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Review

# Research Progress on the Impact of Land Use Change on Soil Carbon Sequestration

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**Abstract:** Land use change is the most important driving factor of terrestrial carbon stock change. Soil is the largest carbon reservoir of terrestrial ecosystems, and the impact of land use change on soil carbon sequestration is related to major issues such as the global warming process and food security. The research can provide a basis for land managers and policy makers to develop appropriate planning strategies for soil carbon sequestration management. Despite the widespread attention of relevant studies, macro reviews are still lacking. In order to objectively reveal the current situation of the research field, firstly this paper conducted a bibliometric analysis based on relevant papers in the Web of Science Core Collection database from 1985 to 2021. Secondly, we conducted a review study of land use change on soil carbon sequestration. The research results showed that: (1) the overall amount of the published literature in related fields showed an upward trend, and the development could be divided into three stages, growing slowly from 1985 to 1999, steadily from 2000 to 2009, and rapidly from 2010 to 2021. (2) From the perspective of national distribution, the published papers were mainly from the United States and China, which were much higher than those in other countries. There was mutual cooperation between research institutions in different countries and on a certain scale. (3) Since 2000, soil carbon sequestration has been more frequently mentioned in articles on land use change. Related research was mostly focused on exploring the impact of different land use types and different farming methods on soil organic carbon content in the context of global warming. Land use change and management among agricultural land, woodland, and grassland are the focus of research. The conversion of woodland to agricultural land and grassland is an important reason for the decrease in soil carbon sequestration. Corresponding management measures can be taken to improve soil carbon sequestration. Future research should use multidisciplinary technical means and methods to further explore the interaction mechanism between climate change, land use change, and soil carbon sequestration, so as to carry out more accurate prediction and assessment of different climate scenarios.

**Keywords:** land use; soil carbon sequestration; bibliometrics; Bibliometrix



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## 1. Introduction

Soil is the largest carbon reservoir of the terrestrial ecosystem [1], which is larger than that of the atmospheric and biological carbon reservoirs combined [2,3]. Soil is also an important part of the earth's terrestrial ecosystem and is closely related to multiple life activities [4]. Plants feed the photosynthesis products of water into the soil in the form of litter and root exudates, and the soil organic matter releases carbon dioxide ($CO_2$) into the atmosphere under the action of microorganisms [5]. Small changes in the input and output of soil carbon stocks may greatly affect the atmospheric $CO_2$ concentration, which affects the global warming process [6]. Soil carbon sequestration plays an important role in alleviating the positive feedback between terrestrial carbon and climate [1,4]. On the other hand, soil carbon sequestration is a natural and environmentally friendly process, and it also provides a solution to the global problem of improving soil quality and achieving food security [7]. In view of this, increasing research focuses on the importance of soil carbon sequestration.

Since the 1990s, land use/cover change (LUCC) research has become a hotspot of geography and related disciplines and is also the core area of global environmental change [8,9]. At present, LUCC is an important man-made driving force of the carbon cycle in the terrestrial ecosystem. Over the past two centuries, land use changes have caused a net loss of carbon in the soil [7]. According to the Intergovernmental Panel on Climate Change (IPCC), 1.6 Pg C is emitted into the atmosphere from LUCC every year, and LUCC is the second largest atmospheric carbon source [10,11] after fossil fuel combustion (7.2 Pg C). Nearly 20% of atmospheric carbon dioxide emissions come from soil carbon banks under land use changes [12,13]. Soil may act as a carbon source or a carbon sink, depending on the ratio between inflow and outflow, and land use changes can directly or indirectly affect changes in soil carbon sequestration [14,15]. In the process of transforming from a natural ecosystem to an agricultural ecosystem, the change of land use mode greatly causes the soil carbon stock to significantly drop [2], and even causes the problems such as soil quality and biological yield [16], threatening the global food security problem [17,18]. Therefore, it is of great significance to study the effect of LUCC on soil carbon sequestration.

Bibliometric analysis is a quantitative analysis method [19]. Through statistical analysis of a large number of literature data, the data matrix is constructed according to the external characteristics of the literature, which is used to study the distribution characteristics, quantitative relationship, and change rules of the literature, and then visualize the relationship between information units or groups [20]. Different from other methods, bibliometric analysis can objectively and systematically analyze the hot topics and development trends in the research field. At present, this method is gradually developed and widely used in exploring the development trends of disciplines. For example, based on bibliometric analysis, Xu et al. explored the influencing factors of soil carbon change and future research hotspots [21], Li et al. analyzed the research trends of global forest carbon sequestration [22], and Sun et al. analyzed the characteristics and trends of industrial structure and carbon emission research [23]. The study of soil carbon sequestration is widely concerned worldwide, but as an important driver there is still the lack of a review of research on the impact of land use change on soil carbon sequestration.

A comprehensive understanding of the impact of land use change on soil carbon sequestration is of great significance to address issues such as easing global warming processes and ensuring global food security. Despite the wide attention of related research, a macro review is still lacking. Therefore, based on the Web of Science Core Collection database and the bibliometrix software package in R language, this study systematically reviewed the published papers from 1985 to 2021 in order to clarify the development of existing research and better grasp the future development trend. Based on this, we will conduct a review study of land use change on soil carbon sequestration. This study aims to address the following scientific questions: (1) What kind of trends and laws do the relevant literatures show? (2) What is the impact of land use/land cover change on soil carbon sequestration? (3) What are the future research hotspots and directions in this field?

## 2. Data Sources and Methods

### 2.1. Data Sources

Web of Science is a large-scale comprehensive, multidisciplinary, core journal citation index database, and is also an important database for obtaining global academic information. The data presented in this paper were derived from the Web of Science Core Collection database. The search method was the Topic Subject (TS) search. Using the advanced retrieval tools, with the themes of "Land use/land cover change" and "Soil carbon sequestration", we set the retrieval type to " (TS = (land use) OR TS = (land-use) OR TS = (land use) OR TS = (land utilization) OR TS = (land cover) OR TS = (land-cover)

OR TS = (LUCC) OR TS = (LULC) OR TS = (land use/cover) OR TS = (land use/land cover)) AND (TS = (carbon sink) OR TS = (carbon sequestration) OR TS = (carbon storage))". The literature search period ranged from 1985 to 2021. A total of 13,485 literatures were obtained through de-duplication, and the data were saved in text format.

