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THE INTERESTING CASE OF PHOSPHORUS IN FOREST SOILS: A BIBLIOMETRIC REVIEW

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Abstract

Phosphorus is an essential element in soils. By using VOSviewer and Web of Science tools, we conducted a bibliometric analysis considering titles, and abstracts to identify the types of publications, the scientific fields they belong to, the years, the authors distributed by country, the publishing journals, and the keywords used. The results revealed the existence of 613 publications, of which 595 are articles in the priority fields of Environmental Sciences, Ecology, Forestry, and Soil Science, with an exponential increase in the number of articles published on this topic, especially in the last 10 years. A total of 201 authors were inventoried, with the top two countries being China and the USA. Journals where articles on this topic were published belong to the fields of soil science and forestry, but also include general journals; most articles were published in Forest Ecology and Management, Science of the Total Environment, and Forests. The most frequently used keywords were nitrogen, phosphorus, carbon, soil, and diversity, with an increased emphasis in the last 5 years on the implications of phosphorus in forest soils.

Key words*: publications, keywords, topic, journals, phosphorus.*

INTRODUCTION

Phosphorus (P) is a key element in soil organic matter and originates from the weathering of minerals in parent rock material within natural terrestrial ecosystems. It is often the second most limiting nutrient for terrestrial primary production after nitrogen (Lajtha & Jarrell, 1999). P is vital for ecosystem productivity and agricultural output, but its misuse can undermine agricultural sustainability and lead to serious environmental issues (George et al., 2016). Globally, the phosphorus resource is quite limited, garnering attention as a nonrenewable resource (Cordell et al., 2009).

In forest ecosystems, phosphorus is typically a limiting nutrient, with its soil levels dependent on its presence in plant litter (Lemanowicz, 2018). Understanding the mechanisms of phosphorus availability is crucial for predicting forest productivity in a changing environment. Phosphorus distribution in forest soils is highly variable, both between and within different soil types, regarding content, speciation, availability, and sources (Bol et al., 2016). Human activities are expected to impact phosphorus cycling in temperate forests (Pistocchi et al., 2022).

A significant portion of these articles are from the fields of medicine (Williams et al., 2019; Jiang et al., 2021; Feng et al., 2023), economics (Khan et al., 2022; Jajic et al., 2022; Mi'raj et al., 2024; Rabbani et al., 2024), and environmental sciences (Wu & Wang, 2018; Oh & Lee, 2020; Burki et al., 2021; Putra et al., 2024).

In contrast, bibliometric review articles specifically addressing forest soils are scarce. Existing reviews focus on topics such as global soil water content (Zhang et al., 2022; Singh et al., 2023), soil erosion (Yu et al., 2024), forest litter decomposition (Liu et al., 2024), and soil metagenomics (Vieira et al., 2021).

The objective of this article is to conduct a bibliometric review of publications related to phosphorus in forest soils. This analysis examines the distribution of the main types of publications, the primary scientific fields they pertain to, the yearly distribution of articles, the authors and their countries of origin, the journals in which the articles were published, and the main keywords used.

MATERIALS AND METHODS

The information was sourced from the online version of the SCI-Expanded database on Web of Science. This multidisciplinary database is managed by the Institute for Scientific Information (ISI) in Philadelphia, PA, USA. As Based on the Journal Citation Reports (JCR), the SCI-Expanded database, as of 2015, included 11,149 key journals, featuring citation references across 237 scientific fields and spanning 82 countries. Abstracts have been included in each SCI publication since 1991.

For over four decades, the Institute for Scientific Information (ISI), now part of Thomson Reuters, provided the exclusive bibliographic databases that enabled bibliometricians to develop large-scale bibliometric indicators. These citation indexes, now part of the Web of Science (WoS), have served as the primary sources for bibliometric data.

For this bibliometric study, the online SCI-Expanded database was searched using the keywords "phosphorous in forest soils" to gather a bibliography of all relevant research papers from 1984 to the present.

The data were processed using the facilities offered by the Web of Science Core Collection as well as the Vosviewer program version 1.6.20 Excel and Geocharts.

RESULTS AND DISCUSSIONS

A total of 613 publications were identified and analyzed. Of these, 595 are articles, 19 are proceeding papers, 7 are review articles, and 2 are book chapters (Figure 1).

