RSC Advances

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Cite this: RSC Adv., 2018, 8, 28700

Research on biochar *via* a comprehensive scientometric approach†

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Received 3rd July 2018
Accepted 30th July 2018

DOI: 10.1039/c8ra05689g

rsc.li/rsc-advances

A comprehensive statistical study related to biochar was conducted by using the scientometric method. The publications are mainly in the form of articles (over 16 000), accounting for 87.7% of the total, which demonstrates that researchers have great interest in this research field. Among these articles, 96.8% were written and published in English and came from 2655 different journals. The rate of increase in the annual number of publications was rapid from 2010 to 2017, and it was predicted that the cumulative number of articles concerning biochar will exceed 20 000 by the year 2020. At least one article from 154 countries or regions has been published, and every continent except Antarctica has had articles published over the past 20 years period. The percentage of collaborative articles was 71.9% and the collaboration between the USA and China has been the most fruitful. In addition, the Chinese Academy of Sciences is the research institute with the most publications. Furthermore, over 60% of the articles were published as a result of the cooperation and connection between the Chinese Academy of Sciences and the University of Chinese Academy of Sciences. The article published in *Nature* had the highest citation numbers, while *Environmental Science & Technology* had the most articles (4) that were selected as the top 20 for the most-cited articles. The agriculture research category had the highest average citations among the top four categories (*i.e.*, environmental sciences and ecology, agriculture, chemistry and engineering).

1. Introduction

Nowadays, environmental pollution and energy shortage are the two major global challenges in the world. According to WHO,[1] about 3 million deaths per year are related to the outdoor air pollution. Besides, soil pollution can seriously damage the ecosystem and is harmful to human health.[2] About 80.0% of global wastewater is released into the environment without treatment and polluted drinking water and poor sanitation conditions have led to 80 million deaths worldwide in 2012.[3] Regarding the energy shortage, the primary energy consumption has been increasing continuously globally,[4] and the global reserves of oil, gas and coal will be exhausted in 25, 27 and 97 years, respectively.[5] In order to solve these problems, many research efforts involving various methods have been made, and among these, biochar has drawn significant attention. According to the International Biochar Initiative,[6] biochar is defined as a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. Biochar, an alternative name for charcoal, is used widely in several areas, *e.g.*, fuel energy. Biochar has many applications, which include solid biofuel,[7–9] carbon sequestration,[10] water or air pollutant adsorbents,[11–14] catalysts,[15–17] and soil amendments.[18]

With the development of science and technology, people living in this age (the big data era) are surrounded by an incredible amount of information and usually have much more and easier methods to get information than they did several decades before. Even though big data can provide convenience, it can also cause confusion. For example, there are plenty of journals publishing hundreds or even thousands of new papers every year concerning biochar. Traditional reviews mainly focus on the small specific field, so people cannot easily consider or judge a special research area from the macroscale. Fortunately, scientometric evaluations based on big data can make up for this shortage.[19] For the reasons discussed above, biochar is a hot research topic that has been shown a lot of interest from researchers. Even though Coelho *et al.*[20] used the scientometric approach to study the research status concerning macroalgal biomass as a source of biofuel feedstock, there is no scientometric paper about the entire biochar research area on the web of science. It is therefore urgent and necessary to provide a timely update, and the aim of this paper is to utilize a scientometric approach to provide a comprehensive statistical

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† Electronic supplementary information (ESI) available. See DOI: 10.1039/c8ra05689g

evaluation of the research on biochar published and indexed over the last two decades (from 1998 to 2017).

2. Materials and methods

The data concerning biochar were obtained from the database of the Web of Science Core Collection using the Science Citation Index Expanded (SCI-EXPANDED) on March 28th, 2018. The time range is from 1998 to 2017, and the search terms used in this paper were ("Charcoal*" OR "biochar*" OR "bio-char*"). According to the research results, the number of publications that met these search criteria was 18 908. Then, the "Save to other file formats" option was selected, and full records of these publications were downloaded as .txt files with the Tab-delimited (Win, UTF-8) file format, then several software programs such as Microsoft Excel, SPSS, BibExcel, and Gephi, Originlab Pro 2017 *etc.* were used to analyze the obtained original data. Detailed data processing procedures were available elsewhere.[19] In this paper, several major parts of these full records were studied, including document types, titles, languages, publication years, publishers, countries, keywords, citations, and research areas.

3. Results and discussion

3.1 Document types

These 18 908 publications were divided into 12 document types, namely article, proceedings paper, review, meeting abstract, letter, editorial material, news item, correction, book chapter, reprint, book review and biographical-item. Due to the relatively small numbers, letters, editorial materials, news items and corrections were classified as 'others'. As shown in Fig. 1, the main type of these publications was articles, accounting for 87.7% of the total. The second and third document types were proceedings and review papers, and the percentages of these two document types were 4.98% and 3.89%, respectively. The fourth and fifth document types were meeting abstracts and others, accounting for 1.73% and 1.72%, respectively.