### *2.2. Methods*

Bibliometric analysis enables a comprehensive overview of a large body of research literature and an objective identification of past and present research topics. Bibliometrix is a bibliometric software package developed based on the R language, with a more efficient statistical analysis capability and visualizing the results than other metrology software. In addition, the window interactive interface of the software reduces the user's threshold of use and is easy to operate. The specific workflow of the Bibliometrix software package mainly includes three steps: data collection, data analysis, and data visualization (Figure 1). The specific calculation method of the Bibliometrix software package can refer to the related research of Massimo and Corrado [24].

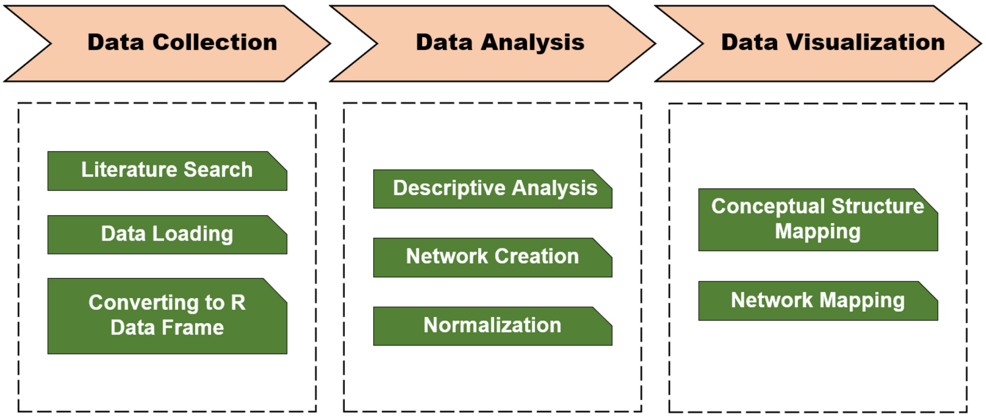


**Figure 1.** Bibliometrix workflow.

## 3. Results of Bibliography Analysis

### *3.1. Number of Annual Publications*

The number of published literature and its changes can reflect the degree of attention in the research field and is an important indicator to measure the progress in the field. From 1985 to 2021, the Web of Science core collection database included 13,485 documents (Figure 2), showing obvious stage characteristics. From the perspective of the overall change trend, the relevant research had roughly gone through three stages. The first stage was the slow growth stage (1985–1999), during which the number of documents was relatively small, with less than 100 articles published annually, and the growth trend was slow. The second stage was the steady growth stage (2000–2009), with more than 100 articles being issued every year, showing a steady growth trend. The third stage was the rapid growth stage (2010–2021), during which the number of documents issued further increased, accounting for 80.0% of the total number of sample documents, and showing an exponential growth trend. It can be seen that with the development of economy and society, the accelerated urbanization process, and the gradual emergence of global climate change and soil environment problems they brought, it had become the focus of scholars' attention.

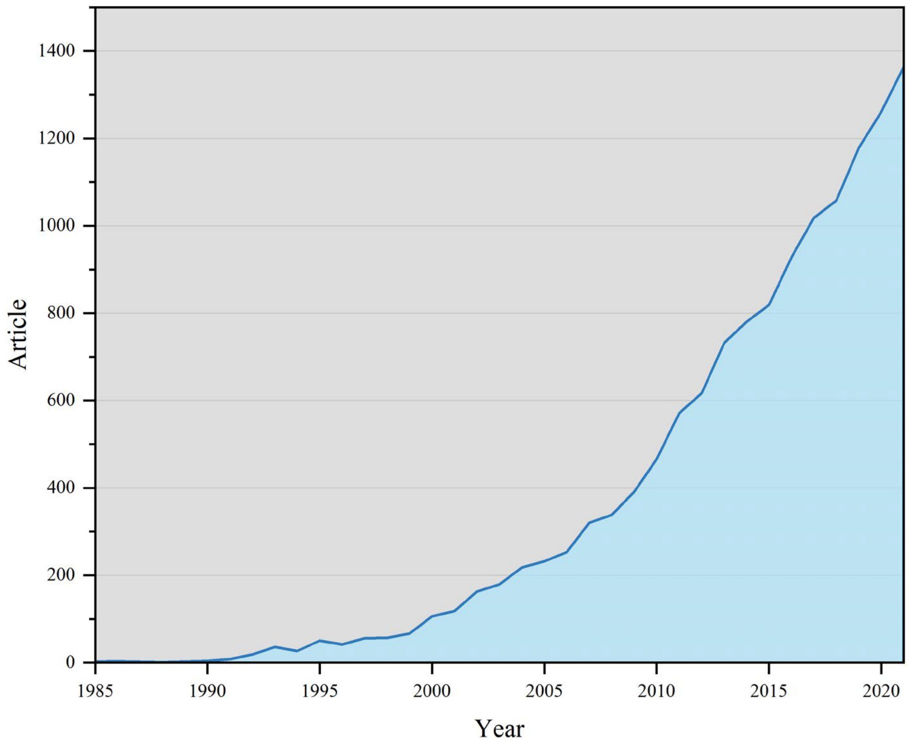


**Figure 2.** Impacts of Land Use Change on Soil Carbon Sequestration from 1985 to 2021.

### *3.2. Published Journals and High-Cited Literature*

#### 3.2.1. Published Journals and Subject Fields

According to the retrieval data, the number of articles published by each journal was counted, and the top 25 journals published from 1985 to 2021 were obtained. In addition, statistics were made on the domain, impact factor, and partition of journals (refer to the domain, impact factor, and partition information of journals in Clarivate Journal Citation Reports [25]) (Table 1). As can be seen from the statistical journal information, the journals covered ten disciplines, including environmental science, soil science, forestry, biodiversity conservation, and agronomy. Among them, the journals in the field of environmental science published the most articles at 1506 articles. The second field is soil science, all journals published a total of 808 articles. In terms of the journal impact factors and zoning, 96.0% of the journals belonged to the Q1 and Q2 divisions, and the journals were ranked at a high level. Among them, 19 journals belonged to Q1, accounting for 76.0% of the total number of journals included. The second was the Q2 division, with 5 journals, accounting for 20.0% of the total number of journals included.

From the publication volume, the top 25 journals had published more than 100 articles, and the top 5 journals had published more than 300 articles, which had a certain influence in this field. They were Global Change Biology, Science of the Total Environment, Agriculture Ecosystems & Environment, Geoderma, and Forest Ecology and Management (Table 1). Among them, the journal Global Change Biology ranked first with 431 articles, and its impact factor was also the highest among journals included, reaching 13.111, followed by Science of the Total Environment, with 379 articles and an impact factor of 10.237.