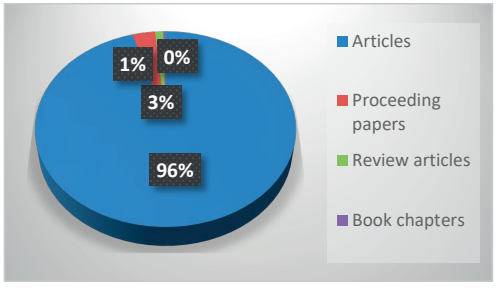

Figure 1. Distribution of the main types of publications used in the bibliometric analysis

Regarding the scientific fields to which the published articles belong, the most representative are Environmental Sciences (172), Ecology (131), Forestry (111), and Soil Science (102) (Figure 2).

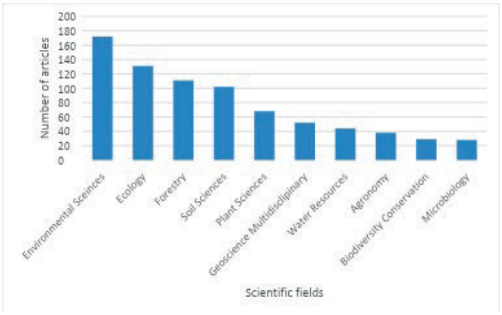

Figure 2. Distribution of the main 10 scientific fields of publications used in the bibliometric analysis

Concerning the years in which the articles were published, there is an exponential increase in the number of articles on this topic, especially in the last 10 years (Figure 3).

The first article on this topic was published in a renowned scientific journal in 1984.

Figure 3. Distribution of articles published per year

A total of 201 authors have published articles on this topic, with the most articles written by Jorge Mataix-Solera (8), Xavier Ubeda (6), and Manuel Esteban Lucas-Borja (6), all of whom are Spanish.

The published articles have authors from almost all countries (except some from Africa or Asia) and continents (Figure 4).

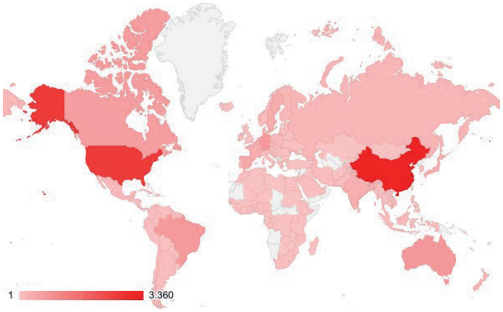

Figure 4. Geography of the use of phosphorus in soil in published articles. 1-3000 the number of articles

The countries with the highest representation are: China = 164; USA = 134; Spain = 49. In total, there are authors from 88 countries, with significant contributions from Germany, Brazil, India, Italy, Sweden, France, England, and many others in addition to the top three countries mentioned above. The node size and thickness of the connecting lines are proportional to the number of documents assigned to each country. The connections represent the collaboration network among research institutions (Figure 5).

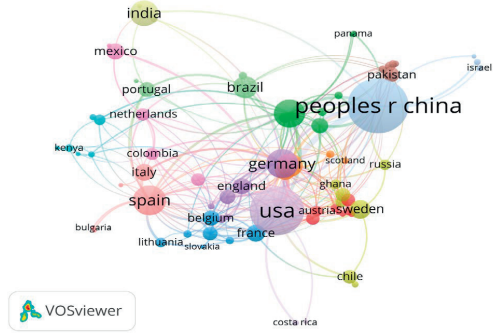

Figure 5. Countries with authors of articles on phosphorus in soil

Similar to the distribution of authors by country is the representation of their respective institutions. The most numerous are from China: Chinese Academy of Sciences = 54; University of Chinese Academy of Sciences = 20; Chinese Academy of Forestry = 17.

Articles on this topic are published in 207 journals, with the most articles appearing in Forest Ecology and Management (33), Science of the Total Environment (28), and Forests (16). Based on total link strength, the most important journals are Science of the Total Environment, Catena, Ecological Engineering, and Geoderma (Table 1).

Table 1. The most representative journals where articles about the phosphorus in soil have been published

Crt. No.	Journal	Documents	Citations	Total link strength
1	Science of the Total Environment	28	622	23
2	Catena	14	293	14
3	Ecological Engineering	8	245	9
4	Geoderma	8	291	9
5	Forests	16	114	8
6	Land Degradation & Development	7	195	6
7	Forest Ecology and Management	33	717	5
8	Applied Soil Ecology	7	243	4
9	Journal of Environmental Management	7	109	4
10	Journal of Forestry Research	12	96	4
11	Plant and Soil	15	358	4
12	Pedologia	5	271	3
13	Plos One	11	252	3
14	Soil Biology and Biochemistry	14	806	3

In terms of clusters, the journals are grouped into three clusters: one comprising journals in Forestry and Ecosystems (Forest Ecology and Management, Forestry, Frontiers in Microbiology, Ecosystems), another in Environmental Sciences (Science of the Total Environment, Ecological Engineering, Ecological Indicators), and another in applied sciences (Applied Soil Ecology, Land Degradation & Development, Geoderma, Journal of Environmental Management) (Figure 6).

