

BIOPORE EFFECTIVENESS IN INCREASING SOIL ORGANIC CARBON AND ADDRESSING ENVIRONMENTAL ISSUES

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ABSTRACT

The study, conducted in May 2024, focused on searching the Scopus.com database for literature on biopores, resulting in 208 articles published between 1985 and 2024 as the final dataset. Metadata was obtained from Scopus.com and analyzed descriptively. The dataset was exported into Excel CSV format and subsequently processed using VOSViewer (VV) version 1.6.20 to provide a clear overview of the research landscape. Findings revealed variations in the number of publications on biopores over time, with Kautz recognized as the most prolific scholar. The main publication outlets included the IOP Conference Series: Earth and Environmental Science, Soil and Tillage Research, and Geoderma. The dominant document categories were journal articles, conference proceedings, and reviews. Germany, the United States, and Indonesia emerged as the leading contributors to biopore-related research. Influential institutions in this field were the University of Bonn, Leibniz Centre for Agricultural Landscape Research (ZALF e.V.), and the University of Copenhagen. The results further indicated that biopores contribute significantly to enhancing soil organic carbon, thereby improving soil fertility and agricultural productivity. Moreover, biopores were shown to be an effective approach for managing organic waste by transforming it into compost, which in turn supports higher land productivity.

Keywords: climate change mitigation, green infrastructure, organic waste management, soil organic carbon improvement, water infiltration enhancement

ABSTRAK

Penelitian ini dilakukan pada bulan Mei 2024 dengan mencari database Scopus.com khusus untuk Penelitian ini dilaksanakan pada Mei 2024 dengan melakukan pencarian pada database Scopus.com terkait topik biopori, yang menghasilkan sebanyak 208 artikel terpublikasi antara tahun 1985 hingga 2024 sebagai basis data penelitian. Metadata diperoleh melalui Scopus.com dan dianalisis secara deskriptif. Selanjutnya, data diekspor ke format Excel CSV dan diproses menggunakan VOSViewer (VV) versi 1.6.20 untuk memetakan lanskap penelitian secara lebih komprehensif. Hasil penelitian menunjukkan adanya dinamika jumlah publikasi mengenai biopori dari waktu ke waktu, dengan Kautz teridentifikasi sebagai peneliti paling produktif. Beberapa sumber utama publikasi meliputi IOP Conference Series: Earth and Environmental Science, Soil and Tillage Research, serta Geoderma. Jenis dokumen yang dominan adalah artikel jurnal, prosiding konferensi, dan tinjauan. Negara yang paling menonjol dalam pengembangan penelitian biopori adalah Jerman, Amerika Serikat, dan Indonesia. Adapun institusi yang berperan penting antara lain Universitas Bonn, Leibniz Centre for Agricultural Landscape Research (ZALF e.V.), dan Universitas Kopenhagen. Temuan lainnya memperlihatkan bahwa biopori berkontribusi besar dalam meningkatkan kandungan karbon organik tanah sehingga mampu memperbaiki kesuburan tanah dan produktivitas pertanian. Selain itu, penerapan biopori terbukti efektif untuk mengelola limbah organik dengan mengubahnya menjadi kompos, yang berdampak pada peningkatan produktivitas lahan.

Kata kunci: mitigasi perubahan iklim, infrastruktur hijau, pengelolaan limbah organik, peningkatan karbon organik tanah, peningkatan infiltrasi air

1. INTRODUCTION

Global warming and the intensification of climate change have become pressing global issues. Human-driven activities, particularly the release of greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), have been the main contributors to rising global temperatures. Compared to the pre-industrial period, these emissions have triggered a temperature increase of around 1°C, leading to ecosystem imbalances and severe environmental damage (Zhang et al., 2024; Shotten et al., 2017). The key drivers of these emissions include deforestation, the burning of fossil fuels, and industrial activities (Kanna et al., 2024). One potential approach to addressing this issue is by enhancing the organic carbon content in soils. Soil organic carbon plays a vital role in maintaining soil fertility, fostering plant productivity, and mitigating greenhouse gas emissions (Paustian et al., 2016). Nonetheless, boosting soil organic carbon requires sustainable and well-structured management strategies.