The order of document types was similar to previous scientometric research in other research areas.[21,22] Compared with other document types, articles could better reflect the progress of the biochar area, and it was also the dominant type of these 18 908 publications; therefore, the following analysis is based on articles only.

3.2 Publishing languages

The distribution of publishing languages in these articles is shown in Fig. 2. The results demonstrated that 96.8% (16 052) of the articles were written and published in English, followed by Portuguese with 1.01%. Other languages accounted for 2.16% (358) of the total articles. The results are consistent with most researchers' expectations, after all, most SCI journals are published in English. For this reason, language cannot be used as an indicator to judge the interests of different countries concerning biochar. However, it can be inferred that The Portuguese Republic and Brazil, which are two major Portuguese-speaking countries, had good performance in biochar research.

3.3 Publishing trend

The publishing trend for articles is shown in Fig. 3. On the whole, over 16 000 articles were published on the topic of biochar, which demonstrated that researchers had a great interest in this research field. From 1998 to 2003, the annual numbers of publications on this topic were similar, and about 400 articles were published every year. From 2005 to 2009, there was a slow increase in annual publications. However, from 2010 to 2017, there was an obvious increase in the annual number of publications, and the max annual publications number reached over 2200 in 2017. According solely to the publishing trend, before 2009, global researchers did not widely realize the importance of biochar, and their interest in biochar was limited. Under the global environmental pollution and energy shortage situation, it might be the various applications and relatively low cost of biochar that promoted its development. Besides, there was no increment plateau as shown in Fig. 3, which means that more articles might be published every year in the future. In order to better show the increment trend, the fitting method[23] was used to calculate the relation between the cumulative number of publications and years (eqn (1) with $R^2 = 0.9923$). According to the equation, the cumulative number of articles concerning biochar from 1998 to 2020 will exceed 20 400. It should be pointed out that although the quadratic fitting method is commonly adopted by researchers to make predictions due to its simplicity, it has its limitations. Strictly speaking, it is not accurate from the perspective of data analysis because it involves a special kind of data analysis, namely time series data analysis. To be more specific, a further residual analysis often

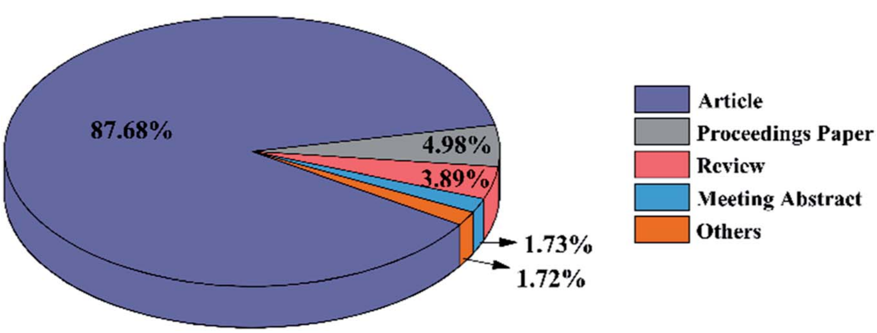

Fig. 1 Percentage distribution of document types.

