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Bibliometric analysis of scientific research on biochar

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ABSTRACT

Objective: To identify the most relevant aspects of global scientific research on biochar in terms of number of articles published, main authors and publishing countries, citation, main issues of scientific journals, funding institutions and general trends.

Design/Methodology/Approach: A bibliometric study was carried out in the Scopus database. The word "biochar" was used in the search engine. The search was limited to articles and reviews published from 2009 to March 2020. The VOS viewer software was used to identify the main thematic axes and to glimpse the knowledge gaps that exist to date.

Results: A total of 11,444 documents were identified. The trend of work on biochar is on the rise. China and the United States are the countries with the highest number of publications on biochar. Jefferson Lehman and Stephen Josephs are the most cited authors on the subject. Global research on biochar focuses on the mitigating effect of climate change and good properties that biochar has to improve physicochemical properties of the soil. Research on biochar in Mexico is scarce.

Study Limitations/Implications: Biochar is a new technology that is not fully understood.

Findings/Conclusions: Interest in biochar as a multifaceted solution to agricultural and environmental problems is growing at a rapid rate both domestically and internationally.

Keywords: bibliometric analysis, biochar, literature review, Scopus, VOS viewer.

INTRODUCTION

Biochar is a solid material that is a product of the thermochemical conversion (pyrolysis) of biomass at over 250 °C in a total or partial absence of oxygen. The result of this process is a low density porous material, rich in carbon, with ample specific surface area, high CEC, generally alkaline, and very resistant to physicochemical and biological degradation (Lehmann and Joseph, 2009). Biochar is produced with the purpose of generating a soil enhancer and as a carbon sink.

Because of the nature of biochar, it possesses properties that can improve the physicochemical characteristics of agricultural land, such as higher moisture and nutrient retention, greater aeration and root penetration, it reduces the bioavailability of potentially toxic elements and is a niche for beneficial microorganisms (Liu *et al*., 2013; Zheng

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et al., 2013; Bruun *et al*., 2014; Hammer *et al*., 2014; Liu *et al*., 2017; Obia *et al*., 2016 Peng *et al*., 2018; Razzaghi *et al*., 2020), all of which increases soil fertility and productivity. The addition of this carbonaceous product to soil can be a palliative to soil fertility loss and the decline of physical, chemical and biological properties of soils. Besides, it enables the mitigation of greenhouse gas (GHG) emissions and is an option for the management of organic wastes (Jeffery *et al*., 2015).

Within the context of climate change, the production of biochar has been proposed as a promising and feasible strategy to mitigate the concentration of greenhouse gases in the atmosphere (Liu *et al*., 2014; Griscom *et al*., 2017, Woolf *et al*., 2018). Biochar has the potential to modify the fluxes of CO_2, CH_4 and N_2O in the soil, through changes in microbial activity and composition, soil pH and other biogeochemical processes (Van Zwieten *et al*., 2010; Song *et al*., 2016).

The greatest contribution to carbon reduction comes from the carbon stabilized within the biochar (40-50%) (Ibarrola *et al*., 2012). It is estimated that if only a fraction of all the biomass generated worldwide annually was transformed into biochar, it would have a great impact, since the annual capture of CO_2 by plants through photosynthesis is eight times greater than anthropogenic greenhouse gas emissions. In other words, if only 1% of net carbon sequestrated in plant biomass is transformed into biochar, this could mitigate 10% of all current carbon emissions (Woolf *et al*., 2010; Ennis *et al*., 2012).

The potential of biochar as a carbon sink is due to its recalcitrant nature (Singh *et al*., 2012; Han *et al*., 2018), which slows the speed at which C is emitted to the atmosphere. The average residence time of C the biochar in soils is variable. It is estimated that it has the potential to remain for 100-1000 years or even 10,000 years depending on the natural conditions (temperature, precipitation, topography, soil type, vegetation) of the place where it is incorporated (Zimmerman 2010; Cross and Sohi 2013).

