forests

Review

Global Bibliometric Analysis of Research on the Application of Biochar in Forest Soils

Zhufeng Chen, Yaqian Gao, Jiaxian Chen, Ling Yang, Shucai Zeng, Yan Su, Jiyue Li, Qian He and Quan Qiu *

Guangdong Key Laboratory for Innovative Development and Utilization of Forest Plant Germplasm, College of Forestry and Landscape Architecture, South China Agricultural University, Guangzhou 510642, China; 20213154010@stu.scau.edu.cn (Z.C.); yaqiangao@stu.scau.edu.cn (Y.G.); jiaxianchen@stu.scau.edu.cn (J.C.); lingyang@stu.scau.edu.cn (L.Y.); sczeng@scau.edu.cn (S.Z.); suyan@scau.edu.cn (Y.S.); ljyue@scau.edu.cn (J.L.); heqian@scau.edu.cn (Q.H.)
* Correspondence: qqiu@scau.edu.cn

Abstract: Considering the impacts of global climate change, paths for sustainable development are of particular importance. Biochar has multiple advantages, including but not limited to climate change mitigation, waste management, soil fertility improvement, and pollution remediation. Forest soils play a significant role in terrestrial ecosystems. The application of biochar in forest soils (ABFS) is therefore considered an essential tool for improving soil quality, capturing carbon, and reducing greenhouse gas emissions. The Web of Science Core Collection database was utilized for the bibliometric analysis of ABFS publications published between 2002 and 2022. Three bibliometric software were used to analyze bibliometrics, networks, and research directions for ABFS: Bibliometrix, VOSviewer, and CiteSpace. The analysis shows that research on ABFS is always rapidly developing. Research on ABFS is engaged globally in a complex network of collaborations, and the main research has occurred in China and the United States. Collaboration among authors is relatively diffuse. Research on ABFS involves interdisciplinary integration. In the early stages of research, the origin of biochar (history and boreal forests) and its characteristics (dynamics, nitrogen content, and chemical composition) were the focus of attention. As research progressed, more attention was given to ABFS (carbon, organic matter, vegetation, and heavy metals). Our research shows that while ABFS research has a certain history, its development trend has been consistently upward and shows no signs of declining. Thus, future research will likely concentrate on ABFS. Due to the complexity of biochar functions, ample research opportunities exist in ABFS.

Keywords: forest soils; biochar; bibliometric analysis; Bibliometrix; VOSviewer; Citespace

Citation: Chen, Z.; Gao, Y.; Chen, J.; Yang, L.; Zeng, S.; Su, Y.; Li, J.; He, Q.; Qiu, Q. Global Bibliometric Analysis of Research on the Application of Biochar in Forest Soils. *Forests* **2023**, *14*, 2238. https://doi.org/10.3390/f14112238

Academic Editor: Choonsig Kim

Received: 27 September 2023
Revised: 29 October 2023
Accepted: 7 November 2023
Published: 13 November 2023

1. Introduction

Biochar, which is an abbreviation of Bio and Charcoal [1], refers to a class of insoluble, stable, and highly aromatic carbon-containing substances synthesized by thermal treatment of biomass wastes under oxygen-limited conditions [2], which have numerous advantages, such as high adsorption capacity, carbon stability, and the ability to embed minerals and trace elements [3,4]. Biochar has been discovered to have various applications, including improving soil, fertilizing soil, environmental remediation, and producing bioenergy [5–7], which accomplishes resource reuse and waste reduction [8]. Biochar can also be a carbon sink to slow the greenhouse effect [9]. The application of biochar can control soil structure (e.g., pore size, distribution), enhance soil physicochemical traits (e.g., cation exchange capacity, water retention capacity), and increase the number of soil nutrients (e.g., nitrogen, phosphorus, potassium) [10], which in turn can improve crop productivity and reduce the reliance on synthetic fertilizers. Biochar is superior to other types of soil organic matter in holding onto nutrients [11]. The characteristics of biochar, such as pH, porosity, and surface functional groups, facilitate the removal of organic and inorganic pollutants and heavy metals from the soil through adsorption, electrostatic attraction, complexation, and diffusion [7,12,13]. The application of biochar is believed to contribute to mitigating global climate change by increasing soil carbon sequestration and reducing greenhouse gas emissions. When biomass is converted into biochar, the carbon content becomes highly stable and can be kept in the soil for up to 1000 years [11]. In addition, the pyrolysis conditions of biochar and its physicochemical characteristics, among others, can adsorb and trap greenhouse gases like carbon dioxide and methane [14,15]. Biochar can be obtained from a wide range of feedstock sources, such as plant, animal, and municipal waste [6,16], and in particular, the conversion of sludge to biochar offers another promising approach to managing waste biomass [17]. Biomass can be heated and treated using pyrolysis and gasification techniques to produce clean energy products such as syngas, biochar, and bio-oil [18]. Therefore, biochar is an economical and environmentally friendly soil amendment that realizes carbon sequestration and reduces greenhouse gas emissions, with extremely high ecological and economic benefits.

About 31% of the surface of the Earth is covered by forests, which cover approximately 4.06 billion hectares [19]. The importance of forests, one of the fundamental components of the Earth's ecosystems, is increasing because they improve livelihoods, sustain ecological balance, regulate water and atmospheric cycles, limit soil erosion, and decrease climate change [20]. The planted forest area rose from 170.06 million hectares to 293.90 million hectares between 1990 and 2020 [19], which shows the significance of sustainable management of plantation forests. However, traditional fertilization methods using nitrogen, phosphorus, and potassium can no longer meet the demands of forest cultivation. Although this method is fast-acting, it is short-lived, has low nutrient utilization, has short-lived fertilizer effects, and is prone to pollution [21]. Therefore, finding appropriate fertilizer application methods to improve the efficiency of nutrient uptake and utilization by forest trees, thus improving the quality of forest trees, is crucial for current forest cultivation. Experimental studies have demonstrated that biochar fertilization has unmatched advantages over conventional fertilization, including a high utilization rate, a long effective supply period of nutrients, an improvement of soil physical properties, a boost in soil pH, an increase in soil organic carbon levels, and benefits to the survival of soil organisms [22–24]. Additionally, biochar can reduce the amount and frequency of fertilizers in agroforestry production [25–27]. Therefore, biochar, a novel type of fertilizer, has a longer-lasting fertilizing impact than conventional fertilizer applications, and its nutrients are more readily absorbed by seedlings and less likely to be wasted. In order to decrease the use of chemical fertilizers while increasing effectiveness, biochar and fertilizer composites of biochar-based fertilizer have emerged as a new research direction for agricultural fertilizers. We must note that we need more knowledge to develop guidelines for using biochar in conjunction with soil fertility and nutrient management planning [22]. Therefore, it is crucial to understand the application of biochar in forest soils (ABFS).

There has been significant interest in biochar application in agriculture, but little research has been conducted on ABFS [28–30]. It is worth studying ABFS as it can improve soil conditions and increase forest productivity, especially in cases where soil nutrients are deficient [31]. Moreover, adding biochar to the soil can help sequester carbon through stable aromatic carbonaceous substances, counteracting increased atmospheric carbon dioxide emissions [11]. Research on the impact of degraded forest soil and tree growth has shown that biochar can help restore degraded forest soil and, in most cases, promote the growth of experimental trees [32]. A study of northern forest soil found that biochar can enhance soil carbon storage and fertility [33]. In addition, biochar applications may have neutral or positive effects on soil nutrients and microbial communities but fail to play a role in soil amelioration [34]. Applying biochar to northern forest soil can increase toxic metal content, negatively impacting early tree growth [35]. Currently, most experiments on forest systems focus on the response of ecosystems to wildfire-generated charcoal or ash [36], and most experiments are only short-term greenhouse or pot experiments [35]. Research on the differences in biochar reactions among plant species and potential toxic effects is relatively limited [35]. Considering the importance of efficient fertilization in artificial forest cultivation and the potential significant contribution of biochar to soil nutrient cycling and forest renewal, understanding research progress on ABFS is of great significance.

Bibliometric analysis is a commonly used and rigorous method for exploring and analyzing large amounts of scientific data [37]. This method involves qualitative and quantitative analysis of published literature using data mining, information processing, and visualization techniques to analyze the social and structural relationships between different research components, such as authors, institutions, countries, journals, and topics [38,39]. This type of analysis is essential for quantitatively evaluating the current status and emerging trends in a given field. Bibliometric techniques are widely applied in commerce, management, medicine, and agronomy [37,39–41]. In recent years, bibliometrics has also dealt with research on a variety of biochar-related topics, including the application of biochar in environmental management [7], the current state of biochar research and its development trend [6,42–44], the remediation of contaminated soils with biochar [45–48], the application of biochar in agriculture [49,50], the preparation of biochar [51], and the impact of biochar in soil and its applications [52,53]. To the best of our knowledge, few bibliometric studies are available on ABFS. Meanwhile, there is a relatively large amount of literature related to ABFS. Therefore, a comprehensive quantitative and qualitative analysis using bibliometric methods can provide a more accurate and comprehensive assessment of ABFS. Based on this, this study used bibliometric methods to statistically analyze and describe the research results related to ABFS to determine the current research status and prevalent trends and to explain the latest research progress and future development trends. Our objectives are to (i) identify and comprehend the development of all ABFS-related literature; (ii) understand the key publications, topics, journals, authors, institutions, and national collaborations in this field; and (iii) track the progress of biochar research frontiers and hotspots.