#### 3.2.2. Highly Cited Literature

Highly cited papers help identify breakthrough research within the field of study that requires our focus. Thirteen papers published from 1985 to 2021 had more than 2000 total citations (Table 2). Among them, Rattan Lal published a paper entitled “Soil Carbon Sequestration Impacts on Global Climate Change and Food Security” in Science in 2004, with the highest total number of citations, reaching 3925 times. This is followed by Yude Pan’s and Gordon B. Bonan’s papers published in Science in 2011 and 2008, respectively, with a total of more than 3000 citations. In terms of average annual citations, Yude Pan's paper entitled "A Large and Persistent Carbon Sink in the World's Forests" attracted the most attention, with an average annual citation of 320.75 times (Table 2). Furthermore, from the sources of the highly cited literature, Science and Global Change Biology are highly influential journals in the study.

**Table 1.** Top 25 Journals in Terms of the Impact of Land Use Change on Soil Carbon Sequestration from 1985 to 2021.

| Journal Name | Category | IF | Quartile | Articles |
|---|---|---|---|---|
| Global Change Biology | Biodiversity Conservation | 13.111 | Q1 | 431 |
| Science of The Total Environment | Environmental Sciences | 10.237 | Q1 | 379 |
| Agriculture Ecosystems & Environment | Agriculture, Multidisciplinary | 7.088 | Q1 | 370 |
| Geoderma | Soil Science | 7.444 | Q1 | 344 |
| Forest Ecology and Management | Forestry | 4.584 | Q1 | 317 |
| Biogeosciences | Ecology | 5.157 | Q1 | 256 |
| Catena | Geosciences, Multidisciplinary | 6.497 | Q1 | 228 |
| Land Degradation & Development | Environmental Sciences | 5.205 | Q2 | 196 |
| Soil & Tillage Research | Soil Science | 7.829 | Q1 | 191 |
| Environmental Research Letters | Environmental Sciences | 8.414 | Q1 | 188 |
| Journal of Environmental Management | Environmental Sciences | 8.549 | Q1 | 179 |
| Sustainability | Environmental Sciences | 4.089 | Q2 | 150 |
| Forests | Forestry | 3.292 | Q1 | 148 |
| Global Biogeochemical Cycles | Environmental Sciences | 7.067 | Q1 | 145 |
| PLoS ONE | Multidisciplinary Sciences | 4.069 | Q2 | 140 |
| Soil Science Society of America Journal | Soil Science | 3.564 | Q3 | 138 |
| Climatic Change | Environmental Sciences | 6.058 | Q2 | 136 |
| Soil Biology & Biochemistry | Soil Science | 9.956 | Q1 | 135 |
| Ecological Indicators | Environmental Sciences | 6.643 | Q1 | 133 |
| Global Change Biology Bioenergy | Agronomy | 6.293 | Q1 | 129 |
| Journal of Cleaner Production | Engineering, Environmental | 11.016 | Q1 | 129 |
| Agricultural and Forest Meteorology | Agronomy | 7.021 | Q1 | 124 |
| Land Use Policy | Environmental Studies | 6.158 | Q1 | 124 |
| Plant and Soil | Agronomy | 5.44 | Q1 | 123 |
| Scientific Reports | Multidisciplinary Sciences | 5.516 | Q2 | 120 |

Note: Journal information refers to the Journal Citation Reports (JCR) published by the Clarivate. When a journal involves a multidisciplinary category, the Category is marked as the top category and partition of the journal category. IF is the abbreviation of Journal Impact Factor, and the data is a 5-year average impact factor. Relevant data can be searched and consulted in the https://jcr.clarivate.com/jcr/browse-journals (accessed on 25 October 2022) [25].

### 3.3. Analysis of Major Countries/Regions

We counted the number of publications in major countries and regions (Figure 3). Among them, the most important countries were the United States and China, with the number of papers published accounting for 23.9% and 18.4% of the total number of publications, respectively, far higher than other countries. The UK, Germany, and Australia were in the second tier, with 656 to 782 papers published, followed by Canada, India, Brazil, France, and Italy. In addition, we can also see from Figure 2 whether the authors of the posts were all from the same country; except for France, in the papers published in other countries, the authors of the same paper were mainly from the same country. Among the papers published by China SCP values were the largest, reaching 937.

The bibliometric analysis on countries shows an objective result. However, different countries vary in size and population size. It has an influence on the number of publications. Therefore, the related results may have some limitations. In future studies, relative outputs can be considered, normalized by the population size of each country. Thus, more objective and reasonable results can be obtained.

**Table 2.** Papers with more than 2000 Citations in the Field of the Impact of Land Use Change on Soil Carbon Sequestration from 1985 to 2021.

| Paper | DOI | TC | TCperYear |
|---|---|---|---|
| LAL R, 2004, Science | 10.1126/science.1097396 | 3925 | 206.58 |
| PAN Y, 2011, Science | 10.1126/science.1201609 | 3849 | 320.75 |
| BONAN GB, 2008, Science | 10.1126/science.1155121 | 3303 | 220.20 |
| JOBBAGY EG, 2000, Ecological Applications | 10.2307/2641104 | 3057 | 132.91 |
| BRENNAN L, 2010, Renewable and Sustainable Energy Reviews | 10.1016/j.rser.2009.10.009 | 2783 | 214.08 |
| COX PM, 2000, Nature | 10.1038/35041539 | 2652 | 115.30 |
| SIX J, 2002, Plant Soil | 10.1023/A:1016125726789 | 2507 | 119.38 |
| GUO LB, 2002, Global Change Biology | 10.1046/j.1354-1013.2002.00486.x | 2413 | 114.90 |
| COLE JJ, 2007, Ecosystems | 10.1007/s10021-006-9013-8 | 2382 | 148.88 |
| REICHSTEIN M, 2005, Global Change Biology | 10.1111/j.1365-2486.2005.001002.x | 2256 | 125.33 |
| BRONICK CJ, 2005, Geoderma | 10.1016/j.geoderma.2004.03.005 | 2245 | 124.72 |
| DIXON RK, 1994, Science | 10.1126/science.263.5144.185 | 2207 | 76.10 |
| ENTEKHABI D, 2010, Proceedings of the IEEE | 10.1109/JPROC.2010.2043918 | 2001 | 153.92 |

Note: Total citation data are from the Web of Science Core Collection. The TC is the abbreviation of Total Citations.