While biochar has been the subject of many studies in the last decade. However to date there are still large gaps in knowledge that it would be advisable to address. Research on biochar and the technologies for its efficient implementation are in early development. However, interest in biochar as a multifaceted solution address to agricultural and environmental problems is increasing at an accelerated pace both nationally and internationally. The objective of this study was to identify the most relevant aspects of global scientific research on biochar in terms of the number of published articles, principal authors and publishing countries, citation, subjects of scientific journals, funding institutions, general trends; and to identify the knowledge gaps through analysis of bibliometric data and the creation of co-occurrence network maps.

MATERIALS AND METHODS

During the month of March, 2020, documentary research was undertaken in order to develop a bibliometric analysis on biochar. The Scopus database was consulted, with regards to online peer-reviewed scientific articles. Scopus is an exhaustive citation and summary database that includes millions of records from journals, books and conference proceedings. The word "biochar" was used as a search engine. This word is usually used in English and occasionally in Spanish in the title, abstract or keywords.

The search was limited to articles and reviews carried out within the period from 2009 to March 2020. With the help of intelligent tools to track, analyze and visualize the Scopus research, the annual production of studies published on biochar, the main authors, country of origin of the research, area of knowledge of the scientific journals where they were published and affiliate institutions, were identified. These data were registered in a database on Excel.

Using the VOSviewer software 1.6.14 (Van Eck and Waltman, 2010) the previously constructed database was analyzed and a co-occurrence network map was generated, as well as connectivity networks of keywords. This map allowed the visual identification of the key thematic axes of the research on biochar and highlighted the knowledge gaps that exist to date.

RESULTS AND DISCUSSION

A total of 11,444 documents were retrieved, both articles and reviews. An upward trend of studies on biochar was found (Figure 1). In the past five years alone, 75% of all publications were produced. It is estimated that in 2020 approximately 3110 papers on biochar will be produced.

According to the smart classification made by Scopus, the main sources of scientific journals where biochar research has been published are: bio-resource technologies, environmental sciences, environmental chemistry, science and environmental pollution research and environmental management, in that order (Figure 2).

China and the United States of America are the countries with the most papers on biochar. Both lead in publications on biochar with 63% of the total (Figure 3). In general, in these countries the publications on biochar are in the area of environmental sciences, agricultural and biological sciences. The studies are about the effect of biochar as an adsorbent agent for soil pollutants and as a retainer of nutrients in soil. In Mexico, the number of publications on biochar is scarce; only 41 articles were retrieved, which represents only 0.35% of the total of research papers. Research on biochar in Mexico is focused mainly on its use in the remediation of soils polluted with heavy metals and to retain nitrogen and phosphate nutrients. No papers on biochar were found relating to climate change or as mitigator of greenhouse gas emissions. (Figure 4).

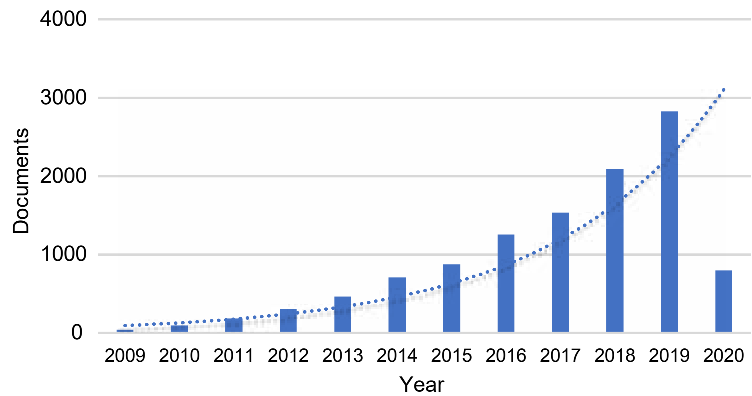

Figure 1. Worldwide production of scientific papers on biochar per year.