2. Data Statistics and Methodology

2.1. Gathering Data

On 12 July 2023, we gathered publications from the Web of Science Core Collection (WoSCC) database. The search string is: TS = ((“biochar” OR “black carbon” OR “charcoal”) AND (“forest*” OR “plantation*” OR “forestry” OR “tree*”) AND (“soil*”)), and its language is limited to English. The document types selected were “article” and “review”. From 1 January 2002 to 31 December 2022 was set as the time span. Due to the absence of complete literature data for 2023 and the fact that the research on the subject was published in 2002, publications published after 1 January 2023 are omitted. It obtained 2158 related publications on the field of ABFS from WoSCC, including 2042 articles and 116 reviews. The selected publications are exported in pure text files containing information such as the number of publications, keywords, and references, which can be used for literature measurement and visual analysis.

2.2. Statistic Analysis

Performance analysis and scientific mapping are two main categories in which the methods of bibliometric analysis are embodied. Performance analyses, on the other hand, highlight the contributions of research components, whereas scientific mapping focuses on the intellectual exchanges and structural connections between research components [37,54,55]. In bibliometric analysis, web visualization software is typically utilized, and the most popular web visualization programs include VOSviewer, Bibliometrix R-package, Citespace, Gephi, Leximancer, Bibexcel, SATI, Histcite, and Pajek. VOSviewer, CiteSpace, and Bibliometrix are among the programs primarily used in this study’s statistical analysis for bibliometric analysis. Among them, the Bibliometrix R-package (Version 4.1.3) (https://www.bibliometrix.org) is open-source software written in R that supports recommended workflows to perform bibliometric analyses, and it allows users to perform comprehensive scientific mapping analyses [56,57] and was accessed on 12 July 2023. VOSviewer (Version 1.6.19) (https://www.vosviewer.com/) is a graphical user interfacebased software for co-citation analysis and co-author analysis [37,58] and was accessed on 13 July 2023. Citespace (Version 6.2.R4) (https://citespace.podia.com/) is a Java-based information visualization tool that enables cluster view, timeline view, and dual-map [59,60] and was accessed on 15 July 2023.

In this research paper, we aim to establish a connection between ABFS-related publications over the last two decades and analyze their current state and trends. The study is divided into three primary sections: (i) general bibliometric analysis, (ii) publication network analysis, and (iii) primary research areas. For general bibliometric analysis, we used Bibliometrix to identify essential characteristics of publications such as authors, institutions, countries, and journals. We also utilized Bibliometrix, Citespace, and VOSviewer to analyze the cooperation network of authors, institutions, countries, and journals in ABFS for publication network analysis. Moreover, we performed dual-map overlays of journals and co-citation analysis using these software tools. Lastly, we used Bibliometrix and Citespace for primary research areas to detect burst keywords and references and reveal strategy maps and theme evolution in ABFS-related publications.

3. Results

3.1. General Analysis

3.1.1. Overall Trend of Publications and Citations

Figure 1 shows the annual trend and total citations of publications related to ABFS from 2002 to 2022, with a general upward trend in the number of papers. ABFS has three stages of development based on annual publications and growth rate: the budding period (2002–2007), the slow growth period (2008–2014), and the rapid growth period (2015–2022). (i) Budding period: Articles on ABFS appeared in 2002, with a maximum of only 45 articles per year. However, over time, the citation rate for these publications gradually increased. (ii) Slow growth period: The number of publications steadily increases, with an average citation rate of 4464. (iii) Rapid growth period: There has been a significant increase in publications. The maximum annual number of publications increased to 255, but the citation rate slightly decreased.

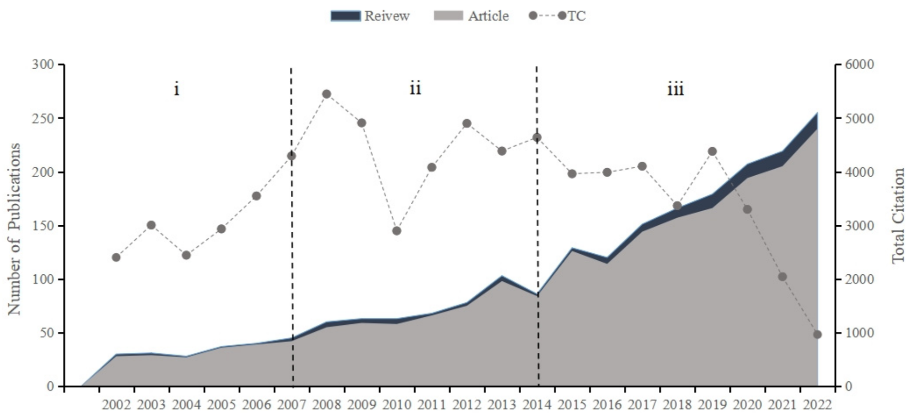


Figure 1. Annual trend of publications and citations related to the application of biochar in forest soils (ABFS). TC: Total citation.

3.1.2. Active Authors, Institutes, Countries, and Journals

Table 1 shows that KNICKER H and PAYETTE S are the most prolific authors, with 35 and 25 publications, respectively, and KNICKER H has the highest number of citations (3460). DELUCA TH, KNICKER H, LEHMANN J, and SCHMIDT MWI published earlier research results. LEHMANN J had the most citations on average per article (21 publications, 4527 citations). The active authors' H-index fell within the range of 13 to 26.

Figure 2 displays the research institutions that have produced the most results regarding ABFS. Zhejiang Agriculture and Forestry University has published the highest number of publications in the field of ABFS, with 73, making up 3.4% of all research results, followed by Laval University (n = 60), the University of Sao Paulo (n = 53) and Zhejiang University (n = 46).

Table 1. The top 10 most productive authors for related publications to ABFS.

Author	NP	TC	AC	H-Index	PY-Start
KNICKER H	35	3460	98.86	26	2003
PAYETTE S	25	438	17.52	13	2005
DELUCA TH	22	2242	101.91	15	2002
LEHMANN J	21	4527	215.57	16	2003
DE LA ROSA JM	20	950	47.50	14	2008
RUMPEL C	18	860	47.78	16	2006
GONZALEZ-PEREZ JA	18	1452	80.67	14	2004
LUO Y	17	620	36.47	13	2010
SCHMIDT MWI	16	1912	119.50	15	2003
DOERR SH	16	1136	71.00	14	2005

NP: Number of publications; AC: Average citations per article; H-index: an author-level metric; PY-start: Year of the first publication.

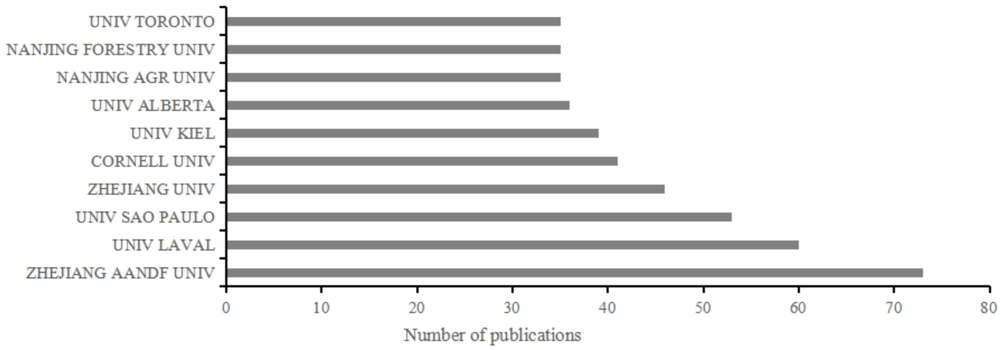


Figure 2. The top 10 most productive institutes for related publications to ABFS.

Our figure shows that from 2002 to 2022, research on ABFS occurred in 115 different countries/regions, and the ten countries with the most publications in the field of ABFS accounted for about 72.24% (n = 1559) of the world (Figure 3). China showed the highest output, with 380 publications and 9235 total citations, followed by the United States (n = 355, TC = 17,171) and Germany (n = 170, TC = 9018).

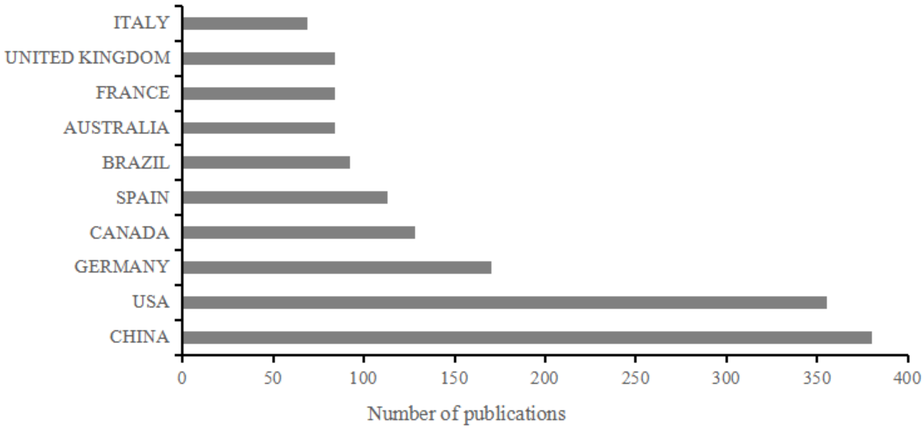


Figure 3. The top 10 most productive countries for related publications to ABFS.

We used Bradford's Law to identify the most active journals in our dataset. The total number of journals counted in this study was 475, of which 16 are core journals, the top five being Science of the Total Environment (ISSN: 0048-9697), Holocene (ISSN: 0959-6836), Forest Ecology and Management (ISSN: 0378-1127), Geoderma (ISSN: 0016-7061), and CATENA (ISSN: 0341-8162), as shown in Figure 4.