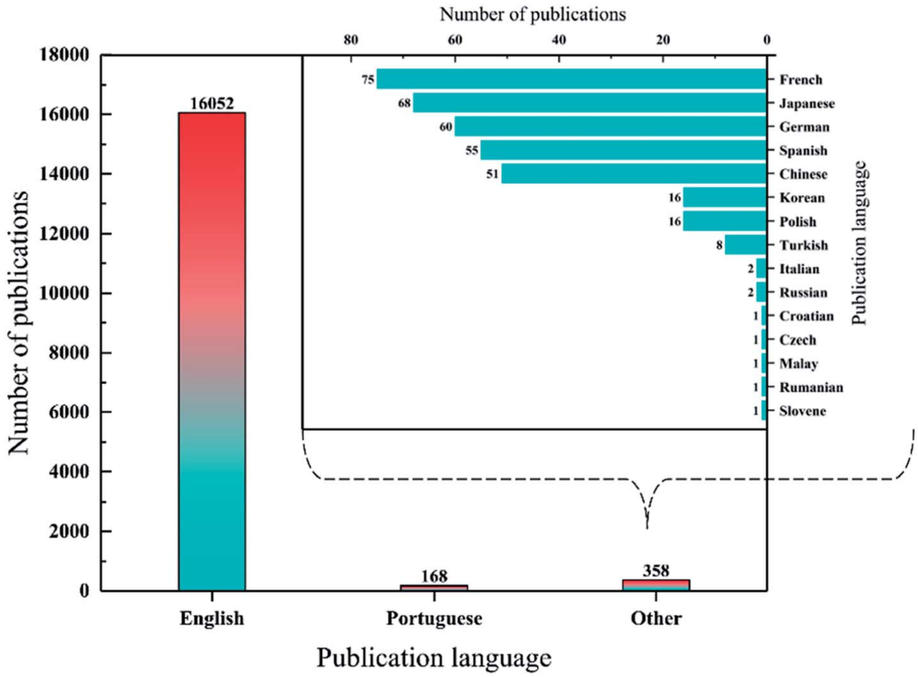

Fig. 2 Number of publications in different languages.

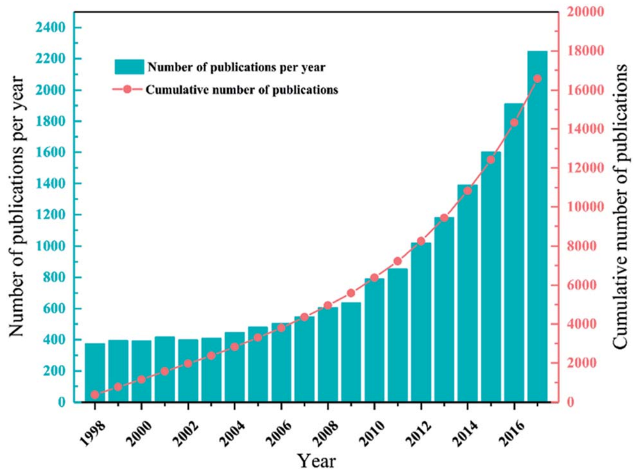

Fig. 3 Number of publications per year and the cumulative number of publications on biochar from 1998 to 2017.

reveals autocorrelation of the residuals rather than normal distribution, the latter of which is usually an assumption of regression analysis.

$$Y = 41.02291 \times X^2 - 163959.62779 \times X + 1.63829 \times 10^8 \quad (1)$$

where Y represents the cumulative number of publications, X represents years.

3.4 Publishing journals

The 16 578 articles researched in this study came from 2655 different journals. However, considering the cumulative number of articles concerning biochar for each journal, 87.6% of the journals had less than 10 articles published during the past two decades. The information from the top 20 most publishing journals is summarized in Table 1. The total number of publications concerning biochar from these 20 journals was 3285, accounting for 19.8% of the total publications in the 20 years span. For these 20 journals, the average number of articles published on the topic of biochar was 164.3 over the past 20 years. As suggested by Table 1, the top three most common publishers were Elsevier, Springer and American Chemical Society (ACS), and Elsevier had the dominating number of journals compared with the other two publishers. The 20 journals spread across 4 countries, and the United Kingdom occupied first place, taking up 40.0%. Besides, all these four countries are developed countries, which possibly indicates that there is a long way for developing countries to create their top journals concerning biochar. As revealed by Table 1 and Fig. 4, *Bioresource Technology* had the most articles published (417) and its H-index (64) was also the highest, while the H-indexes of other journals were in total less than 60. Moreover, the total number of citations of *Bioresource Technology* (14 117) was the highest. Nevertheless, in reference to the average number of citations per paper, *Environmental Science & Technology* occupied the first place, with the H-index being equal to 59. According to Fig. 4, the H-index had a good linear relation with an average number of citations per paper, with the Pearson correlation being significant at the 0.01 level and R^2 being equal to 0.814. The number of publications per year for the top 20 most publishing journals is shown in Fig. 5. In summary, the publication trends for these 20 journals were similar to the cumulative number of publications shown in Fig. 3. However, for these 20 journals, there was a rapid increment from 2007,

Table 1 Top 20 most publishing journals

ID No.	Journal name	Article numbers	Publisher	Country
1	*Bioresource Technology*	417	Elsevier	Netherlands
2	*Holocene*	282	Sagepub	United Kingdom
3	*Chemosphere*	236	Elsevier	United Kingdom
4	*Science of the Total Environment*	188	Elsevier	Netherlands
5	*Journal of Analytical and Applied Pyrolysis*	184	Elsevier	Netherlands
6	*Environmental Science & Technology*	176	ACS	United States
7	*Quaternary International*	165	Elsevier	United Kingdom
8	*Journal of Archaeological Science*	147	Elsevier	United Kingdom
9	*Environmental Science and Pollution Research*	146	Springer	Germany
10	*Palaeogeography Palaeoclimatology Palaeoecology*	138	Elsevier	Netherlands
11	*Vegetation History and Archaeobotany*	132	Springer	United States
12	*Quaternary Science Reviews*	127	Elsevier	United Kingdom
13	*Journal of Environmental Management*	126	Elsevier	United Kingdom
14	*Environmental Pollution*	121	Elsevier	United Kingdom
15	*Energy & Fuels*	120	ACS	United States
16	*PLoS One*	119	PLOS	United States
17	*Biomass & Bioenergy*	118	Elsevier	United Kingdom
18	*Journal of Hazardous Materials*	115	Elsevier	Netherlands
19	*Quaternary Research*	115	Elsevier	United States
20	*Fuel*	113	Elsevier	United Kingdom