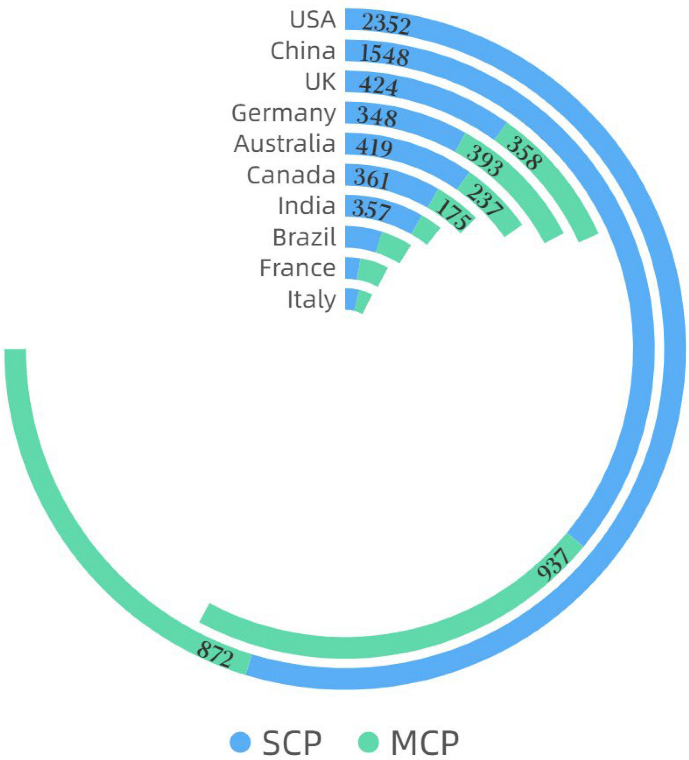


**Figure 3.** Top 10 Countries in Terms of the Impact of Land Use Change on Soil Carbon Sequestration from 1985 to 2021 and the Number of Publications. MCP is the abbreviation of Multiple Country Publications, indicating that the author of the same paper comes from multiple countries; The SCP is the abbreviation of the Single Country Publications, indicating that the same paper authors are all from the same country.

### *3.4. Main Research Institutions, Authors and Cooperative Relationships*

#### 3.4.1. Main Research Institutions

Based on the number of publications, we performed a statistical analysis of the research institutions of the authors of the published papers. Among the top 10 major research institutions with the number of publications from 1985 to 2021 (Table 3), the Chinese Academy of Sciences ranked the first with 540 publications. Colorado State University, Ohio State University, the University of Chinese Academy of Sciences, and Northwest A&F

University ranked 2nd–5th in terms of the number of articles, with more than 400 articles. Notably, the top 10 research institutions were all from China (60%) and the United States (40%). Thus, as the world's two major economies and major carbon emitters, China and the United States had carried out a lot of research work in this field.

**Table 3.** Top 10 Research Institutions in Terms of the Impact of Land Use Change on Soil Carbon Sequestration from 1985 to 2021.

| Affiliations | Articles |
|---|---|
| Chinese Academy of Sciences | 540 |
| Colorado State University | 477 |
| Ohio State University | 469 |
| University of Chinese Academy of Sciences | 439 |
| Northwest A&F University | 430 |
| Institute of Geographic Sciences and Natural Resources Research | 378 |
| Beijing Normal University | 347 |
| University of Florida | 345 |
| University Of Illinois | 300 |
| Peking University | 286 |

The bibliometric analysis on research institutions shows an objective result. However, the relevant results are limited by the development of the country, the number of research projects, and the support of research funding, etc. In future studies, the relative outputs can also be considered. The results can be standardized according to the number of research projects and investment of research funding. In this case, more objective and reasonable results can be obtained.

### 3.4.2. Main Authors

We conducted statistics (Figure 4a) on the top 10 published authors from 1985 to 2021. We can see from the figure, the number of published publications of each author is more than 100. Rattan Lal, who scholars at Ohio State University in the United States, published the most articles, reaching 214; Philippe Ciais, who scholars at the French Laboratory of Climate and Environmental Sciences, published 154 articles, ranking fourth. The rest of the authors are Chinese. In addition, we counted the top 10 authors with the most cited papers and their citations (Figure 4b), of which, the top 7 authors all had more than 10,000 citations, and scholar Rattan Lal remained in first place, with more than 27,000 citations, nearly 6000 times ahead of the second scholar, Philippe Ciais.

### 3.4.3. Cooperative Relationship

Soil carbon sequestration is a global effort, and since research is carried out in most countries, there is bound to be a collaborative relationship between research institutions and academics. The top 30 research institutions and scholars in the number of published papers were counted, and the cooperative relationship between them was analyzed respectively (Figure 5). As can be seen from Figure 5, research institutions in the same country were closely connected, and research institutions in different countries also had mutual cooperation networks, which formed a certain scale (Figure 5a). In terms of scholarly cooperation networks, Chinese scholars were numerous and closely interconnected, but there were relatively few contacts and cooperation with scholars from other countries (Figure 5b). With the deepening of research, research institutions and scholars in various countries will continue to strengthen contact and cooperation in the future.

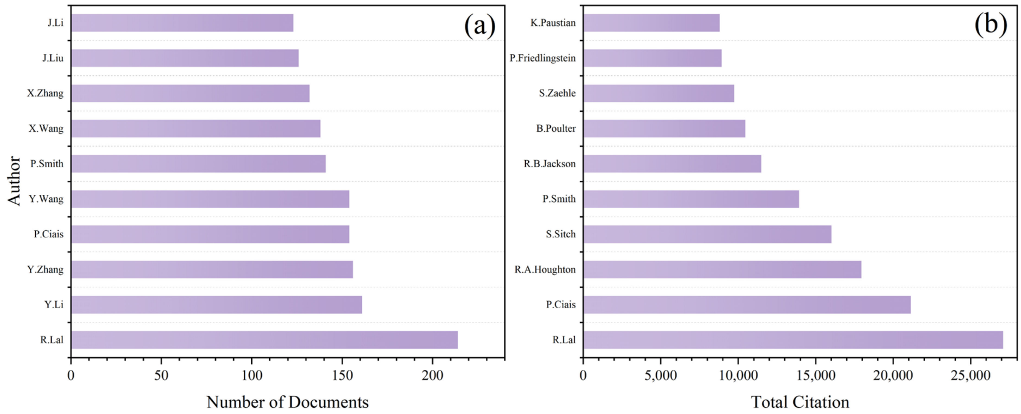


**Figure 4.** Top 10 Authors and Their Number of Publications in the Field of the Impact of Land Use Change on Soil Carbon Sequestration (**a**) and Top 10 Authors with the Most Cited Papers and the Number of Citations, and (**b**) from 1985 to 2021.