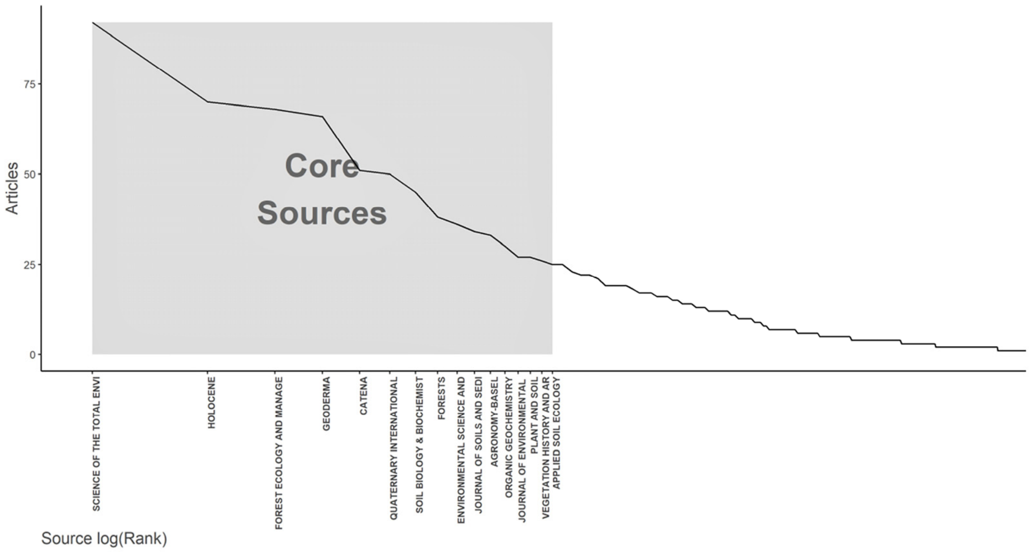


Figure 4. Bradford's Law using Bibliometrix.

3.2. Network Visualization Analysis of Publications

3.2.1. Author, Institution, Country/Regional Cooperation Network Analysis

The visualization in Figure 5 displays the timeline of the author's cooperation network. Out of 8809 authors in the field, 181 qualify with ≥5 published publications. The majority of them, nevertheless, are unconnected. The largest collaborative network has only 69 authors with intensive collaboration. The most active collaborative relationships were Certini Giacomo (University of Florence) and Doerr Stefan H. (Swansea University), followed by Santin Cristina (Swansea University), Gundale Michael J. (Swedish University of Agricultural Sciences), Abiven Samuel (University of Zurich), Knicker Heike (CSIC), and Wardle David A. (Nanyang Technological University). Over time, the number of authors who collaborate has gradually decreased. The authors' collaboration was primarily distributed in 2014 and 2016.

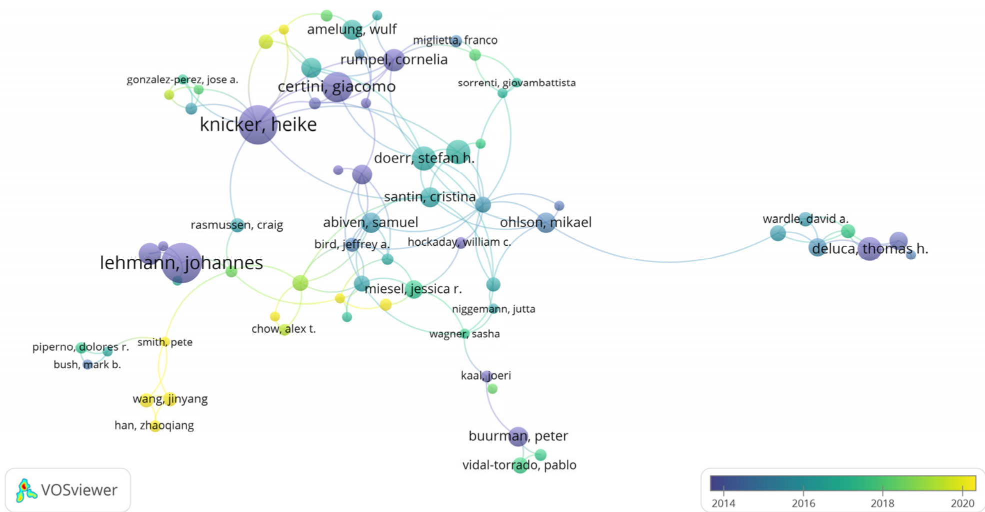


Figure 5. Network visualization of cooperation among authors using VOSviewer.

The visualization in Figure 6 displays the timeline of the institute's cooperation network. Out of 2453 institutions in the field, 32 qualify with ≥20 published publications.

There are apparent quantitative differences in institutional cooperation networks. The Chinese Academy of Sciences has the most partnerships and maintains close relationships with numerous institutes. The University of the Chinese Academy of Sciences, CSIC, the University of Sao Paulo, and the US Forest Service follow it. Most of the institutes actively cooperated from 2012 to 2020.

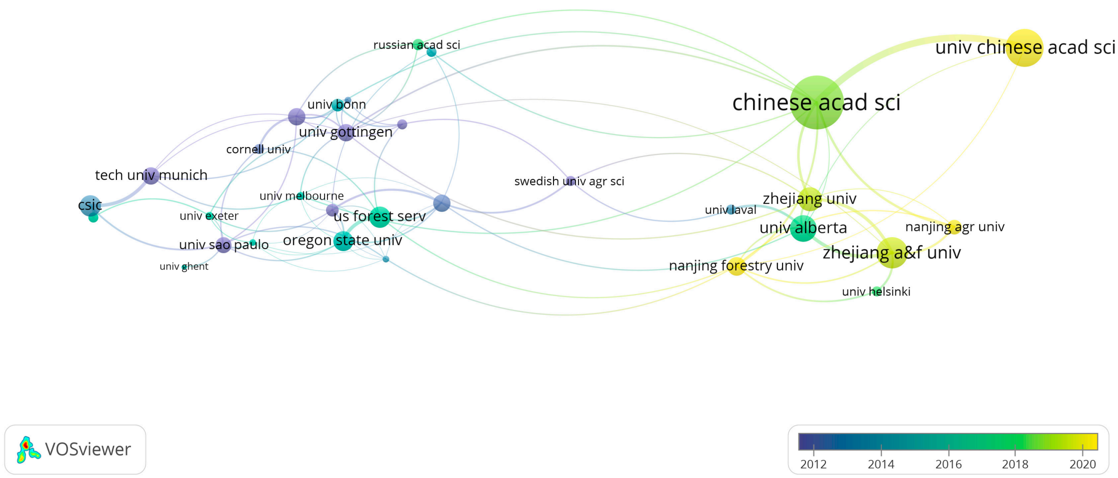


Figure 6. Network visualization of cooperation among institutes using VOSviewer.

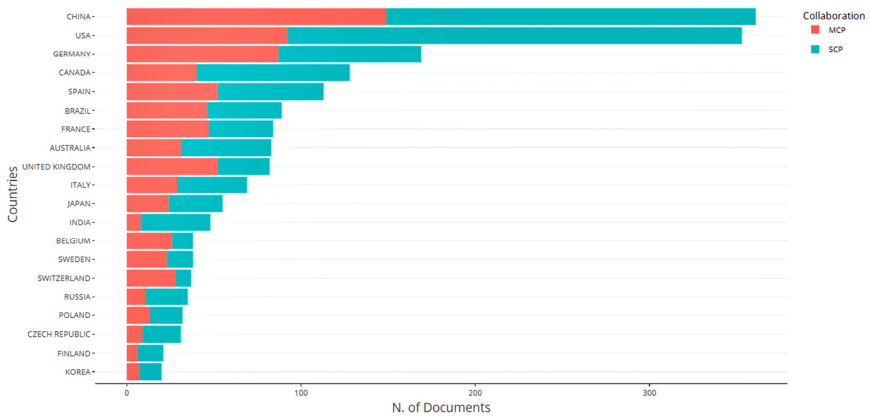
Based on the affiliated countries of the corresponding authors, Figure 7a shows the top 20 most productive countries and their ratios of multiple country publications (MCP) to single country publications (SCP). The corresponding author's country associates each publication with a country based on the corresponding author's affiliation. Additionally, the corresponding author's country can calculate the proportion of publications in which at least one author's affiliated country is different from the corresponding author's affiliated country, which is called MCP, reflecting the intensity of international cooperation in a country [61]. More than half of the publications in Switzerland, Belgium, the UK, Sweden, and France were produced through international cooperation, with Switzerland having the highest multi-country publication rate at 76%.

Figure 7b displays the global distribution of publications and country/region collaborations, with color shading indicating the number of publications per country. The more publications a country has, the darker its color appears on the map. The thicker the connecting lines between countries, the closer the cooperative links between them. The map of cooperation shows that the Americas, Europe, Africa, Asia, and Oceania are all active in ABFS research, except African countries, which have a relatively low level of participation. America, Germany, the United Kingdom, China, Spain, and Australia are the leading regions for research distribution, which comprise a complex global network. The United States and China have published the most research results, have the most academic links, and have excellent cooperation with all other countries. Although Germany and the United Kingdom have published relatively little research, they maintain a strong cooperative relationship with other countries.