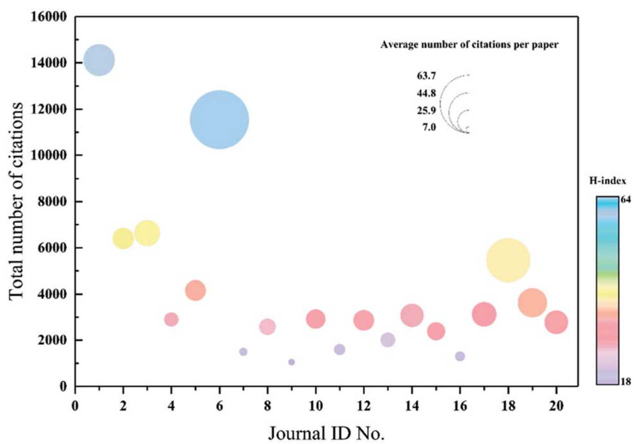

Fig. 4 Total number of citations, average number of citations per paper, and *H*-index of the top 20 most publishing journals.

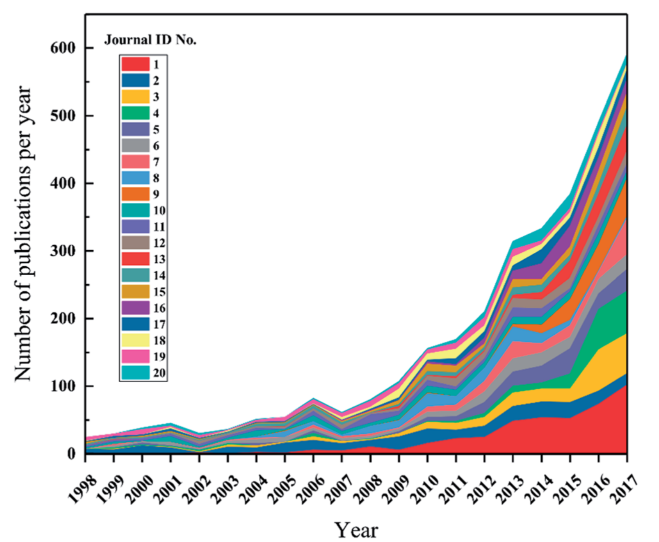

Fig. 5 Number of publications per year for the top 20 most publishing journals.

while the rapid increment of the total 2655 journals was from 2009. Therefore, these 20 most publishing journals could basically reflect the development trend of biochar research. Besides, the publications of four journals had a high rapid increment in the past three years, including *Bioresource Technology*, *Chemosphere*, *Science of the Total Environment* and *Quaternary International*.

3.5 Publishing countries/regions

Viewing these 16 578 articles from the angle of publishing countries or regions, 154 countries or regions published at least one article on the topic of biochar during the past 20 years. As shown in Fig. 6, in general, the percentage of collaborative articles was 71.9%, which was much higher than that of independent articles. Further analysis found that the number of international collaborative articles was almost 1.5 times that of national collaborative articles. It was obviously seen from the situation that international cooperation was common and important in the biochar research area. In order to study the global articles distribution and country cooperation in detail, the global articles distribution and cooperation network map is shown in Fig. 7. It revealed that there were 38 countries or regions that published more than 100 articles in the 20 years span. Except for Antarctica, all the other continents had articles concerning biochar published during the 20 years period, which revealed that the biochar research is a hot research topic worldwide. According to Fig. 7, North America, East Asia, Western Europe, East South America and Oceania published more articles compared with other areas. It might be the larger

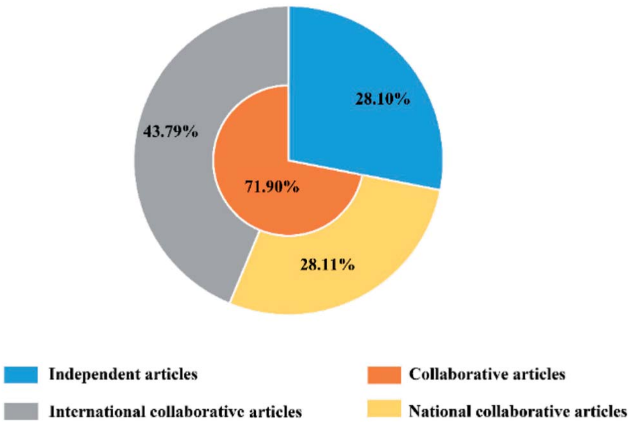

Fig. 6 Percentage distribution of cooperation.