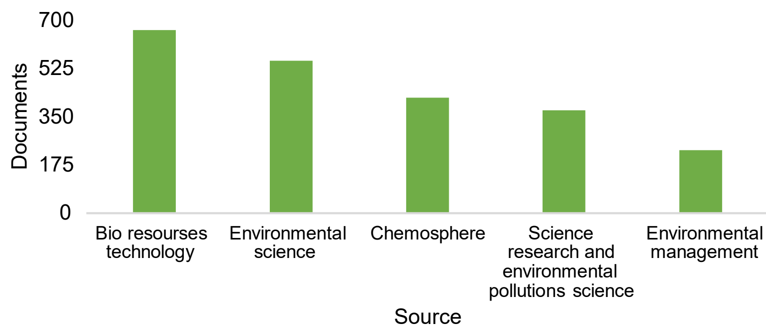

Figure 2. Papers in scientific journals per area of knowledge.

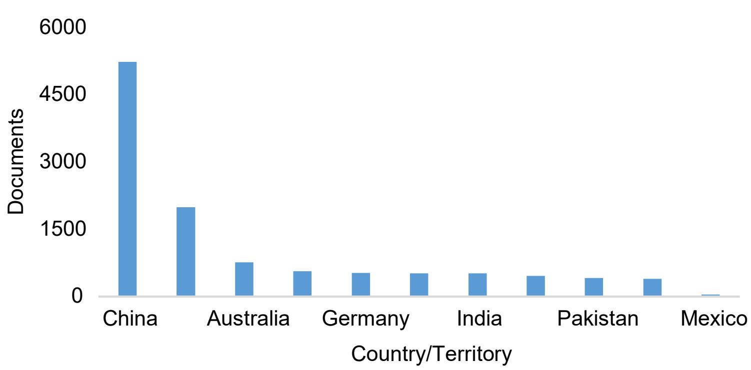

Figure 3. Scientific papers published on biochar by country.

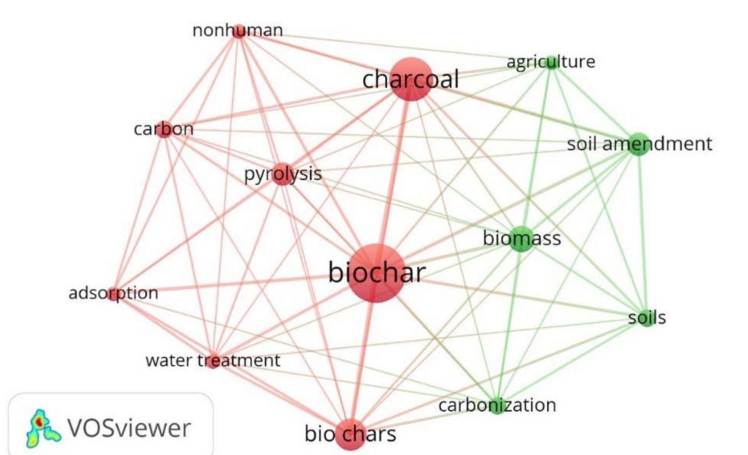

Figure 4. Co-occurrence map of keywords in scientific documents published on biochar in Mexico.

The sources of the publications with the greatest number of citations worldwide are China and the United States of America, followed by the United Kingdom, Australia and Germany. South Korea occupies fourth place with regard to production of scientific papers on biochar; however the papers are not cited as often as those from China, the United States or the United Kingdom (Figure 5). It is evident that publications in English have greater visibility worldwide in the scientific community.