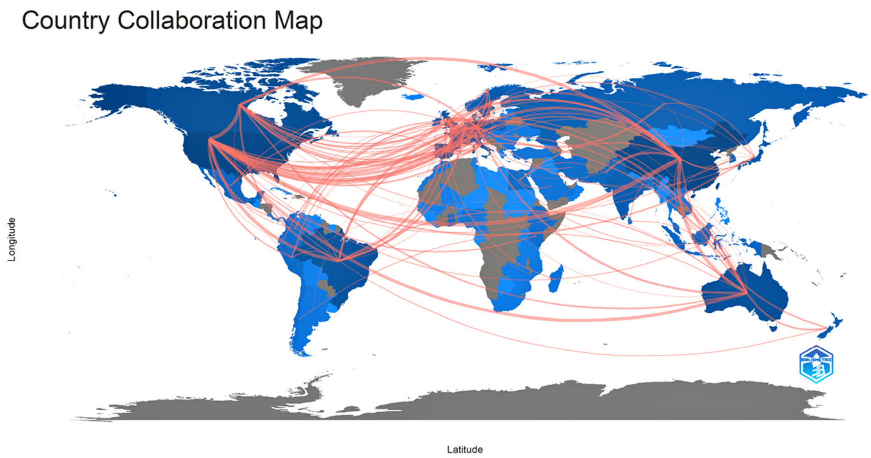
3.2.2. Co-Citation Analysis of Journals

Figure 8 shows the journal co-citation network. We set the minimum number of citations at 40, and 348 out of 22,759 journals met this threshold. Each node represents a journal, and the node's size indicates the number of citations the journal has received. Co-citation connections between journals are shown as lines, and the thickness of the connecting line indicates the degree of co-citation between the two journals. The item's color is determined by the cluster to which it belongs. The journals related to the field of ABFS are classified into six groups based on their citation frequency. These groups are yellow, green, red, blue, and purple, which are Geoderma (ISSN: 0016-7061), Forest

Ecology and Management (ISSN: 0378-1127), Science of the Total Environment (ISSN: 0048-9697), Organic Geochemistry (ISSN: 0146-6380), and Soil Biology and Biochemistry (ISSN: 0038-0717).



(**a**) Corresponding Author's Countries



(**b**) Country/region collaboration map

Figure 7. (**a**) International collaboration of ABFS based on the corresponding author's country and (**b**) Country/region collaboration map of ABFS, both using Bibliometrix.

The citation structure and discipline distribution of journals on ABFS are displayed in Figure 9 through the dual-map overlay. The left graph is generated by mapping the citing journals, while the cited journals that create the bottom graph are on the right [57]. That is, we can find the publications on the left side, while the references are on the right. The ellipse's long and short axes correspond to proportionality to the number of authors and publications. Each color represents a different discipline to which the journal belongs. The curve is the citation path, indicating the connection between disciplines, which can fully show the ins and outs of journal citations. For example, the dazzling blue-yellow line shows the four main citation paths of the dual-map overlay of research on ABFS, which are "ecology, earth, marine" to "plant, ecology, zoology", "ecology, earth, marine" to "earth, geology, geophysics", "veterinary, animal, science" to "plant, ecology, zoology", "veterinary, animal, science" to "environmental, toxicology, nutrition". The main focus of published articles on ABFS has been in journals related to "ecology, earth, marine" and "veterinary, animal, science". In contrast, the majority of the referenced publications were from journals that covered "earth, geology, geophysics", "plant, ecology, zoology" and "environmental, toxicology, nutrition". They reflect the interdisciplinary nature of ABFS research, encompassing ecology, botany, geology, environmental sciences, and geophysics.

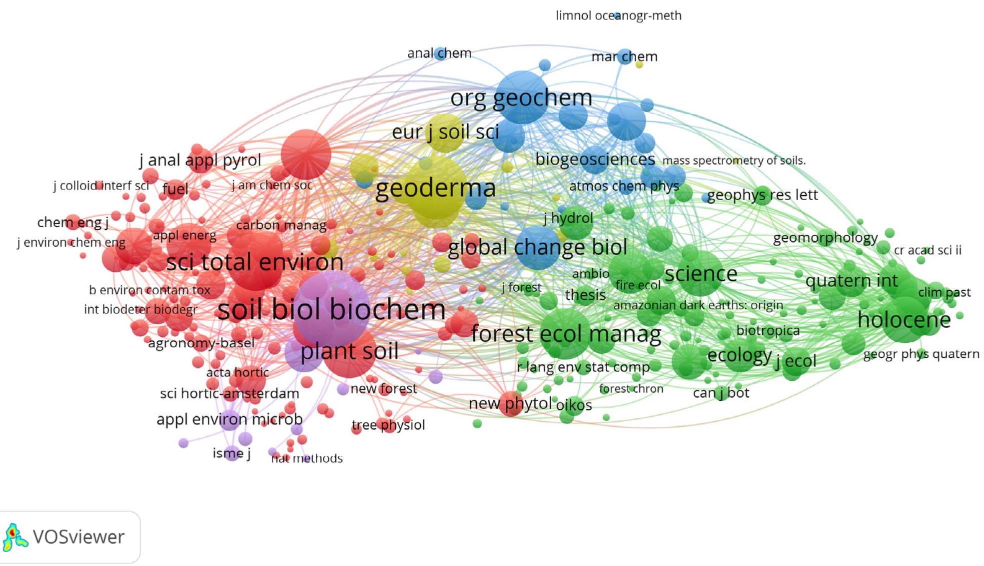


Figure 8. Journal co-citation network using VOSviewer.

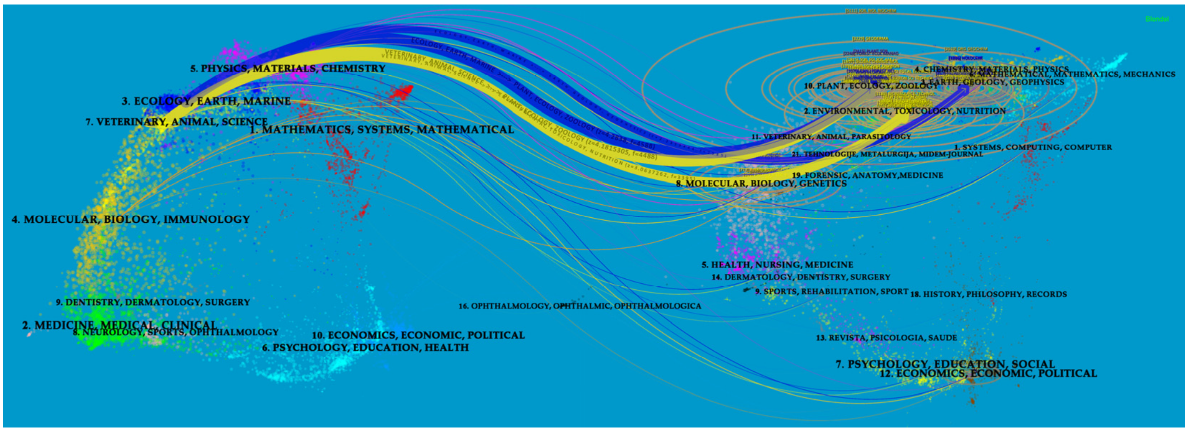


Figure 9. The dual-map overlay for related publications to ABFS using Citespace.

3.3. Analysis of the ABFS's Evolution Trend's Hotspots

3.3.1. Citation Burst Detection of Keywords and References

Citation burst detection reflects the dynamics of publications in the field over a given period, highlighting the appeal of the information explosion to academics, such as burst duration, intensity, and timing, which are the most representative reference indicators. A sudden surge in citations for specific keywords or articles can lead to discovery. This section describes the citation burst detection of keywords and references for research on ABFS. Figures 10 and 11 show the top 10 most cited keywords and references, which were frequently cited in research on ABFS.

Figure 10, highlighted in bold, displays the top 10 keywords with the strongest citation bursts. Based on our research, we have observed that "fire history" has the most significant citation burst intensity. Citation bursts for the keywords "fire history", "climate", "human impact", and "record" occurred earlier and lasted longer than those for other keywords. In addition, the citation bursts of "microbial community", "greenhouse gas emissions", and "amendment" all appeared in 2019 with strong explosive power, which is a possible hotspot for future research.

Figure 11, highlighted in bold, displays the top 10 references with the strongest citation bursts. We note that the article by Lehmann J. has the greatest explosive power, with a value of 25.05. This thesis critically explores research on the relationships between biochar and soil microorganisms to reveal the current state of knowledge and propose new concepts to deepen understanding of the link between biochar properties and biological responses, laying the foundation for future research [62]. In addition, references Li YF, Wang JY, and Santin C have strong outburst power, and the outburst continues, suggesting that the articles are essential references for ABFS in the future. Among them, Li YF's article summarizes and concludes the effects of biochar on forest soil properties and greenhouse gas emissions [63]. According to Wang JY's study [64], biochar is stable in soils, can last there for hundreds of years, and has a favorable impact on soil organic matter dynamics and carbon sequestration.

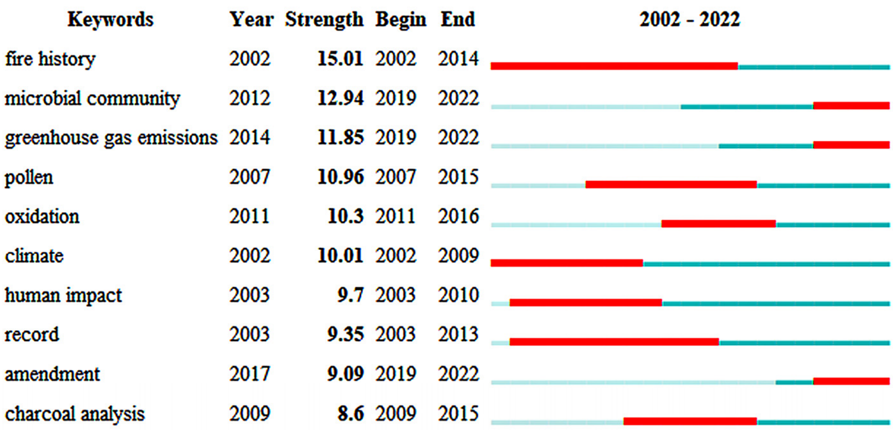


Figure 10. The top ten keywords with the strongest citation bursts using Citespace.