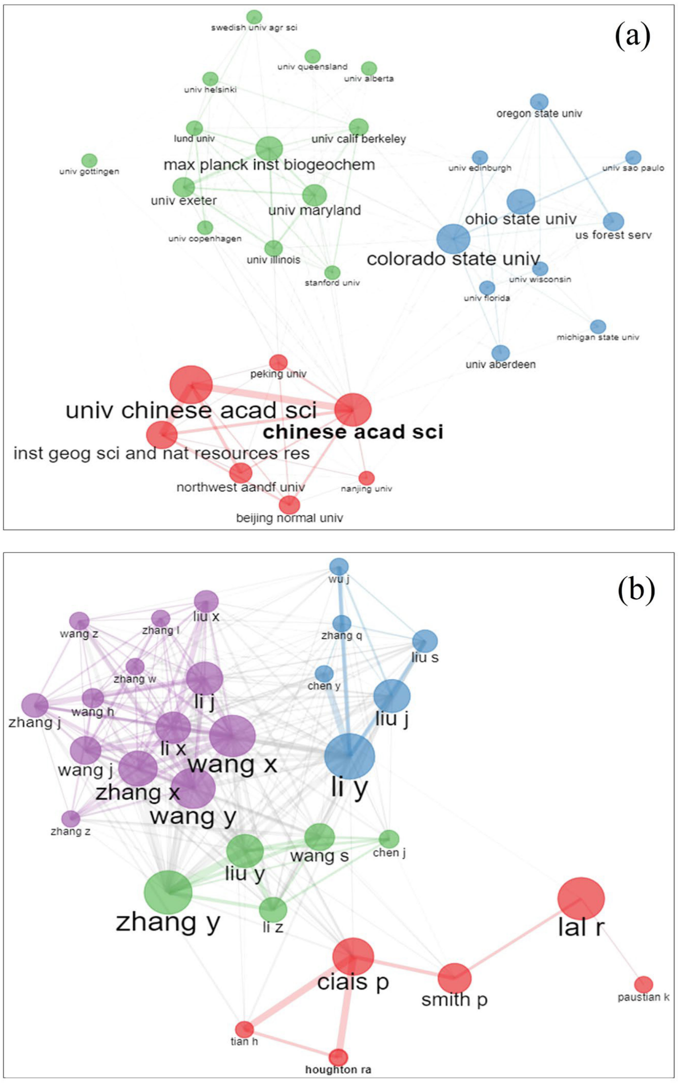


**Figure 5.** (**a**) Inter-Institutional Cooperation, and (**b**) Inter-Author Cooperation, in the Field of Effects of Land Use Change on Soil Carbon Sequestration from 1985 to 2021. The colored circles in the figure represent different cooperative network relationships and the larger the circle is, the more papers published by the research institution or scholar will be.

### *3.5. Keywords*

#### 3.5.1. High-Frequency Keywords

Keywords can reflect the theme concept of the paper, but also is a high summary of the research content. High-frequency keywords have been commonly used to reveal the knowledge structure of the research domain [26]. The word cloud map of the first 30 keywords (Figure 6) showed that "sequestration", "land-use", and "management" had a high frequency of occurrence, all of which exceeded 1600 times, indicating that management was a key concern in the research in this field. "Nitrogen", "climate-change", "$CO_2$", and "emissions" also appeared with high frequencies, indicating that related studies in this field were closely related to climate change. The words "forest", "deforestation", and "conservation" corresponded to land-use changes. "Organic-carbon", "organic-matter", and "biodiversity" corresponded to soil organic carbon content and biodiversity, thereby affecting soil carbon sequestration.

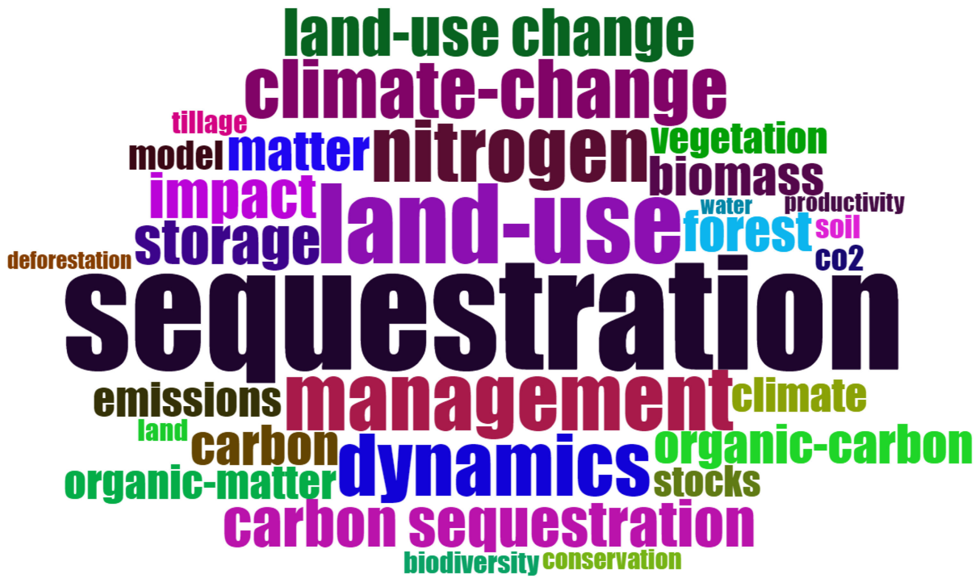


**Figure 6.** High-Frequency Keywords in the Field of Impacts of Land Use Change on Soil Carbon Sequestration from 1985 to 2021.

#### 3.5.2. Cluster Analysis of High-Frequency Keywords

Cluster analysis is the use of statistical methods to simplify complex keywords and divide them into groups according to network relationships, aiming to complete the natural division of network grouping [27]. This study uses corresponding analysis to cluster keywords into three subcategories (Figure 7). Axis 1 (Dim 1) and Axis 2 (Dim 2) explained 52.26% and 20.83% of the variance, respectively, with a cumulative interpretation rate of 73.09%. The first category of the cluster (blue area) was mainly related to climate, $CO_2$, and temperature. Studies of this type were mostly based on global climate change to explore the main driving mechanism behind it. The second type (red area) was mainly related to organic matter, soil carbon pool, microorganisms, and biomass. This type of research focused on soil carbon content, involving soil properties and plant biomass. The third category (green area) was mainly related to biodiversity and ecosystem services, and studies in this category highlighted the key role played by soil in the supply of ecosystem services.