The main authors that have published works on biochar are: Yong Sik Ok from Korea University with 248 studies; Daniel CW Tsang from Hong Kong Polytechnic University with 120 studies; and Bin Gao from University of Florida with 116 (Figure 6). However, Jefferson Lehman and Stephen Joseph are the classic authors, due to their widely recognized book “Biochar

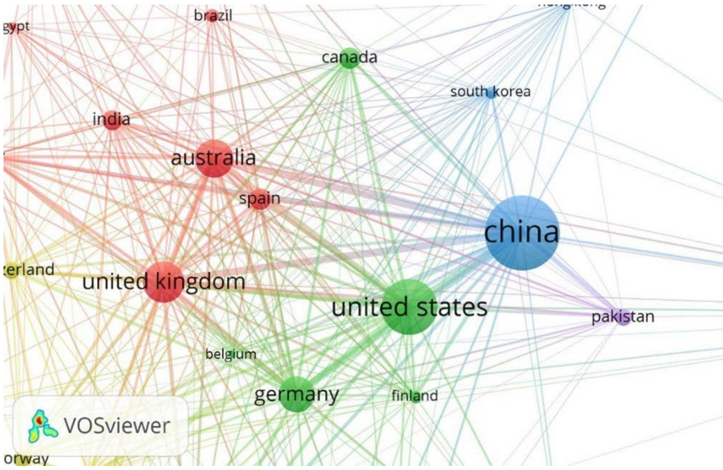

Figure 5. Network map of the citation level of the countries that produce scientific documents on biochar.

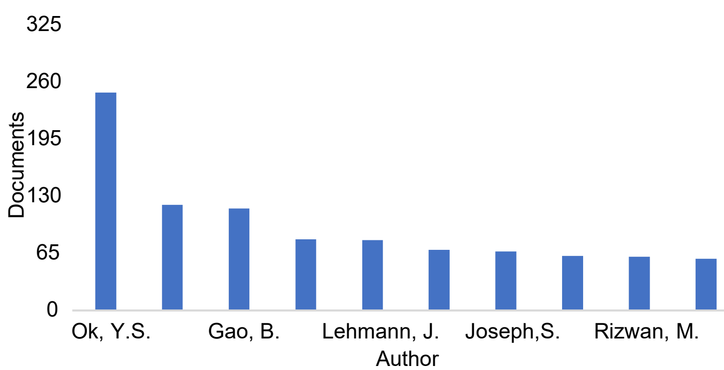

Figure 6. Main authors of research papers and studies on biochar worldwide.

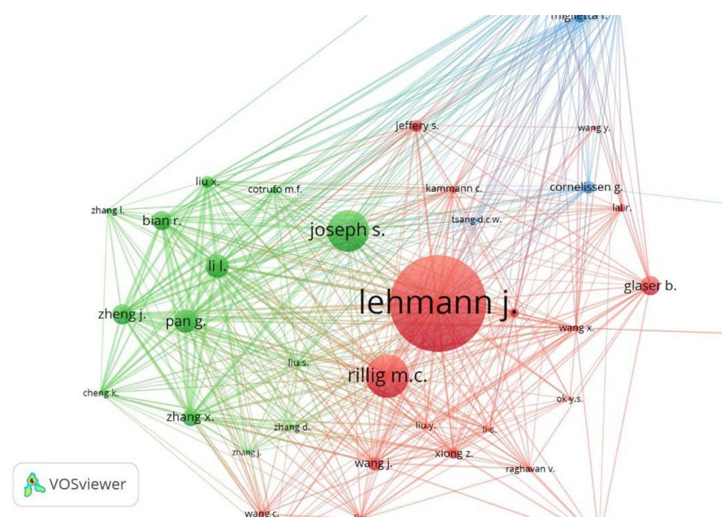

Figure 7. Degree of citation of authors of scientific papers on biochar worldwide.

for environmental management: science, technology and implementation", re-edited in 2015. These two authors, along with Bruno Glaser of Bayreuth University and Matthias C. Rilling, professor of plant ecology at Freie Universität in Berlin, Germany, are the most cited authors on biochar (Figure 7).

The Chinese Academy of Sciences, the Chinese Ministry of Education and the Ministry of Agriculture of the People's Republic of China are the three main institutions in the world that fund research on biochar (Figure 8).