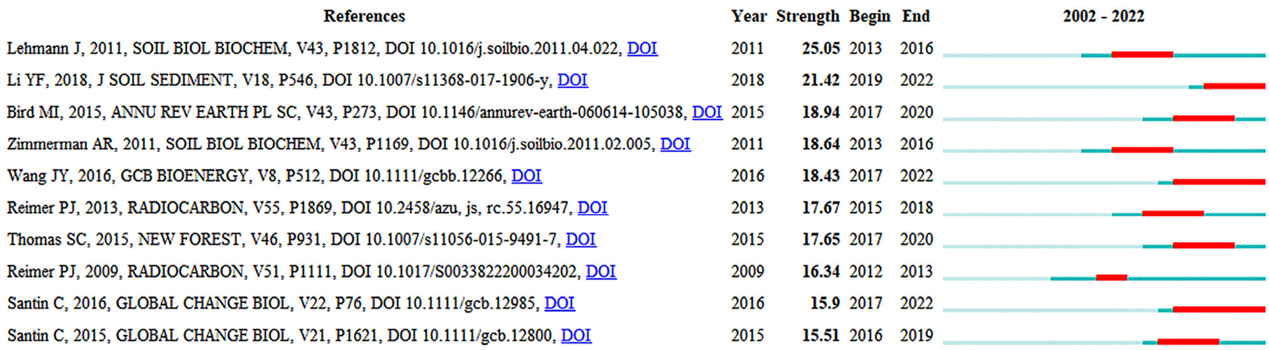


Figure 11. The top 10 references with the strongest citation bursts using Citespace.

3.3.2. Strategic Diagram of ABFS-Related Publications

Based on the count of publications and the growth rates, we divided the period since ABFS research emerged into three sub-periods, as illustrated in Figure 12: (a) 2002–2007, (b) 2008–2014, and (c) 2015–2022, to reveal the thematic evolution of research on ABFS over time. A strategy map that divides ABFS research themes into four quadrants based on centrality and density provides a clear picture of research hotspots. Centrality refers to how well a current topic is connected to other clusters. Density shows the level of cohesion within the cluster, measuring how closely related the keywords in the cluster are [57]. Each circle on the diagram represents a topic that is identified by its most commonly used keyword. The size of the circle increases with the frequency of the keyword. The first quadrant (upper right) shows a motor theme, which is well-developed and critical to the field of ABFS. The second quadrant (upper left) is an isolated theme, indicating that the theme is highly specialized with relatively few researchers. The third quadrant (bottom left) is an emerging theme, indicating that the theme is emerging or declining. Compared with the themes of other quadrants, the development of this theme is relatively weak and needs to develop as the whole field develops towards them. Finally, the fourth quadrant (bottom right) is the fundamental theme, characterized by high centrality and low density. These are essential future research directions but have not received sufficient attention.

Figure 12. The strategy diagram shows ABFS-related publications from 2002 to 2022 using Bibliometrix. (**a**) 2002–2007; (**b**) 2008–2014; (**c**) 2015–2022.

The first sub-period (2002–2007) of "nitrification", "ambient ozone", and "history" related research was well developed. The studies of "humid tropics", "extraction method", and "basin" seemed to be isolated. The research on "tissue-cultures", "temperature", and "quantification" was an emerging theme at that time. Studies related to "emissions", "dynamics", and "boreal forest" were future research trends. In the second sub-period (2008–2014), for the first time, the themes of "vegetation", and "nitrogen" appeared, both of which were the motor themes. Additionally, research on "coal" seemed highly specialized. Research on "biodiversity" and "chemical-composition" was an emerging theme. In the third sub-period (2015–2022), research on "carbon" had been well developed. However, "heavy-metals" had emerged as a highly specialized and new theme, while research on "vegetation" had declined. Moreover, research on "organic-matter" had become a fundamental theme and a key direction for future research [65–67].

3.3.3. Thematic Evolution of ABFS-Related Publications

We summarize the thematic evolution of publications related to ABFS in Figure 13. In the first sub-period, "emissions", "nitrification", "ambient ozone", "humid tropics", "extraction method", "quantification", "boreal forest", and "dynamics" were merged into "nitrogen" in the second sub-cycle. In the third sub-period, part of the branch was separated into "organic-matter" and "carbon". Several original themes were divided and rearranged into new ones for the following sub-period. For instance, "quantification", which appeared in the first sub-period, was derived in the second sub-period as "nitrogen" and "chemical-composition". However, different themes such as "nitrogen", "dynamics", "chemical-composition", and "biodiversity" were reintegrated into "carbon" in the second sub-period. In addition, the "organic-matter" of the third sub-period evolved from the "nitrogen", "dynamics", "vegetation", "chemical-composition", and "biodiversity" of the second sub-period. According to the evolution of the theme, we can see that the main elements constituting the basic framework of the research theme are constantly changing.

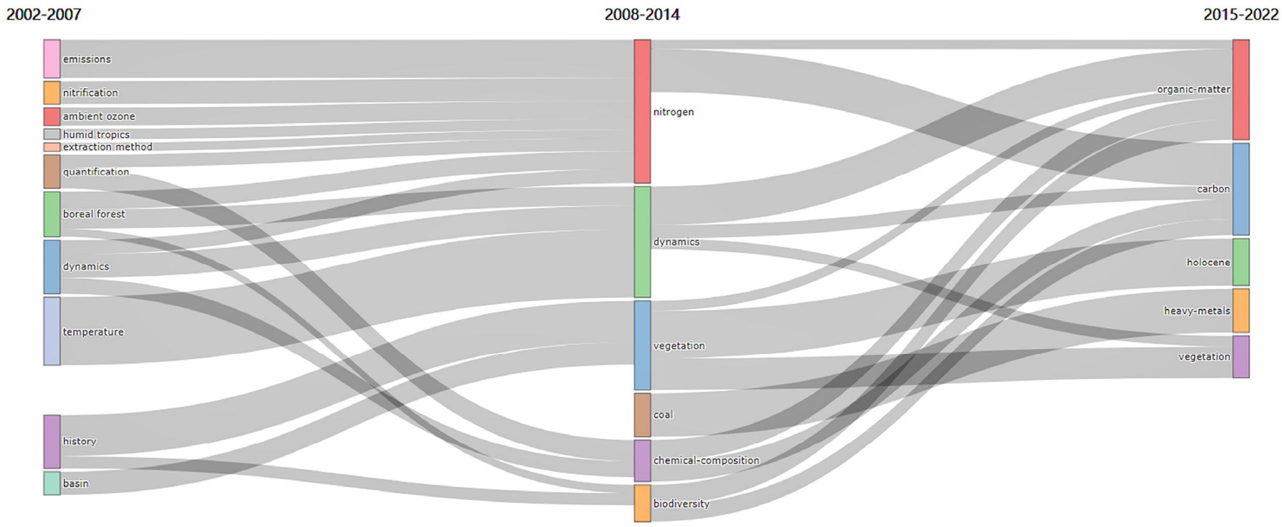


Figure 13. Thematic evolution of ABFS-related publications using Bibliometrix.

4. Discussion

According to the evolution of related research on ABFS from 2002 to 2022, we can understand its history, current situation, and prospects and provide new research ideas for ABFS. Research related to ABFS appeared in 2002. Notably, the highest number of citations was in 2008, mainly due to the appearance of a publication on biochar's ability to produce bioenergy, achieve permanent carbon sequestration, and improve soil and water quality [9]. It can be seen that biochar has various performance properties that have attracted the interest of researchers. Due to its many advantages, ABFS is becoming increasingly important. After 2008, publications grew faster, reaching 255 in 2022. According to the number of publications and its growth rate, we divide the research history into three sub-periods: (i) budding period (2002–2007), with a low number of publications and a low number of citations; (ii) slow growth period (2008–2014), with a gradual increase in the number of publications and the highest citation rate; (iii) rapid growth period (2015–2022), the rate of publications climbed while the rate of citations declined. 2021 and 2022 publications have low citation rates because recent publications are less likely to be mentioned than older publications.

According to our analysis, the most prolific authors have written over 30 pieces on this subject since 2002. The research of the most productive author, KNICKER H, focused on soil organic matter [36,68,69]. The highest cited author, LEHMANN J, whose research focuses on the behavior of biochar in soil [70–73], has received 4527 citations. Most scholars have no academic exchanges, and a small number of scholars have cooperation, which is relatively concentrated. With time, the number of authors cooperating decreased. Zhejiang Agriculture and Forestry University is the institution that has published the most results on ABFS. However, the organization with the most significant number of collaborative relationships is the Chinese Academy of Sciences, which serves as the hub of collaboration and maintains tight ties with most institutes. International cooperation can promote the sharing of knowledge and experience, improve research standards, and achieve high-quality outputs. Switzerland has the highest multi-country publication rate at 76%. However, countries at the forefront of this field generally work independently rather than in international collaboration for their high-quality output. In total, 115 countries have published research on ABFS, with China having the highest output, followed by the United States. All five continents of the world (America et al.) are involved in research on ABFS and form a complex network of cooperation, among which Africa is the continent with the least involvement in this network. China and the United States lead in research on ABFS, and the research results are comparable between the two countries, but the United States has more and more diverse partnerships.