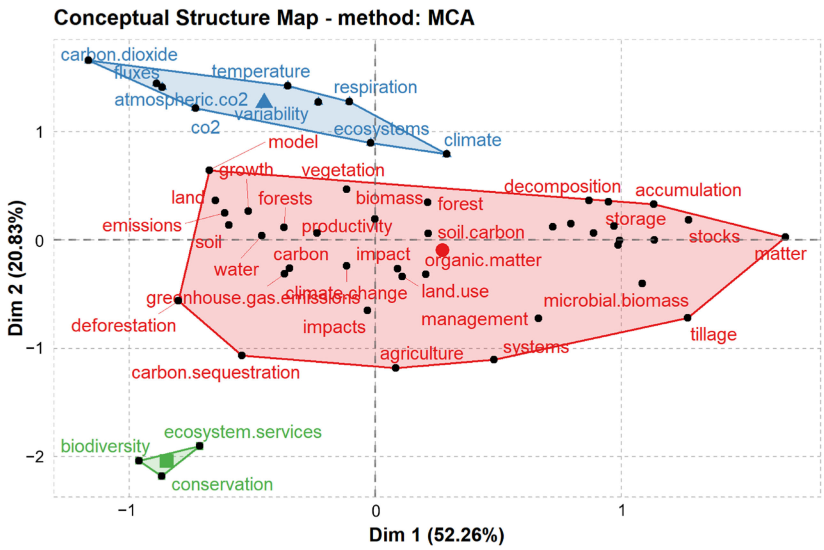


**Figure 7.** Cluster Analysis of Keywords in the Influence of Land Use Change on Soil Carbon Sequestration from 1985 to 2021.

### 3.6. Theme Evolution

This paper described the evolution of the research themes in the context of the three stages (Figure 8). "Emissions", "nitrogen", and "model" were the themes of research from 1985 to 1999. Related studies focused on the quantitative study of impacts of land use on carbon emissions and soil carbon sequestration using model methods. In the two stages of 2000–2009 and 2010–2021, the two themes of "forest" and "land use" had gradually attracted attention, and the academic community had become more aware that land use change and soil carbon sequestration were closely linked, and related research had gradually deepened, and forest land was the focus of research. Overall, "$CO_2$" and "sequestration" had always been the themes of research, and the proportion of the two themes combined had gradually increased. It can be shown that the research on the impact of land use change on soil carbon sequestration focused on the impact of different land use types and different farming methods on soil organic carbon content, and soil carbon sequestration under the background of global warming.

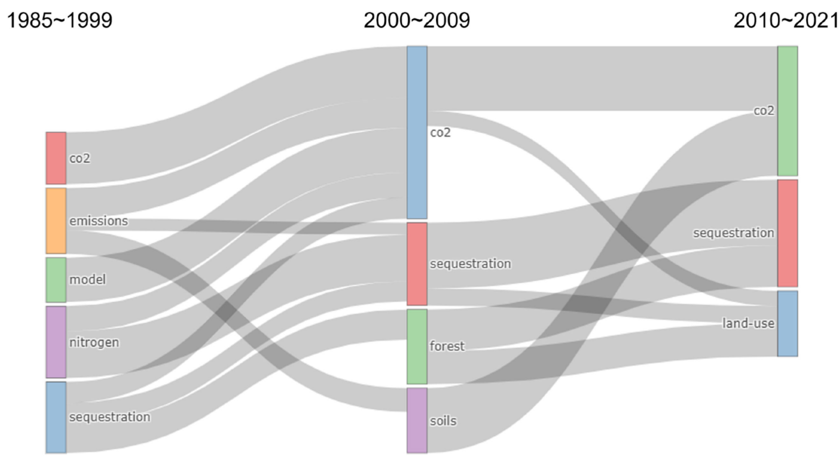


**Figure 8.** Evolution of Research Themes on the Effects of Land Use Change on Soil Carbon Sequestration from 1985 to 2021.

## 4. Review of Impact of Land Use Change on Soil Carbon Sequestration

Land use change is a core area of global environmental change research and an important driver of the carbon cycle in terrestrial ecosystems [28]. Land use change affects the surface heat balance, global climate processes, and thus global food security by altering surface albedo and roughness [29], changing vegetation [30] and soil carbon pools [31], etc. Understanding land use change has important implications for soil carbon sequestration. From the results of the bibliometric analysis, this paper is generally consistent with the results of previous studies [32,33]. Land use change is a high-frequency keyword for related studies and a subject of theme evolution (Figures 6 and 8). How land use change affects soil carbon sequestration deserves an in-depth study.

Land use change can be divided into two basic types, which are use transfer and intensity change [34]. Use transfer refers to the change of land use type. Intensive change can be explained by the change of land management mode. The change of both effects the structure and function of land ecosystem system [35]. Soil is the largest terrestrial ecosystem, and soil carbon sequestration is affected by land use change, and land use change has become the most important human factor.

### *4.1. Impact of Land-Use Type Change on Soil Carbon Sequestration*

Based on the analysis of the existing literature, we found that the shift in land use types inevitably led to changes in soil carbon sequestration [36]. Different soil decomposition processes of litter and plant species with different traits can cause differences in soil carbon content, and potential rates of change in carbon stocks among different land use types [37]. The transition between cultivated land, woodland, and grassland in land use types has a greater impact on soil carbon sequestration.

In order to display the impact of land use type change on soil carbon sequestration more intuitively, we used net carbon rate for quantification. Based on the results of the bibliometric analysis, we carefully read the high-cited review articles to obtain the relevant data results. At the same time, we also referred to the existing Intergovernmental Panel on Climate Change (IPCC) report [38], which helped us to obtain the data more efficiently and authoritatively. Combining the relevant contents, we summarized and compiled some conclusions in this regard (Table 4).

**Table 4.** Changes in soil carbon sequestration under land-use type change.

| Land-Use Type Change | Net C Rate ($t\ C\ ha^{-2}\ yr^{-1}$) | References |
|---|---|---|
| Cultivated land to grassland (50 yr) | 0.3–0.8 | [38] |
| Cultivated land to grassland (35 yr) | 0.63 | [39] |
| Cultivated land to woodland (25 yr) | 0.3–0.6 | [40,41] |
| Grassland to cultivated land (20 yr) | −0.95 | [42,43] |
| Grassland to cultivated land | −1.0 to −1.7 | [40,41] |
| Grassland to afforestation (90 yr) | 0.1 | [43] |
| Grassland to afforestation (10 yr) | 0.5–0.7 | [44] |
| Cultivated land or grassland at forest margins to agroforestry (25 yr) | 1–5 | [38] |
| Woodland to cultivated land | −0.6 | [40,41] |
| Woodland to grassland (8–25 yr) | −0.9 to 0.91 | [45] |
| Woodland to grassland | −0.1 | [43] |

Note: The net C Rate is the mean value. Positive values indicate an increase in net C and negative values a decrease.