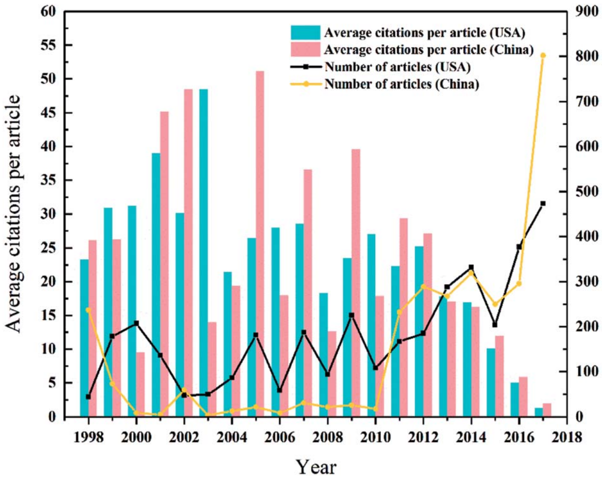

Fig. 8 The growth trends of articles and citations per year in the USA and China from 1998 to 2017.

energy consumption of these areas that caused the differences in research interests, which could have further led to the different publishing distributions. Among these counties or regions, the United States and China were the top two most publishing countries, and published 3625 and 2984 articles, respectively. The sum of articles for the United States and China accounted for 29.0% of the total articles. The green lines in Fig. 7 mean the cooperation between two countries or regions, and the width of the line means the cooperation times. As suggested by Fig. 7, the United States had the largest and most complicated cooperation net. Among these countries and regions, the USA had the most fruitful collaborations with China. The cooperation between the UK and USA, and between Germany and the USA occupied the second and third places, respectively.

Because the USA and China were the top two most publishing countries, the growth trends for articles and citations per year in the USA and China from 1998 to 2017 were further investigated (Fig. 8). As for the growth trends of articles, the average numbers of articles per year were relatively lower for both countries during the 2002–2010 time period. The correlation between the USA and China for the growth trends of articles was negative from 1998 to 2003, while the correlation became positive since 2004. Generally, the USA had more articles published in most years, but China has undergone a rapid increment in the number of articles since 2010 and reached the highest number (802) in 2017. This progress was possibly due to more attention being directed toward environmental problems and increasing investments in scientific research.[24] From the perspective of average citations per article, China was higher than the USA in 11 years during the 20 years span. The average number of citations per article for the USA (19.13) was higher

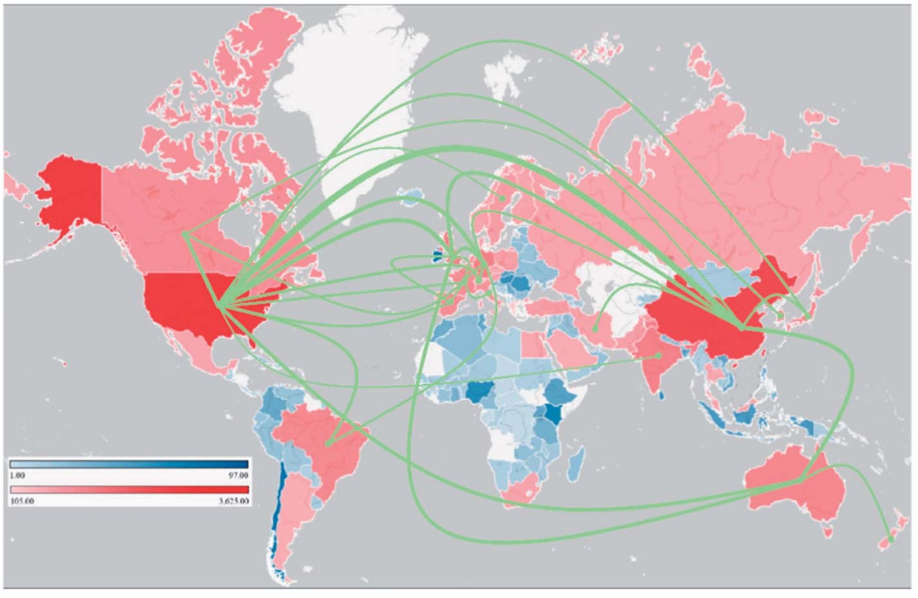

Fig. 7 Global article distribution and cooperation network map (countries or regions with collaborations of more than 50 times are connected by lines).