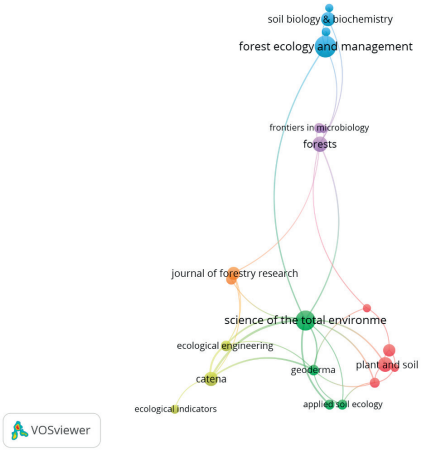

Figure 6. Main journals where articles on phosphorus in soil have been published

There are 102 publishers, with the most prominent being Elsevier (194 articles), Springer Nature (125 articles), and Wiley (60 articles).
The most frequently used keywords are nitrogen, phosphorus, carbon, soil, and diversity (Figure 7 and Table 2).

Table 2. The most commonly used keywords in articles about the phosphorus in soil

Crt. No.	Keyword	Occurrences	Total link strength
1	nitrogen	14	51
2	carbon	10	43
3	phosphorus	10	38
4	traits	3	18
5	climate	3	17
6	quality	3	17
7	soil	6	17
8	ecological stoichiometry	3	16
9	N-P stoichiometry	3	16
10	storage	3	16
11	organic matter	4	15
12	diversity	5	12
13	plant	3	12
14	water	3	10
15	biomass	3	9
16	vegetation recovery	3	7
17	fire severity	3	6
18	growth	3	6

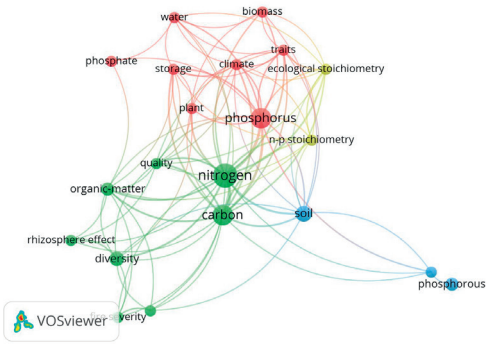

Figure 7. Authors' keywords regarding phosphorus in soil

We can observe two main clusters: one includes keywords such as nitrogen, carbon, quality, organic matter, rhizosphere effect, diversity, and fire severity; the other includes keywords such as climate, plant, storage, water, biomass, and traits. Additionally, there is a smaller cluster represented by the keywords N-P stoichiometry and ecological stoichiometry.

Regarding the distribution of keywords over the years, it is observed that in the last 5 years, there has been an increasing emphasis on the implications of phosphorus in forest soils, with keywords such as accumulation, strategy, root functional traits, and ecosystem services being used (Figure 8).

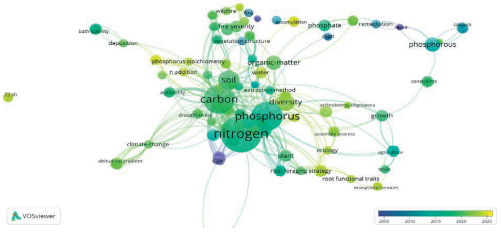

Figure 8. Distribution of keywords concerning phosphorus in soil over the years

The subject areas considered in this review are diverse but often interconnected and mutually inclusive. For instance, the majority of articles fall under the category of Environmental Science, which broadly encompasses the categories ranked 2nd and 7th (Ecology and Biodiversity). Naturally, the field of Soil Science is also prominently featured (ranked 4th in this case), along with other areas closely related to the studied subject (Plant Science, indicating an inclination of the authors to study not only the effects of phosphorus in soil but also its influence on vegetation) and Forestry (where soil phosphorus plays a significant role). Other scientific fields are also well-represented, including Geosciences, Microbiology, and Agronomy.
The sustained increase in the number of published articles over the past 10 years concerning phosphorus in forest soils mirrors the trend observed in nearly all topics analyzed through bibliometric review methods (Hsieh et al., 2004; Chiu & Ho, 2005; Ho, 2007; Buffardi & Ruberti, 2023). This trend is attributed to the growing number of published articles in the last decade and the increasing interest of researchers in the analyzed subject.
The largest number of authors comes from the USA and China. These two countries also top the list in other bibliometric review topics: severe acute respiratory syndrome (Chiu et al., 2004), adsorption technology in environmental science (Chiu & Ho, 2005), and land subsidence in coastal and alluvial plains (Buffardi &

Ruberti, 2023). The large number of authors from the USA and China can be attributed not only to the size of these countries and the number of researchers but also to specific issues related to soil phosphorus in these regions.