According to the published journals, research on ABFS is multidisciplinary. ABFS benefits from its ability to achieve carbon sequestration in soil carbon pools and the amelioration of greenhouse gases, among other reasons. Soils and environmental sciences have a tight connection to ABFS. According to Bradford’s Law, the top five active journals are Science of the Total Environment, Holocene, Forest Ecology and Management, Geoderma, and Catena. As evidence of the significance of ABFS in agroforestry, four of these journals are renowned in the Agricultural and Biological Sciences. In addition to the Agricultural and Biological Sciences, the disciplinary categories identified as having the most influence are oil Science, Forestry, Environmental Science, Earth Sciences, and Ecology.

The top 10 strongest bursts of keywords and references were obtained based on the burst detection analysis of keywords and references. “Fire history” had the strongest of these bursts; it was the first keyword to show up and lasted the longest. The addition of highly concentrated and resilient black charcoal produced by the fire to soils can increase the passive soil organic matter pool [74]. Charcoal is present in most boreal forest soils due to naturally occurring wildfires, which convert 0.7%–2% of biomass to charcoal, which accounts for 8%–10% of soil carbon and 1 Pg of global carbon [75]. In addition, since fire is the most important contributor to natural forest disturbances globally, adding biochar to forest soils can also be considered a means to better “mimic” natural disturbance processes [62]. We also discovered that citations to the keywords “microbial community”, “greenhouse gas emissions”, and “amendment” had increased dramatically in the last three years. One of the most quoted sources is a paper on soil microorganisms in the journal Soil Biology and Biochemistry [62], which analyzes the interaction between microbial communities, fauna, and plant root behavior, forming a complete system with biochar research. Biochar will provide a habitat for soil microorganisms and promote their growth due to its unique characteristics, such as high surface area, high porosity, and abundance of various pore sizes [64]. The journal GCB Bioenergy published a paper on the stability of biochar, which can reach 100-year carbon sequestration [64]. Furthermore, the Journal of Soils and Sediments released a paper on the effect of biochar on greenhouse gas emissions that received many citations [63]. It can be seen that "microbial community" and "greenhouse gas emissions" are some of the main hotspots in the current research field of ABFS.

The thematic evolution map for the keywords involved in the research on ABFS can be summarized as biochar's origins, characteristics, and functions. Regarding the origins of biochar, temperature is one of the main conditions for preparing biochar, especially the production of biochar from wildfires in boreal forests [76]. The generation of biochar on a large scale from natural fires has been a part of human history for thousands of years and has had a long-lasting impact on soil processes [77]. These experiences are crucial for ABFS [78]. The dynamics study of biochar runs through the first and second sub-cycles. Biochar has dynamic impacts on soil, plant nutrition, and soil microbes due to its characteristics [79–81]. For instance, the adsorption of biochar results in dynamic interactions with soil microorganisms that influence the cycling of substances like polycyclic aromatic hydrocarbons in the soil and their environmental persistence [82], as well as the fact that biochar can persist in soils on centennial scales and that it has a positive effect on soil organic matter dynamics [64], and it has been found that the occurrence of wildfires in forest ecosystems has a long-lasting impact on both the microbial composition and the organic matter, which can affect the overall soil dynamics [83]. It is worth noting that in the third sub-cycle, biochar applications continue to appear in terms of "organic-matter", "biodiversity", "heavy-metals", "vegetation", and "nitrogen". In the contemporary context of reducing global warming, achieving carbon sequestration is crucial. Oxidation of biomass is usually incomplete, and in addition to thermal modification of pre-existing C-forms in the ecosystem, fires produce a range of pyrolytic compounds and particulate organic matter in aerosols. These changes result in the evolution of organic matter into "pyrolytic humus" with weak colloidal properties and increased resistance to chemical and biological degradation [84]. Biochar has been shown to have positive effects on forest soils. However, the potential ecological risks that come with its use are still unclear and a cause for concern. Conversion of sludge to biochar through pyrolysis can be an effective way to achieve solidification of heavy metals [83,85], and other studies have found that biochar reduces the risk of heavy metal uptake by plants but decreases over time, and its effectiveness is yet to be fully explored [79].

5. Conclusions and Limitations

According to bibliometric analyses of publications published between 2002 and 2022, research on ABFS is still in a fast-growing stage and growing at a moderate and consistent rate. The most productive authors published 35 articles, and the collaboration of authors is still fragmented and has to be enhanced further. The world is involved in research on ABFS, creating a complex web of cooperation, with China and the United States setting the standard for research output. The United States has the most complex and diverse cooperation, and the published results are comparable to China's. Research on ABFS involves the interdisciplinary integration of ecology, botany, geology, environmental sciences, and geophysics. Additionally, the origin and characteristics of biochar have attracted much greater attention in research. This research has focused on topics like its history, dynamics, and nitrogen. The applications of biochar in forestry, such as vegetation, biodiversity, organic matter, and heavy metals, have gradually evolved due to the ongoing growth of these research hotspots.

It is important to note that this study has certain limitations. There will be omissions of articles because of the restrictions on the databases and their machine searching. Furthermore, given the limitations of bibliometrics, its conclusions could need content analyses for additional clarification. Biochar research was conducted before the term was unified at the First International Biochar Conference in Australia in 2007. Some search terms may not be included. Additionally, there are some parallels between the applications of biochar in forestry and agriculture, which broadens the scope of search results. Experiments on forest systems have mainly studied the response of charcoal or ash from wildfires to ecosystems, not industrially produced biochar, and cannot adequately represent ABFS. In addition, the properties of biochar change with age, as does its effect on soil properties, so much of the experimental data from short-term greenhouse or pot experiments is not fully representative of field experiments.

Author Contributions: Conceptualization, Q.Q.; methodology, Q.Q.; software, Z.C., Y.G. and L.Y.; validation, Q.Q.; data curation, Z.C. and J.C.; writing—original draft preparation, Z.C.; writing—review and editing, Y.G., J.C., L.Y. and Q.Q.; project administration, S.Z., Y.S., J.L. and Q.H.; Supervision, S.Z., Y.S., J.L. and Q.H.; funding acquisition, S.Z. and Q.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Guangdong Forestry Science and Technology Innovation Project (2022KJCX015).

Data Availability Statement: All datasets presented in this study can be found within the article.

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

References

1. Ning, L. The basic research of physicochemical properties of biochar and its application in agriculture. Ph.D. Thesis, Shengyang Agricultural University, Shenyang, China, 2014.
2. Colantoni, A.; Evic, N.; Lord, R.; Retschitzegger, S.; Proto, A.R.; Gallucci, F.; Monarca, D. Characterization of biochars produced from pyrolysis of pelletized agricultural residues. *Renew. Sust. Energ. Rev.* **2016**, *64*, 187–194. [CrossRef]
3. Braida, W.J.; Pignatello, J.J.; Lu, Y.; Ravikovitch, P.I.; Neimark, A.V.; Xing, B. Sorption hysteresis of benzene in charcoal particles. *Environ. Sci. Technol.* **2003**, *37*, 409–417. [CrossRef] [PubMed]
4. Glaser, B.; Lehmann, J.; Zech, W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal-A review. *Biol. Fert. Soils* **2002**, *35*, 219–230. [CrossRef]
5. Abhishek, K.; Shrivastava, A.; Vimal, V.; Gupta, A.K.; Bhujbal, S.K.; Biswas, J.K.; Singh, L.; Ghosh, P.; Pandey, A.; Sharma, P.; et al. Biochar application for greenhouse gas mitigation, contaminants immobilization and soil fertility enhancement: A state-of-the-art review. *Sci. Total Environ.* **2022**, *853*, 158562. [CrossRef] [PubMed]
6. Yang, T.; Zhang, Z.; Zhu, W.; Meng, L. Quantitative analysis of the current status and research trends of biochar research-A scientific bibliometric analysis based on global research achievements from 2003 to 2023. *Environ. Sci. Pollut. Res.* **2023**, *30*, 83071–83092. [CrossRef]
7. Kumar, A.; Bhattacharya, T.; Shaikh, W.A.; Roy, A.; Chakraborty, S.; Vithanage, M.; Biswas, J.K. Multifaceted applications of biochar in environmental management: A bibliometric profile. *Biochar* **2023**, *5*, 11. [CrossRef]
8. Osman, A.I.; Fawzy, S.; Farghali, M.; El-Azazy, M.; Elgarahy, A.M.; Fahim, R.A.; Maksoud, M.I.A.A.; Ajlan, A.A.; Yousry, M.; Saleem, Y.; et al. Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: A review. *Environ. Chem. Lett.* **2022**, *20*, 2385–2485. [CrossRef]
9. Laird, D.A. The charcoal vision: A win-win-win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. *Agron. J.* **2008**, *100*, 178–181. [CrossRef]
10. Yuan, S.; Zhao, L.; Meng, H.; Shen, Y. The main types of biochar and their properties and expectative researches. *Plant Nutr. Fert. Sci.* **2016**, *22*, 1402–1417.
11. Lehmann, J. Bio-energy in the black. *Front. Ecol. Environ.* **2007**, *5*, 381–387. [CrossRef]
12. Kumar, A.; Bhattacharya, T. Removal of arsenic by wheat straw biochar from soil. *Bull. Environ. Contam. Toxicol.* **2022**, *108*, 415–422. [CrossRef] [PubMed]
13. Ahmad, M.; Rajapaksha, A.U.; Lim, J.E.; Zhang, M.; Bolan, N.; Mohan, D.; Vithanage, M.; Lee, S.S.; Ok, Y.S. Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere* **2014**, *99*, 19–33. [CrossRef] [PubMed]
14. Gwenzi, W.; Chaukura, N.; Wenga, T.; Mtisi, M. Biochars as media for air pollution control systems: Contaminant removal, applications and future research directions. *Sci. Total Environ.* **2021**, *753*, 142249. [CrossRef] [PubMed]
15. Yang, W.; Feng, G.; Miles, D.; Gao, L.; Jia, Y.; Li, C.; Qu, Z. Impact of biochar on greenhouse gas emissions and soil carbon sequestration in corn grown under drip irrigation with mulching. *Sci. Total Environ.* **2020**, *729*, 138752. [CrossRef] [PubMed]
16. Weber, K.; Quicker, P. Properties of biochar. *Fuel* **2018**, *217*, 240–261. [CrossRef]
17. Chen, T.; Zhang, Y.X.; Wang, H.T.; Lu, W.J.; Zhou, Z.Y.; Zhang, Y.C.; Ren, L.L. Influence of pyrolysis temperature on characteristics and heavy metal adsorptive performance of biochar derived from municipal sewage sludge. *Bioresour. Technol.* **2014**, *164*, 47–54. [CrossRef] [PubMed]
18. Kumar, A.; Bhattacharya, T.; Mozammil Hasnain, S.M.; Kumar Nayak, A.; Hasnain, M.S. Applications of biomass-derived materials for energy production, conversion, and storage. *Mater. Sci. Energy Technol.* **2020**, *3*, 905–920. [CrossRef]
19. FAO. *Global Forest Resources Assessment 2020*; FAO: Rome, Italy, 2020.
20. Gao, W.; Qiu, Q.; Yuan, C.; Shen, X.; Cao, F.; Wang, G.; Wang, G. Forestry big data: A review and bibliometric analysis. *Forests* **2022**, *1549*, 19. [CrossRef]