Table 2 Top 20 most publishing research institutes

ID No.	Research institute	Article numbers	Country
1	Chinese Academy of Sciences	554	China
2	USDA-ARS	296	USA
3	Zhejiang University	175	China
4	Spanish National Research Council	163	Spain
5	University of Florida	152	USA
6	Cornell University	127	USA
7	University of Sao Paulo	127	Brazil
8	University of Chinese Academy of Sciences	119	China
9	University of Illinois	115	USA
10	Kangwon National University	112	South Korea
11	Nanjing Agriculture University	108	China
12	University of Bern	105	Switzerland
13	The National Center for Scientific Research	95	France
14	University of Oxford	94	UK
15	The University of Queensland	94	Australia
16	The Australian National University	93	Australia
17	University of Minnesota	93	USA
18	The University of Edinburgh	91	UK
19	Federal University of Vicosa	90	Brazil
20	The University of Newcastle	88	Australia

than that of China (15.55) during the 20 years period. However, it did not mean that the USA had a greater percentage of high-quality articles because China published much more articles than the USA in 2017 and the articles published in 2017 had relatively lower citations due to the time.

3.6 Publishing institutes

The number of records containing publishing institutes was 16 527. According to these records, as a whole, over 10 000 institutes took part in the publication of articles on the topic of biochar, and 76 institutes contributed no less than 50 articles in the past 20 years span. As shown in Table 2, the Chinese Academy of Sciences published the most articles (554) among a huge number of research institutes. The United States Department of Agriculture-Agriculture Research Service (USDA-ARS) and Zhejiang University occupied the second and third places. The number of articles from the Chinese Academy of Sciences exceeded the sum from USDA-ARS and Zhejiang University. The total number of citations per institute, average number of citations per paper, and *H*-index of the top 20 most publishing research institutes are shown in Fig. 9. In terms of the *H*-index, the Chinese Academy of Sciences and USDA-ARS were both 51.0, the highest of the top 20 most publishing research institutes. However, regarding the average number of citations per paper (ANCPP) for these 20 institutes, Cornell University had a much better performance (83.7). The ANCPP for other institutes was no more than 55.0. Besides, Cornell University was the only research institute that the ANCPP was higher than the *H*-index, which means that the percentage of highly cited articles from Cornell University was higher.

Over 60% of the articles were published as a result of the cooperation between at least two research institutes. Furthermore, 501 pairs of institutes took part in the publication of articles and published one or more articles together. Among these institutes, the connection between Chinese Academy of Sciences and University of Chinese Academy of Sciences was the strongest and they published 36 articles together. However, the cooperation times for other institutes were no more than 10. As suggested by Fig. 10, in summary, the cooperation among these research institutes was not strong, and the network graph is relatively simple and clear. Among the top 20 most publishing research institutes, Chinese Academy of Sciences and USDA-ARS ranked top two in terms of the cooperation times, and both had collaborations with 4 different research institutes. Interestingly, Chinese Academy of Sciences and USDA-ARS had good performances in publishing articles on the topic of biochar, but there was no cooperation between them. It is reasonable to infer that more studies will be published if the Chinese Academy of Sciences and USDA-ARS cooperate together in the future.

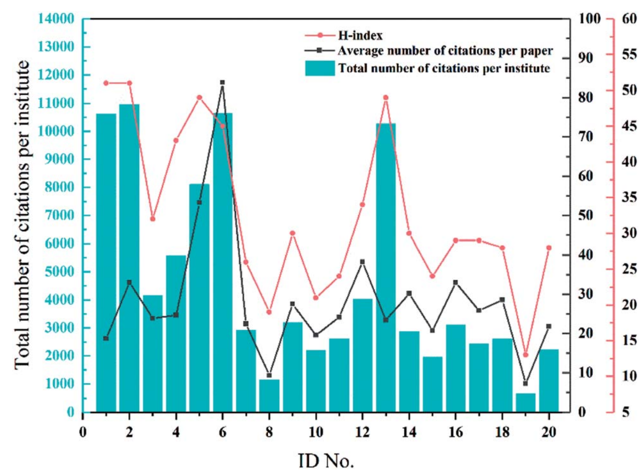

Fig. 9 Total number of citations per institute, average number of citations per paper, and *H*-index of the top 20 most publishing research institutes.