A large amount of carbon is stored in soil as organic carbon (SOC), and woodland is the most important type of land use for SOC storage [46], which is also the focus of current research. Woodland plays a critical role in the global carbon cycle. Smaller changes in it would have a significant impact on the global carbon cycle. Data showed that the average carbon reserves of native forests increased by 84.4%, 26.4%, and 33.7% compared with bare land, cultivated land, and artificial forest [47], respectively. This is due to the fact that woodland and grassland soil are not disturbed by tillage, and there are more plant root biomass and residues, resulting in more SOC reserves in woodland and grassland soil. In the process of transforming natural ecosystems into agro-ecosystems, changes in land use patterns lead to a significant decline in soil carbon sinks [48,49], i.e., the conversion from woodland to grassland or agriculture land, or the conversion of grassland to agriculture land, the process of which disturbs soil and vegetation, resulting in the loss of SOC stocks and nutrients [50]. Meanwhile, the reverse conversion usually leads to an increase in SOC stocks. This view is also confirmed by the change in the net SOC sequestration rate (Table 4). Agriculture land abandonment and conversion of agriculture land to forest or grassland are important land use changes. Studies have shown that the SOC content and recovery rate of abandoned land are significantly higher than that of cultivated land [51,52]. And in the process of conversion of agriculture land to forest or grassland, the soil carbon content can be increased by 19% after the conversion of farmland to grass. Soil carbon content can be increased by 18% and 53% after conversion of agriculture land to plantation and secondary forests [40]. It has a positive effect on mitigating the greenhouse effect.

When forest ecosystems are destroyed, it leads to a large release of carbon from the terrestrial biosphere to the atmosphere, which can be comparable to the release of $CO_2$ caused by fossil fuel combustion. This contributes to the global greenhouse effect. However, changes in soil carbon loss may contradict common sense. It has been argued that deforestation and burning do not lead to soil carbon loss, and sometimes even increase it. It is the conversion of deforestation to agriculture land and grassland that causes soil carbon loss [53]. Therefore, the main reason for the decrease in soil carbon is the land use after deforestation. The conversion of deforestation to agriculture land and grassland significantly reduces surface biomass, while changes in soil carbon sequestration are more complex. The direction and rate of change of SOC content after land use type shift depends on many factors. The conversion of woodland to agriculture land resulted in a decrease in SOC content due to a decrease in litter input. The destruction of the physical protection of organic matter by tillage measures resulted in a decrease in SOC content [41]. In addition, tillage makes the soil well mixed and destroys the structure of soil aggregates, exposing organic matter and accelerating its degradation [54]. Unlike the conversion to agriculture land, in the initial stage of conversion of woodland to grassland, there is a similar trend of change in surface soil carbon content to that of agriculture land. However, after many years, the surface soil carbon content of grassland could recover to the level of carbon content of woodland before conversion [45,55].

### 4.2. Impact of Changes in Land Management Patterns on Soil Carbon Sequestration

Changes in land management mode mainly affect soil carbon sequestration by changing the soil carbon input rate and soil organic matter loss rate. Therefore, in order to improve soil carbon sequestration, it is only necessary to increase the input rate of organic matter into the soil or reduce the decomposition rate of organic matter in the soil.

#### 4.2.1. Agriculture Land

The main strategies to improve soil carbon sequestration in agricultural land mainly include two aspects; one is to restore the soil ecosystem. Restoring soil ecosystems can increase biomass and increase SOC content. Second, it is necessary to carry out appropriate production activities. During agricultural production, farming interference, improper management of soil fertility, removal of crop residues, overuse of pesticides, and other chemicals can destroy soil aggregates to increase the mineralization rate of organic carbon [56], resulting in rapid depletion of soil SOC [57]. Measures such as conservation tillage, fertilization management, and residue management are conducive to soil carbon sequestration. Traditional farming methods can destroy the soil aggregate structure and generally cause the loss of SOC, which is also the reason why the SOC content is more in forests and grassland than in agriculture land. Conservation tillage measures, such as no-tillage and less tillage, have increased the input of crop residues, most of which are easily decomposed and some of which are converted into humus, contributing to the long-term increase of soil organic carbon reservoirs [58]. The conversion intensity of soil carbon by fertilization is much greater than the change in land use [59]. Fertilization can improve the biomass of crops, increase the input of plant residues, affect the soil microbial activity, and thus improve the soil SOC content. However, the application of organic fertilizer can significantly improve the soil organic carbon and inorganic carbon reserves, while the chemical fertilizer will reduce the inorganic carbon reserves. We need to pay attention to the proportion of organic fertilizer and inorganic fertilizer application. If comprehensive agricultural measures, such as conservation tillage, straw returning to the field, and rational fertilization are taken, studies have shown that this can re-fix 60–70% of carbon loss [57].

#### 4.2.2. Woodland

Due to the increasing human demand for forest resources, many primary forests have been destroyed. This human interference has broken the relatively closed nutrient cycle of primary forests, thus exposing their growth to various nutrient limitations [60]. Therefore, the adoption of reasonable forest management measures will greatly improve the carbon sequestration capacity of forest ecosystems.

Among the options for carbon sink measures to increase forest land use, protecting forest ecosystems is the primary choice. For the sustainable development of ecosystems, deforestation should be stopped, natural forest ecosystems should be protected, and the productivity of existing forest ecosystems should be improved. Second, in the management of forest ecosystems, unreasonable land use processes may often increase carbon sources and weaken carbon sink functions. Therefore, management activities should reduce the disturbance of soil and increase the legacy of residues [61].

Different forest management activities may affect soil carbon sequestration, such as the length of rotation period, the selection of tree species, and taking soil and water conservation measures, which cause changes in soil carbon storage [50]. Historically, the global forest area has been significantly reduced due to human activities. With the socio-economic development and the enhancement of people's environmental awareness, countries around the world have started to take active protective measures. It is generally accepted that after forest harvesting there is a significant reduction in surface biomass, leading to a large reduction in SOC and soil loss caused by erosion increases significantly [54]. However, it has been argued that although forest harvesting leads to a trend of reducing forest SOC, the effect of different harvesting methods on SOC varies significantly [62]. For example, there was a small decrease in SOC under whole-tree harvesting. However, if the understory vegetation was sprayed with herbicides before and after whole-tree harvesting, SOC showed a significant decrease [63]. In addition, exploring the changes in soil properties during the initial stages of forest harvesting can help to understand the impact of forest harvesting on soil organic carbon dynamics, and to develop corresponding management measures to mitigate the carbon loss caused by forest harvesting. The relevant research results showed that increasing the amount of nitrogen fertilizer applied and improving the soil fertility after forest harvesting would be beneficial to the SOC storage [64].