The co-occurence map, using the key words in the 11,444 articles in the Scopus database, revealed the issues relationship between biochar research and other subjects of worldwide interest (Figure 9). The size of the circles is determined by the weight or relevance of the words within the network. That is, the bigger the circles, the bigger the concurrence or citation that the keyword had within the addressed data set. The distance between two circles represents affinity; the closer they are, the higher affinity. The lines represent the level of co-citation. It can be noted that the word "biochar" has great affinity with soil, climate change, fertility, soils, agriculture, soil amendment, carbon, pyrolysis, and biomass. Due to the size of the network it is not possible to see, but the green circles next to biochar correspond to carbon sequestration and climate change.

Zooming in on the network (Figure 10), "biochar" can be seen to have a strong relationship to words such as: climate change, carbon sequestration, soil amendment, agriculture, greenhouse gases, greenhouse effect, fertilizer, carbon footprint, biomass, agricultural waste. The largest green circle, which is found along with the word "biochar", is missing the word "climate change". This reaffirms that biochar is widely considered in the literature as a key element in climate change mitigation.

With the help of these graphic tools it is possible to identify the knowledge gaps or the subjects where more research is needed. On the edges of the network (Figure 11). It can be observed the keywords that are more segregated and therefore less developed. In this co-occurence network of all the keywords in published scientific papers on biochar it is clear that biological matters within the subject of biochar have not been concretely addressed; for example: soil microbiology, soil microfauna, bacteria, fungi, as well as issues of oxidation and mineralization of compounds. It can also be seen that soil temperature, soil respiration, cation exchange, economic analysis,

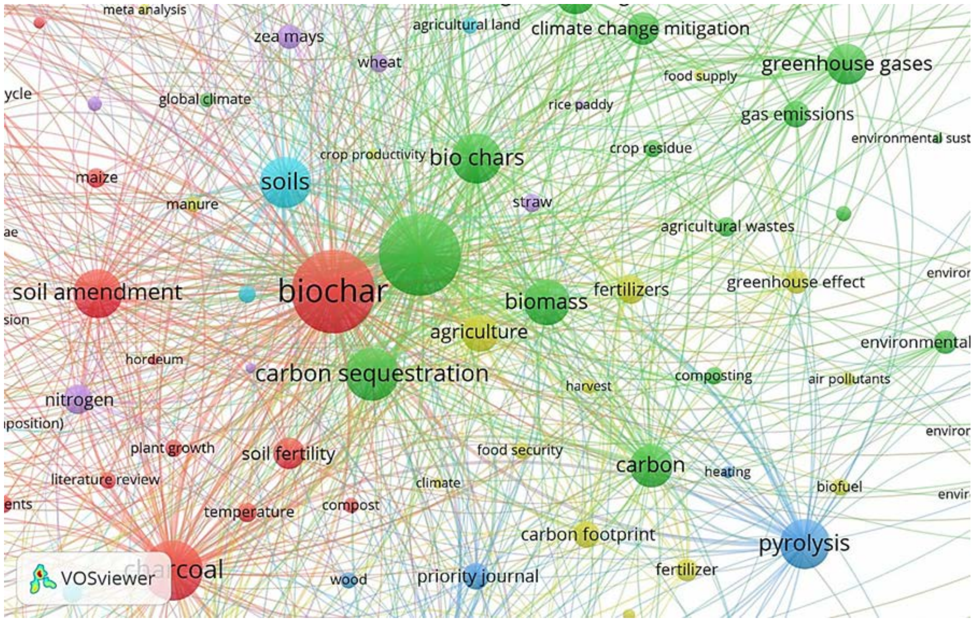

Figure 8. Main institutions that finance biochar research worldwide.

