?	Quilliam et al. (2013)	Scotland	*Soil Biology & Biochemistry*

Four articles of the top five in the cited frequency per year were involved in soil C or N changes after biochar amendment. For example, the top article had an annual citation frequency of 89 times. This study investigated the interaction of pyrogenic C and SOC using an incubation experiment over more than one year. Biochar addition increased or decreased the CO_2 emissions (positive or negative priming effect) in soils compared with unamended soils. The biochar produced at low temperatures induced a greater positive priming effect, especially in low-C soils. The high average cited frequency of the three studies indicates a growing interest in biochar as a method for increasing the soil fertility and sequestering atmospheric carbon over the last 10 years, along with the investigation of SOC changes after the biochar amendment. The fourth top article was cited 38 times annually. This study indicated that the effect of no-tillage on SOC sequestration was greatly dependent on the cropping system and the increased cropping frequency could benefit increasing the efficiency of SOC sequestration via a meta-analysis. These results suggest that the effect of biochar on the soil C cycle and its mechanisms have been the SOC research hotspot in recent years. The physical protection mechanism is an important potential mechanism inhabiting SOC mineralization and should be paid more attention in future studies.

Although this study has identified the basic characteristics, research output and knowledge base as well as the research trends regarding agricultural SOC mineralization, it had the following shortcomings. First, we investigated the research trend of agricultural SOC mineralization by using bibliometric analysis, which is a quantitative approach that focused on publication and citation data. Thus, this study may not capture the full breadth or quality of agricultural SOC mineralization research and may overlook important qualitative aspects such as study design, data collection methods, and the impact on policy or practice. The qualitative aspects could be obtained by meta-analysis in future studies. Second, we only included the studies involving agricultural SOC mineralization during 2000–2022. Although the chosen databases and period did not include all periods, introducing a bias in the sample and favoring certain types of studies or topics, the studies involving agriculture

SOC mineralization are mainly in the last 20 years and the selected databases (Web of Science Core Collection) included high-level studies recognized by global researchers.

4. Conclusions

This study provides a unique snapshot of the knowledge domain involved in agricultural SOC mineralization based on the data source from the Web of Science Core Collection. The number of articles continuously increased from 2000 to 2022, especially in the last seven years. The top three subject categories are Agriculture, Environmental Sciences Ecology, and Plant Sciences. *Soil Biology & Biochemistry* is the top journal in terms of its influential effect. The USA is the main cooperation center among countries. The number of articles from China sharply increased after 2018 and far more than that of other countries; thus, China was able to play an important role in the evolution of agricultural SOC mineralization research. The top five articles in terms of the citation frequency were involved in SOC dynamics following biochar addition and the effect of no-tillage on SOC, which would become hotspots in recent years. Physical protection is an important way to stabilize SOC, which benefits alleviating greenhouse gas emission. However, the mechanisms of physical protection of agricultural SOC mineralization remain largely unexplored. The effects of soil mineral composition and activity and their interaction with the microbial community on SOC change should be explored in future research.

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