21. Galloway, J.N.; Winiwarter, W.; Leip, A.; Leach, A.M.; Bleeker, A.; Erisman, J.W. Nitrogen footprints: Past, present and future. *Environ. Res. Lett.* **2014**, *9*, 115003. [CrossRef]
22. Gul, S.; Whalen, J.K. Biochemical cycling of nitrogen and phosphorus in biochar-amended soils. *Soil Biol. Biochem.* **2016**, *103*, 1–15. [CrossRef]
23. Oladele, S.O.; Adeyemo, A.J.; Awodun, M.A. Influence of rice husk biochar and inorganic fertilizer on soil nutrients availability and rain-fed rice yield in two contrasting soils. *Geoderma* **2019**, *336*, 1–11. [CrossRef]
24. Liu, S.; Zhang, Y.; Zong, Y.; Hu, Z.; Wu, S.; Zhou, J.; Jin, Y.; Zou, J. Response of soil carbon dioxide fluxes, soil organic carbon and microbial biomass carbon to biochar amendment: A meta-analysis. *GCB Bioenergy* **2016**, *8*, 392–406. [CrossRef]
25. Velichkova, R.; Pushkarov, M.; Angelova, R.A.; Sandov, O.; Markov, D.; Simova, I.; Stankov, P. Exploring the potential of straw biochar for environmentally friendly fertilizers. *Sustainability* **2022**, *14*, 6323. [CrossRef]
26. Saeed, M.; Ilyas, N.; Jayachandran, K.; Shabir, S.; Akhtar, N.; Shahzad, A.; Sayyed, R.Z.; Bano, A. Advances in biochar and PGPR engineering system for hydrocarbon degradation: A promising strategy for environmental remediation. *Environ. Pollut.* **2022**, *305*, 119282. [CrossRef] [PubMed]
27. Kizito, S.; Luo, H.; Lu, J.; Bah, H.; Dong, R.; Wu, S. Role of nutrient-enriched biochar as a soil amendment during maize growth: Exploring practical alternatives to recycle agricultural residuals and to reduce chemical fertilizer demand. *Sustainability* **2019**, *11*, 3211. [CrossRef]
28. Kavitha, B.; Reddy, P.V.L.; Kim, B.; Lee, S.S.; Pandey, S.K.; Kim, K. Benefits and limitations of biochar amendment in agricultural soils: A review. *J. Environ. Manag.* **2018**, *227*, 146–154. [CrossRef]
29. Gao, S.; Deluca, T.H.; Cleveland, C.C. Biochar additions alter phosphorus and nitrogen availability in agricultural ecosystems: A meta-analysis. *Sci. Total Environ.* **2019**, *654*, 463–472. [CrossRef]
30. Lu, X.; Li, Y.; Wang, H.; Singh, B.P.; Hu, S.; Luo, Y.; Li, J.; Xiao, Y.; Cai, X.; Li, Y. Responses of soil greenhouse gas emissions to different application rates of biochar in a subtropical Chinese chestnut plantation. *Agr. For. Meteorol.* **2019**, *271*, 168–179. [CrossRef]
31. Palviainen, M.; Aaltonen, H.; Lauren, A.; Koster, K.; Berninger, F.; Ojala, A.; Pumpanen, J. Biochar amendment increases tree growth in nutrient-poor, young Scots pine stands in Finland. *For. Ecol. Manag.* **2020**, *474*, 118362. [CrossRef]
32. Palviainen, M.; Berninger, F.; Bruckman, V.J.; Köster, K.; de Assumpção, C.R.M.; Aaltonen, H.; Makita, N.; Mishra, A.; Kulmala, L.; Adamczyk, B.; et al. Effects of biochar on carbon and nitrogen fluxes in boreal forest soil. *Plant Soil* **2018**, *425*, 71–85. [CrossRef]
33. Gundale, M.J.; Nilsson, M.C.; Pluchon, N.; Wardle, D.A. The effect of biochar management on soil and plant community properties in a boreal forest. *GCB Bioenergy* **2016**, *8*, 777–789. [CrossRef]
34. Bieser, J.M.H.; Thomas, S.C. Biochar and high-carbon wood ash effects on soil and vegetation in a boreal clearcut. *Can. J. For. Res.* **2019**, *49*, 1124–1134. [CrossRef]
35. Stavi, I. Biochar use in forestry and tree-based agro-ecosystems for increasing climate change mitigation and adaptation. *Int. J. Sust. Dev. World* **2013**, *20*, 166–181. [CrossRef]
36. Knicker, H.; Hilscher, A.; de la Rosa, J.M.; Gonzalez-Perez, J.A.; Gonzalez-Vila, F.J. Modification of biomarkers in pyrogenic organic matter during the initial phase of charcoal biodegradation in soils. *Geoderma* **2013**, *197*, 43–50. [CrossRef]
37. Donthu, N.; Kumar, S.; Mukherjee, D.; Pandey, N.; Lim, W.M. How to conduct a bibliometric analysis: An overview and guidelines. *J. Bus. Res.* **2021**, *133*, 285–296. [CrossRef]
38. Zeleznik, D.; Blazun, V.H.; Kokol, P. A bibliometric analysis of the Journal of Advanced Nursing, 1976–2015. *J. Adv. Nurs.* **2017**, *73*, 2407–2419. [CrossRef]
39. Mukherjee, D.; Lim, W.M.; Kumar, S.; Donthu, N. Guidelines for advancing theory and practice through bibliometric research. *J. Bus. Res.* **2022**, *148*, 15. [CrossRef]
40. Secinaro, S.; Calandra, D.; Secinaro, A.; Muthurangu, V.; Biancone, P. The role of artificial intelligence in healthcare: A structured literature review. *BMC Med. Inform. Decis. Mak.* **2021**, *21*, 125. [CrossRef]
41. Wang, B.; Zhang, Q.; Cui, F. Scientific research on ecosystem services and human well-being: A bibliometric analysis. *Ecol. Indic.* **2021**, *125*, 107449. [CrossRef]
42. Wu, P.; Singh, B.P.; Wang, H.; Jia, Z.; Wang, Y.; Chen, W. Bibliometric analysis of biochar research in 2021: A critical review for development, hotspots and trend directions. *Biochar* **2023**, *5*, 6. [CrossRef]
43. Qin, F.; Li, J.; Zhang, C.; Zeng, G.; Huang, D.; Tan, X.; Qin, D.; Tan, H. Biochar in the 21st century: A data-driven visualization of collaboration, frontier identification, and future trend. *Sci. Total Environ.* **2022**, *818*, 151774. [CrossRef] [PubMed]
44. Li, D.; Zhao, R.; Peng, X.; Ma, Z.; Zhao, Y.; Gong, T.; Sun, M.; Jiao, Y.; Yang, T.; Xi, B. Biochar-related studies from 1999 to 2018: A bibliometrics-based review. *Environ. Sci. Pollut. Res.* **2020**, *27*, 2898–2908. [CrossRef] [PubMed]
45. Nan, H.; Wang, L.; Luo, D.; Zhang, Y.; Liu, G.; Wang, C. A bibliometric analysis of biochar application in wastewater treatment from 2000 to 2021. *Int. J. Environ. Sci. Technol.* **2023**, *20*, 13957–13974. [CrossRef]
46. Zama, E.F.; Reid, B.J.; Arp, H.P.H.; Sun, G.; Yuan, H.; Zhu, Y. Advances in research on the use of biochar in soil for remediation: A review. *J. Soils Sediments* **2018**, *18*, 2433–2450. [CrossRef]
47. Liu, K.; Liang, J.; Zhang, N.; Li, G.; Xue, J.; Zhao, K.; Li, Y.; Yu, F. Global perspectives for biochar application in the remediation of heavy metal-contaminated soil: A bibliometric analysis over the past three decades. *Int. J. Phytorem.* **2023**, *25*, 1052–1066. [CrossRef] [PubMed]