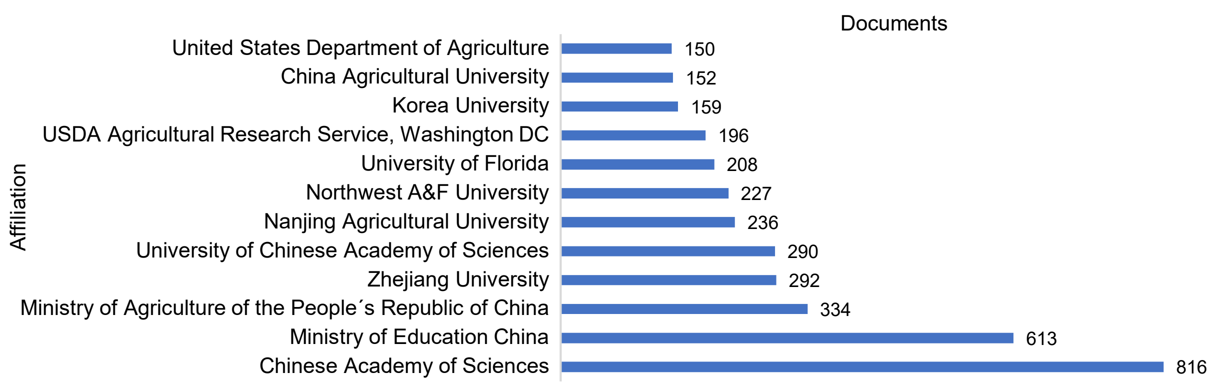

Figure 9. Co-occurrence of all keywords from published scientific papers on biochar.

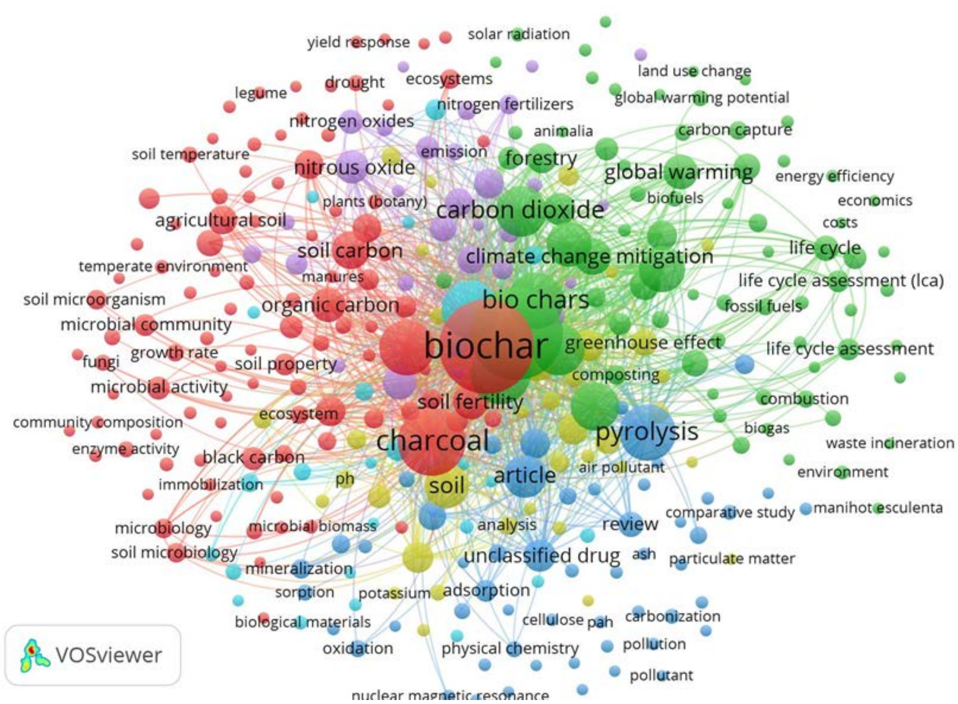

Figure 10. Close-up to the co-occurrence network of the biochar database.