Proper stand management practices can enhance forest biomass and soil SOC, which can maintain or increase soil carbon sequestration. Measures such as increasing woodland storage, adopting soil and water conservation measures, reducing deforestation, improving biodiversity, and applying fertilizers appropriately can increase the soil carbon pool [42]. It can also prevent or slow down deforestation and limit forest degradation, thereby enhancing the sustainability of forest land use.

#### 4.2.3. Grassland

Globally, grassland biodiversity and ecosystem functions have declined significantly, leading to a reduction in organic carbon stocks [65]. The main factor affecting grassland carbon sequestration is grazing. Grazing is the most important interference mode of human activities to grassland soil, which will affect the SOC content by changing the composition of community species. However, SOC responses vary depending on management practices. Some studies have shown that different degrees of grazing can cause damage to grassland soil SOC [66], showing overgrazing > heavy grazing > light grazing > medium grazing. However, some studies have found that moderate grazing can improve the soil degradation rate of plant residues, as shown by the increase of SOC sequestration rate due to light, moderate, or even heavy grazing in the short term, but the decrease of soil carbon sequestration due to long-term grazing [67]. Overgrazing causes loss of SOC; on the one hand, livestock feeding reduces the carbon return from plants to soil. On the other hand, it causes disturbance to soil physicochemical properties and accelerates soil respiration [68].

Synthesis of existing studies suggests that improving grassland management can lead to an increase in soil C sequestration by an average of 0.47 Mg C·ha$^{-1}$·yr$^{-1}$ [69,70]. To ensure the sustainability of the grassland ecosystem, measures are taken in local conditions to rationally use grassland (such as mowing and fencing), reduce grazing intensity, improve vegetation traits [71], and improve grassland productivity, so as to improve soil carbon sequestration.

### *4.3. Causes of Land Use Change*

Land use change is the most direct manifestation of the interaction between human activities and the natural environment [72]. It plays a key role in reflecting regional and global environmental change. Land use change is driven by political systems, and socioeconomic, technological, and environmental factors [73]. It has a major impact on food security, global climate change, biodiversity, biogeochemical cycles, water availability, soil and environmental quality, human welfare, and socio-economic development.

According to the available studies, there are multiple influences on LUCC. Among them, resource scarcity leads to increased pressure on resource production due to population growth [74]. Cultivated land is the natural basis for food security. In order to meet agricultural production, a large amount of cultivated land resources is needed, and the scarcity of resources has led to the expansion of cultivated land in some areas. For example, in Southeast Asia, despite the increase in the number of protected forest areas, the tropical forest loss rate in Southeast Asia is higher [75]. This is mainly manifested in the expansion of cultivated land in the highland regions of mainland Southeast Asia [76]. It is largely due to land scarcity. The abrupt loss of carbon-rich forests may have profound socioeconomic and environmental impacts [77].

In contrast, however, in the mountains of China, rural-to-urban migration and a series of government policies have returned agricultural land to forest on sloping highlands. This suggests that external policy interventions can also lead to land use changes. During 1990 and 2010, China experienced dramatic changes in land use, with more than 15% of its carbon emissions coming from land use change-related factors [78]. In September 2020, China announced its goal of addressing climate change, which is to achieve a peak in carbon emissions by 2030 and be carbon neutral by 2060 [79]. Land use change has a dominant role in China's terrestrial carbon sink, providing a strong guarantee for the continued consolidation and enhancement of ecosystem carbon sink capacity [80].

### *4.4. Soil Carbon Fixation Management*

Soil carbon sequestration has many benefits. Mitigating climate change requires clean energy and removing carbon from the atmosphere, and increasing soil carbon sinks and reducing emissions are important approaches. Global food security is closely related to high soil quality, depending on the sufficient level of soil organic carbon content [81]. Soil carbon sequestration management is particularly important for the global carbon cycle, climate change mitigation, and food security.

The research on the impact of land use on soil carbon sequestration is very active, showing a clear feature of the comprehensive research and interdisciplinarity, involving soil, remote sensing, ecology, agronomy, geography, and land planning, while each discipline has its own key content. But for this issue, we should understand how carbon sequestration is affected by future climate and land use changes, helping land managers and policy makers develop appropriate planning strategy [11] to enable soil carbon sequestration management. Therefore, future research is needing to be more comprehensive, and it is necessary to use multidisciplinary technical means and methods to conduct a more in-depth quantitative analysis of carbon sources and carbon sink effects of past and current land use changes, and further explore the interaction mechanism between climate change, land use change, and soil carbon sequestration, so as to carry out more accurate predictions and evaluations for different climate scenarios.

## 5. Conclusions

Based on the Web of Science Core Collection database, the research literature in the field of the impact of land use change on soil carbon sequestration from 1985 to 2021 was retrieved. This paper used the Bibliometrix software package of R language for bibliometric analysis, data mining, and visual display of search results. The research progress on the impact of land use change on soil carbon sequestration was reviewed. This study enables us to comprehensively understand the impact of land use change on soil carbon sequestration, which is of great significance for mitigating global climate change and ensuring global food security.

This study concludes that the annual publication volume generally shows an upward trend, and the development can be divided into three stages, among which the period 1985–1999 is a slow growth stage, 2000–2009 is a stable growth stage, and 2010–2021 is a rapid growth stage. Global Change Biology and Science of the Total Environment have published a large number of papers, and Science and Global Change Biology are influential journals. The U.S. and China published far more papers than other countries. There is mutual cooperation between research institutions in different countries on a certain scale. Since 2000, land use change has been closely related to soil carbon sequestration. Land use change affects soil carbon sequestration by changing the rate of soil carbon input and the rate of soil organic matter loss. At present, most related studies focus on exploring the effects of different land use types and different farming methods on soil organic carbon content in the context of global warming. Land use change and management among agricultural land, woodland, and grassland are the focus of research. The conversion of woodland to agricultural land and grassland is an important reason for the decrease in soil carbon sequestration. Management measures should be taken for agricultural land, woodland, and grassland to improve soil carbon sequestration. Future research should use multidisciplinary technical means and methods to further explore the interaction mechanism between climate change, land use change, and soil carbon sequestration, so as to carry out more accurate prediction and assessment of different climate scenarios.

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