48. Thangagiri, B.; Sivakumar, R. Biochar for toxic chromium removal: Its impacts, mechanism, and future direction. *Biomass Convers. Biorefin.* **2023**, 28. [CrossRef]
49. Arias, C.M.; Silva, L.F.S.D.; Soares, M.R.; Forti, V.A. A bibliometric analysis on the agricultural use of biochar in Brazil from 2003 to 2021: Research status and promising raw materials. *Renew. Agr. Food Syst.* **2023**, *38*, 19. [CrossRef]
50. Ajibade, S.; Nnadozie, E.C.; Iwai, C.B.; Ghotekar, S.; Chang, S.W.; Ravindran, B.; Awasthi, M.K. Biochar-based compost: A bibliometric and visualization analysis. *Bioengineered* **2022**, *13*, 15013–15032. [CrossRef]
51. Jiao, Y.; Li, D.; Wang, M.; Gong, T.; Sun, M.; Yang, T. A scientometric review of biochar preparation research from 2006 to 2019. *Biochar* **2021**, *3*, 283–298. [CrossRef]
52. Yan, T.; Xue, J.; Zhou, Z.; Wu, Y. The trends in research on the effects of biochar on soil. *Sustainability* **2020**, *12*, 7810. [CrossRef]
53. Arfaoui, A.; Ibrahimi, K.; Trabelsi, F. Biochar application to soil under arid conditions: A bibliometric study of research status and trends. *Arab. J. Geosci.* **2019**, *12*, 45. [CrossRef]
54. Noyons, E.C.M.; Moed, H.F.; Luwel, M. Combining mapping and citation analysis for evaluative bibliometric purposes: A bibliometric study. *J. Am. Soc. Inf. Sci.* **1999**, *50*, 115–131. [CrossRef]
55. Baker, H.K.; Kumar, S.; Pandey, N. Forty years of the Journal of Futures Markets: A bibliometric overview. *J. Futures Mark.* **2021**, *41*, 1027–1054. [CrossRef]
56. Aria, M.; Cuccurullo, C. Bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
57. Wang, X.; Xu, Z.; Qin, Y. Structure, trend and prospect of operational research: A scientific analysis for publications from 1952 to 2020 included in Web of Science database. *Fuzzy Optim. Decis. Mak.* **2022**, *21*, 649–672. [CrossRef]
58. van Eck, N.J.; Waltman, L. Software survey: Vosviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
59. Chen, Y.; Chen, C.M.; Liu, Z.Y.; Hu, Z.G.; Wang, X.W. The methodology function of Citespace mapping knowledge domains. *Stud. Sci. Sci.* **2015**, *33*, 242–253.
60. Chen, C. Science mapping: A systematic review of the literature. *J. Data Inf. Sci.* **2017**, *2*, 1–40. [CrossRef]
61. Akın, M.; Bartkiene, E.; Özogul, F.; Eyduran, S.P.; Trif, M.; Lorenzo, J.M.; Rocha, J.M. Conversion of organic wastes into biofuel by microorganisms: A bibliometric review. *Clean. Circ. Bioeconomy* **2023**, *6*, 100053. [CrossRef]
62. Lehmann, J.; Rillig, M.C.; Thies, J.; Masiello, C.A.; Hockaday, W.C.; Crowley, D. Biochar effects on soil biota-A review. *Soil Biol. Biochem.* **2011**, *149*, 107940. [CrossRef]
63. Li, Y.; Hu, S.; Chen, J.; Müller, K.; Li, Y.; Fu, W.; Lin, Z.; Wang, H. Effects of biochar application in forest ecosystems on soil properties and greenhouse gas emissions: A review. *J. Soil. Sediments* **2018**, *18*, 546–563. [CrossRef]
64. Wang, J.; Xiong, Z.; Kuzyakov, Y. Biochar stability in soil: Meta-analysis of decomposition and priming effects. *GCB Bioenergy* **2016**, *8*, 512–523. [CrossRef]
65. Dymov, A.A.; Gorbach, N.M.; Goncharova, N.N.; Karpenko, L.V.; Gabov, D.N.; Kutyavin, I.N.; Startsev, V.V.; Mazur, A.S.; Grodnitskaya, I.D. Holocene and recent fires influence on soil organic matter, microbiological and physico-chemical properties of peats in the European North-East of Russia. *Catena* **2022**, *217*, 106449. [CrossRef]
66. Hyvaluoma, J.; Miettinen, A.; Keskinen, R.; Rasa, K.; Lindberg, H. Structural and chemical changes in pyrogenic organic matter aged in a boreal forest soil. *Pedosphere* **2023**, *33*, 436–447. [CrossRef]
67. Bonhage, A.; Raab, T.; Schneider, A.; Fischer, T.; Ramezany, S.; Ouimet, W.; Raab, A.; Hirsch, F. Vertical SOC distribution and aromatic carbon in centuries old charcoal-rich Technosols. *Eur. J. Soil Sci.* **2022**, *73*, 13293. [CrossRef]
68. Leal, O.D.A.; Dick, D.P.; de la Rosa, J.M.; Leal, D.P.B.; Gonzalez-Perez, J.A.; Campos, G.S.; Knicker, H. Charcoal fine residues effects on soil organic matter humic substances, composition, and biodegradability. *Agronomy* **2019**, *9*, 384. [CrossRef]
69. Knicker, H.; Nikolova, R.; Dick, D.P.; Dalmolin, R.S.D. Alteration of quality and stability of organic matter in grassland soils of Southern Brazil highlands after ceasing biannual burning. *Geoderma* **2012**, *181*, 11–21. [CrossRef]
70. Cheng, C.; Lehmann, J.; Thies, J.E.; Burton, S.D. Stability of black carbon in soils across a climatic gradient. *J. Geophys. Res. Biogeosci.* **2008**, *113*, G2027. [CrossRef]
71. Gueerena, D.T.; Lehmann, J.; Walter, T.; Enders, A.; Neufeldt, H.; Odiwour, H.; Biwott, H.; Recha, J.; Shepherd, K.; Barrios, E.; et al. Terrestrial pyrogenic carbon export to fluvial ecosystems: Lessons learned from the White Nile watershed of East Africa. *Glob. Biogeochem. Cycles* **2015**, *29*, 1911–1928. [CrossRef]
72. Kimetu, J.M.; Lehmann, J. Stability and stabilisation of biochar and green manure in soil with different organic carbon contents. *Aust. J. Soil Res.* **2010**, *48*, 577–585. [CrossRef]
73. Lehmann, J.; Silva, J.D.; Steiner, C.; Nehls, T.; Zech, W.; Glaser, B. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: Fertilizer, manure and charcoal amendments. *Plant Soil* **2003**, *249*, 343–357. [CrossRef]
74. Gonzalez-Perez, J.A.; Gonzalez-Vila, F.J.; Almendros, G.; Knicker, H. The effect of fire on soil organic matter-A review. *Environ. Int.* **2004**, *30*, 855–870. [CrossRef]
75. Thomas, S.C. *Biochar and Its Potential in Canadian Forestry*, 1st ed.; Silviculture Magazine: Vancouver, Canada, 2013; pp. 4–6.
76. Deluca, T.H.; Mackenzie, M.D.; Gundale, M.J.; Holben, W.E. Wildfire-produced charcoal directly influences nitrogen cycling in ponderosa pine forests. *Soil Sci. Soc. Am. J.* **2006**, *70*, 448–453. [CrossRef]

77. Luo, Y.; Yu, Z.; Zhang, K.; Xu, J.; Brookes, P.C. The properties and functions of biochars in forest ecosystems. *J. Soil. Sediments* **2016**, *16*, 2005–2020. [CrossRef]
78. Deluca, T.H.; Aplet, G.H. Charcoal and carbon storage in forest soils of the Rocky Mountain West. *Front. Ecol. Environ.* **2008**, *6*, 18–24. [CrossRef]
79. Shaaban, M.; Van Zwieten, L.; Bashir, S.; Younas, A.; Nunez-Delgado, A.; Chhajro, M.A.; Kubar, K.A.; Ali, U.; Rana, M.S.; Mehmood, M.A.; et al. A concise review of biochar application to agricultural soils to improve soil conditions and fight pollution. *J. Environ. Manag.* **2018**, *228*, 429–440. [CrossRef]
80. Hossain, M.Z.; Bahar, M.M.; Sarkar, B.; Donne, S.W.; Ok, Y.S.; Palansooriya, K.N.; Kirkham, M.B.; Chowdhury, S.; Bolan, N. Biochar and its importance on nutrient dynamics in soil and plant. *Biochar* **2020**, *2*, 379–420. [CrossRef]
81. Gomez, J.D.; Denef, K.; Stewart, C.E.; Zheng, J.; Cotrufo, M.F. Biochar addition rate influences soil microbial abundance and activity in temperate soils. *Eur. J. Soil Sci.* **2014**, *65*, 28–39. [CrossRef]
82. Dutta, T.; Kwon, E.; Bhattacharya, S.S.; Jeon, B.H.; Deep, A.; Uchimiya, M.; Kim, K. Polycyclic aromatic hydrocarbons and volatile organic compounds in biochar and biochar-amended soil: A review. *GCB Bioenergy* **2017**, *9*, 990–1004. [CrossRef]
83. Buss, W. Pyrolysis solves the issue of organic contaminants in sewage sludge while retaining carbon-Making the case for sewage sludge treatment via pyrolysis. *ACS Sustain. Chem. Eng.* **2021**, *9*, 10048–10053. [CrossRef]
84. Hart, S.; Luckai, N. Charcoal function and management in boreal ecosystems. *J. Appl. Ecol.* **2013**, *50*, 1197–1206. [CrossRef]
85. Zhang, X.; Xie, H.; Liu, X.; Kong, D.; Zhang, S.; Wang, C. A novel green substrate made by sludge digestate and its biochar: Plant growth and greenhouse emission. *Sci. Total Environ.* **2021**, *797*, 149194. [CrossRef] [PubMed]