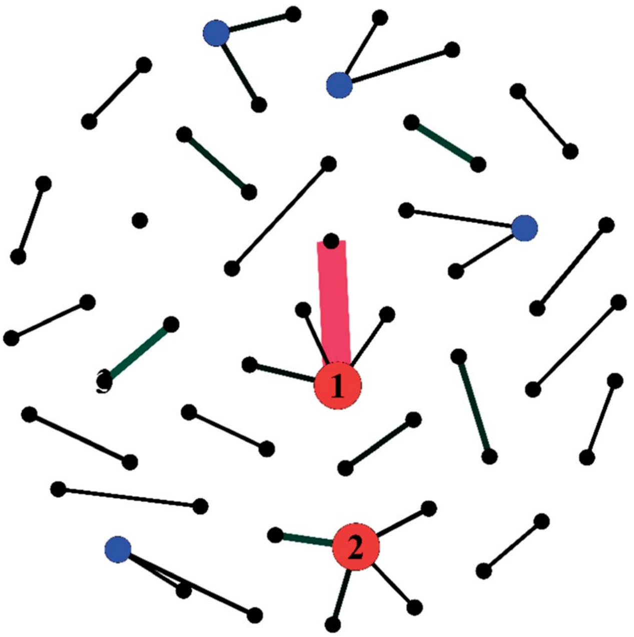

Fig. 10 Research Institute collaboration network graph (Institutes whose collaborations exceeded 5 times are connected by lines. The size and the color of the circles represent the number of research institutes connected; a bigger and brighter circle means that more research institutes were connected with this institute. The width and color of the connecting line represent the connection times; a thicker and brighter line means more connections between two institutes. 1-Chinese Academy of Sciences; 2-United States Department of Agriculture-Agriculture Research Service; 3-Zhejiang University).

3.7 Most-cited papers

The top 20 most-cited articles on the topic of biochar during the past 20 years period are summarized in Table 3, and citations, journal name, research category and published year (shown in reference column in Table 3) were collected as well. It should be noted that the research categories in Table 3 are not mutually exclusive, and were the major research direction of one article. For instance, an article may have also involved materials analysis but the major aim or direction of the article was soil remediation. Hence, the research category of this article was also classified as soil remediation instead of materials. As revealed in Table 3, the biochar had a lot of applications and the research categories were also various, while the materials were the most studied. Besides, the citations number for the materials was the highest among the 9 research categories. From the perspective of the journal, it was obvious that the article published in *Nature* had the highest citation number, while *Environmental Science & Technology* had the most articles (4) that were selected as the top 20 most-cited articles.

3.8 Title analysis

As suggested by Fig. 11, for the occurrence frequency, "biochar" and "charcoal" occupied the first and second place, respectively. This was due to biochar and charcoal being the research terms and also the topics of this paper and was in agreement with the expectation. The third highest frequency word was "soil", which indicated that research concerning soil was the most frequent subfield. This was reasonable because it was demonstrated that land degradation would have a great negative influence on the food security and crop yields worldwide.[45] The reasons causing land degradation were various, including growing exhaustive crops, using too much chemical fertilizers and using improper agriculture practices.[46,47] Biochar had some good characteristics, including being rich in nutrients, improving the nutrient utilization efficiency of crops, adjusting soil pH and removal of soil pollutants, *etc.*[48–52] Due to these characteristics, biochar could improve the soil quality, thus the research concerning biochar and soil(s) were relatively hotter. The further analysis of these 2062 articles containing soil or soils revealed that "carbon" and "effects" were the first and second most used words, after soil(s) and biochar. Therefore, research concerning

Table 3 Top 20 most-cited articles

No.	Citations	Journal name	Research category	Reference
1	1973	*Nature*	Material	25
2	863	*Thrombosis and Haemostasis*	Medicine	26
3	706	*Environmental Science & Technology*	Material	27
4	694	*Soil Science Society of America Journal*	Material	28
5	693	*Forest Ecology and Management*	Forestry	29
6	685	*Energy Conversion and Management*	Energy	30
7	660	*Plant and Soil*	Agriculture	31
8	611	*Frontiers in Ecology and the Environment*	Energy	32
9	534	*Nature Communications*	Geochemistry & geophysics	33
10	533	*Australian Journal of Soil Research*	Soil remediation	34
11	527	*Energy Conversion and Management*	Energy	35
12	524	*Advances in Environmental Research*	Water treatment	36
13	516	*Environmental Science & Technology*	Water treatment	37
14	451	*Organic Geochemistry*	Geochemistry & geophysics	38
15	443	*Plant and Soil*	Agriculture	39
16	438	*Soil Biology & Biochemistry*	Soil remediation	40
17	438	*Environmental Science & Technology*	Water treatment	41
18	431	*Soil Biology & Biochemistry*	Soil biology	42
19	415	*Plant and Soil*	Agriculture	43
20	413	*Environmental Science & Technology*	Materials	44