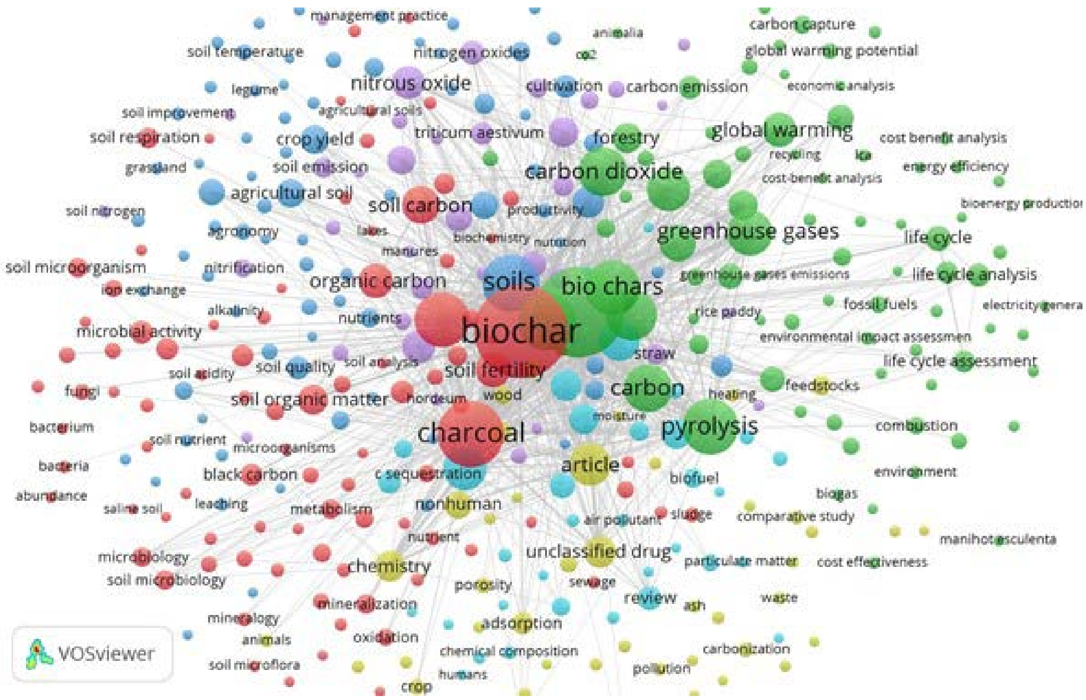

Figure 11. Network of co-occurrence of all keywords in scientific documents on biochar.

cost-benefit analysis, energy efficiency, bioenergy production, and pollution processing are areas where research efforts need to be focused.

CONCLUSIONS

The bibliometric analysis allowed identifying that during the past decade there has been a growing interest in carrying out research on biochar. China and the United States are leaders in research on biochar on a global level, not only in publications but also in citation of their studies. The three main authors on biochar focus their attention on its function to amend environment pollution with potentially toxic elements. Jefferson Lehman and Stephen Joseph are the most cited authors on the subject of biochar. Unfortunately, research on biochar in Mexico is still scarce.

In general, research on biochar worldwide focuses its attention on determining three mail areas: 1) The potential of biochar to stabilize carbon in residual biomass. 2) The capacity of biochar to modify the physicochemical properties of soil and its productivity. 3) The effect of biochar on retaining nutrients and potentially toxic agents in the soil. However, aspects such as biological interactions within the soil, economic and financial analyses, and their evaluation as part of a production system (agroecosystem) have not been completed addressed in research on biochar.

Much of the research on biochar and its effects on productivity and the capacity to mitigate GHG is developed under laboratory or greenhouse conditions. It is evident that research must be scaled up to determine the environmental, economic and social feasibility at farm level and producing biochar from agricultural residues or other types of raw materials. More research is needed about the optimization of the process to produce biochar and its use to sequester higher amounts of carbon. In other words, reactors and processes linked to the production of biochar need to be optimized, in addition to estimating financial feasibility, improving energy yields and promoting its portability and social adoption. The development of a reactor design scaled to a diversity of needs (family, intermediate or industrial) must be contemplated, with considerations for the recycling of potentially polluting or underutilized organic wastes.

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