Global soil phosphorus levels are lowest in tropical and subtropical regions (Taylor, 1964; Zhang et al., 2005), which includes parts of China. Additionally, total phosphorus in soils decreases with weathering (Walker & Syers, 1976), a phenomenon common in China (Duan et al., 2002; Shao et al., 2015). These factors lead to limitations in net primary production (Pan et al., 2011) and decreases in biomass and diversity (Vitousek et al., 2010), which are sensitive issues for Chinese researchers.

In the USA, the dominant research aspects include phosphorus in wetlands (Bruland et al., 2006; Odhiambo et al., 2018) and the influence of harvesting on soil properties (Lockaby et al., 1997; Rapp et al., 2021).

Among the authors, besides those from China and the USA, Spanish researchers are notable. In Spain, wildfires are a common phenomenon, leading researchers to publish numerous articles related to this issue and phosphorus in forest soils (Braga et al., 2024; Peña-Molina et al., 2024). The country also has numerous degraded soils in semi-arid regions, an aspect correlated by authors with soil phosphorus (Fernandez et al., 2007; Mataix-Solera et al., 2011; Cerdà et al., 2021).

Journals where articles on this topic have been published primarily belong to the fields indicated in the title: soil science (Pedologia, Plant and Soil, Soil Biology and Biochemistry, Catena) and forestry (Forests, Forest Ecology and Management, Journal of Forestry Research). However, the most well-represented journal is a general environmental journal (Science of the Total Environment), along with others in the same category (Ecological Engineering, Land Degradation & Development). Thus, besides strictly specialized journals, the subject of phosphorus in forest soils is also addressed in general journals.

Keywords are essential in research outputs, providing insights into the content of each publication (Ashraf et al., 2022), highlighting the most relevant topics, and indicating main research trends (Medina-Mijangos & Seguí-Amórtegui, 2020).

The appearance of nitrogen and carbon alongside phosphorus in the predominant keywords demonstrates the interconnectivity of these three chemical elements (Hume et al., 2018; Smith et al., 2000) and their importance in soil studies (Fatemi et al., 2016; Brödlin et al., 2019).

Nitrogen appears even more frequently than phosphorus due to its significant role in plant nutrition and development (Rennenberg & Dannenmann, 2015; Cánovas et al., 2019). The concentration of carbon in forest soils is also a highly topical subject (Dincă, et al., 2012; Grüneberg et al., 2014; Dincă et al., 2015; Zhao et al., 2019).

The grouping of keywords into two clusters occurs in the first case according to organic matter and its representatives (organic matter, nitrogen, carbon) and their influence on ecosystems (rhizosphere effect, diversity, and fire severity), and in the second case according to environmental factors (climate, water, biomass, and traits). The smallest cluster is represented by stoichiometry, a topic studied in relation to its connection with soil microorganisms (Li et al., 2014; Zederer et al., 2017; Maaroufi et al., 2020; Cui et al., 2022) or with organic matter (Cui et al., 2022; Stahr et al., 2018; Gan et al., 2020; Spohn & Stendahl, 2022).

CONCLUSIONS

We can conclude that phosphorus in forest soils is indeed an interesting topic due to the numerous scientific aspects it raises and the diversity of studies conducted. The role and importance of phosphorus in forest soils are highlighted by the large number of research efforts undertaken. Since 1984, and especially in the last 10 years, numerous articles (as well as proceeding papers and book chapters) have been published in specialty journals in the fields of Environmental Sciences, Ecology, Forestry, and Soil Science. A total of 207 journals where articles have been published were identified, with the most representative being Forest Ecology and Management, Science of the Total Environment, and Forests, by authors from 88 countries, the most significant being China, the USA, and Spain. The most frequently used keywords were nitrogen, phosphorus, carbon,

soil, and diversity. Journals can be grouped into two clusters, and keywords into three clusters, based on importance and the connections between different components. This topic has been an intensely studied scientific aspect, both independently and in correlation with other soil chemical elements, particularly nitrogen and carbon.

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