Fig. 11 Word cloud generated from the top 500 titles based on frequency.

carbon and biochar effects were the most frequently studied in the soil subfield during the past 20 years. Besides, "activated", "adsorption", "removal" and "production" were another four common words appearing in the titles. It is possible that related researches were also hot subfields of biochar. In order to get a comprehensive analysis, the keyword analysis was also studied and showed similar results to Section 3.7 and 3.8. The information is given in detail in the ESI.†

3.9 Research category analysis

In this section, the research categories discussed were defined by the Web of Science as shown in the SC column. There were 16 572 articles having research categories classified by the Web of Science, and these articles came from 124 different research areas. The total number of appearances of these research categories was 27 811, and every article had 1.68 categories on average. ESE (environmental sciences & ecology), AGR (agriculture), CHE (chemistry) and ENG (engineering) were the top four most common research categories and the only four categories that appeared over 2000 times. Besides, the total appearance time of these four research categories were 10 652, which reached 38.30% of the total appearance times of entire articles. The numbers of articles and average citations per paper in the top four research categories every year from 1998 to 2017 were analyzed (Fig. 12). For these four research categories, in most of the years, there were more articles published than former years. Besides, the increment rate of ESE was the most rapid among these four categories. From the viewpoint of average citations per paper for these four categories, the trend was similar. The average number of citations per paper for ESE was higher than that of AGR before 2002, while the situation was the opposite after 2002. The average number of citations per paper for CHE was lower compared to ENG, and occupied fourth place among these four research categories. Further analysis found that some

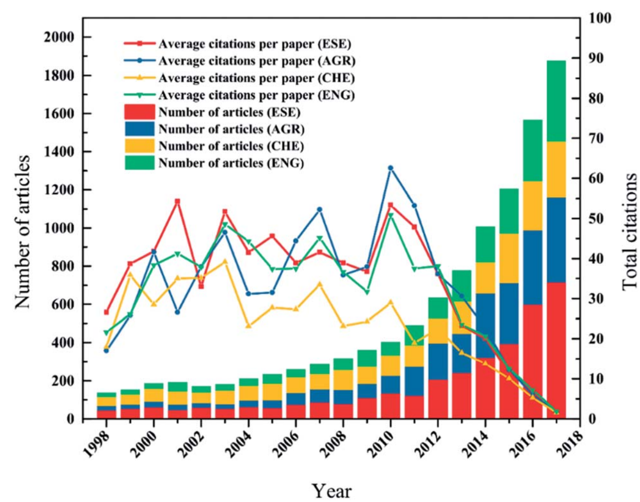

Fig. 12 Number of articles and average citations per paper in the top four research categories every year from 1998 to 2017.

articles concerning soil and soil remediation were classified as agriculture by the Web of Science, and the serious land degradation situation discussed in Section 3.7 might explain the growth trend for agriculture articles.

4. Conclusion

In this article, a comprehensive statistical study was conducted based on the 18 908 publications related to biochar by using the scientometric approach. Over 16 000 articles were published on the topic of biochar, accounting for 87.7% of the total publications, which demonstrated that researchers had a great interest in this research field. Besides, about 96.8% (16 052) of the articles were written and published in English, followed by Portuguese with 1.01%. The increment speed of the annual number of publications was rapid from 2010 to 2017, and it was predicted that the cumulative number of articles concerning biochar will reach 20 000 by 2020. The articles researched in this study came from 2655 different journals, and *Bioresource Technology* had the most related articles published, the highest *H*-index and the most total citations. Viewing these articles from the angle of publishing countries or regions, 154 countries or regions published at least one article, and all the continents except Antarctica had articles published during the 20 years period. The percentage of collaborative articles was 71.9%, and the cooperation between the USA and China was the most fruitful. Besides, the Chinese Academy of Sciences was the most publishing research institute. Also, over 60% of the articles were published as a result of institute cooperation, and the connection between the Chinese Academy of Sciences and the University of Chinese Academy of Sciences was the strongest. From the publishing journal perspective, the articles published in *Nature* had the highest number of citations, while *Environmental Science & Technology* had the most articles (4) that were selected as the top 20 most-cited articles. ESE, AGR, CHE and ENG were the top four most common research categories among the 124 categories. Furthermore, the AGR category had the highest number of average citations for these top four categories.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgements

This work was financially supported by Key Technologies R & D Program of Tianjin [16YFZCSF00410], Natural Science Foundation of Tianjin [15JCQNJC15200] and the Fundamental Research Funds for the Central Universities.

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