At the same time, food waste has emerged as a critical challenge across many nations. The accelerating pace of global economic and population growth has exacerbated the food waste crisis. It is estimated that nearly one-third (33.3%) of food intended for human consumption is either lost or discarded along the supply chain, amounting to 1.6 billion metric tons annually and causing economic losses of approximately \$750 billion (Pramanik et al., 2019). Beyond financial setbacks, this waste leads to environmental degradation and contributes significantly to methane emissions, a greenhouse gas with greater warming potential than carbon dioxide. Furthermore, recurrent flooding in both rural and urban regions has intensified, resulting in substantial economic damage and social disruption.

Biopore technology emerged as a potential solution to solving several problems simultaneously. Biopores are small holes in the soil that enhance water infiltration, soil aeration, and plant growth (Nespoulous et al., 2019). These structures are created naturally through root growth and earthworm activity, forming networks of large, interconnected pores that differ biologically and chemically from surrounding soil (Sun and Yuan, 2020; Wendel et al., 2022; Petzoldt and Kautz, 2021). By providing pathways that allow roots to reach deeper soil layers, biopores facilitate nutrient and water access, benefiting plant growth (Nespoulous et al., 2019; Behrend et al., 2025). Initially developed in Indonesia by Ir. Kamir R. Brata in the early 2000s as a low-cost solution for urban flooding and organic waste management (Brata, 2008), biopore technology has proven effective in reducing water stagnation and managing organic waste by promoting in-situ composting within biopore holes, thereby increasing soil organic carbon (Setiadi et al., 2021).

Research suggests that using biopores can increase water infiltration and reduce water drainage, thereby reducing the risk of flooding (Naharuddin et al., 2024; Hutabarat and Simanjuntak, 2022). Moreover, biopore also helps to accelerate the decomposition of organic material, produce nutrient-rich composts, and improve soil fertility. Thus, biopores play a role in mitigating floods and improving soil quality, along with increased pH and soil water levels, through increased organic carbon content (Sharma et al., 2023). One method of enhancing soil through natural processes is through earthworm-formed biopores, which are crucial for the quick movement of gases, solutions, and nutrients, offer a route for root development to the lower soil layers for the uptake of nutrients and air, aid in the absorption of carbon, and more (Kuz'yakov and Kooch, 2024).

In addition to these environmental benefits, biopores offer a practical and sustainable method for managing food waste. Globally, food waste accounts for 1.3 billion metric tons of food lost or waste annually. In Indonesia, the Ministry of Environment and Forestry reported

in 2022 that the country generates 37.37 million metric tons of waste each year, with food residues and other organic matter comprising 40.35% of the monthly waste volume (Ministry of Environment and Forestry, 2022). Biopores facilitate the natural composting of such waste, reducing greenhouse gas emissions from traditional landfills and producing organic fertilizer beneficial for agricultural productivity and reforestation efforts (Geng et al., 2024; Pramanik et al., 2019).

2. METHOD

In this research, we conducted a bibliometric analysis on "Biopore" studies, using Scopus as the primary source for literature. The literature search was performed using the Boolean search string: TITLE-ABS-KEY ("biopore" OR "bio-pore" OR "biopore infiltration hole"), with no restriction on document type or language. Documents were included if they were directly related to biopore research in soil science, hydrology, or environmental management. Documents from unrelated subject areas (e.g., ophthalmology or astronomy, which appeared due to the broad initial search) were excluded. The initial search returned 13,335 documents spanning 1985–2024. After applying the inclusion and exclusion criteria and removing duplicate and non-primary records, the dataset was refined to 208 relevant indexed papers. This approach provides a comprehensive review of pertinent and recent publications, focusing on sustainable agricultural practices and sedimentation techniques. Notable authors contributing to this field (Kanna 2024; Karmoui, 2022; Neelam and Sood, 2020; Sun and Yuan, 2020).

The extracted data, in CSV format, contains various bibliometric details, such as citations, abstracts, keywords, authors, and their affiliations, publications years, and funding information. VOSviewer software was then used to analyze key terms across the data. Developed by Shotten and Van Eck (Schotten et al., 2017; Eck and Waltman, 2017) in 2010, VOSviewer applies clustering methodologies to identify core themes and keyword occurrences, facilitating the discovery of significant research trends.

2.1 Bibliometric Analysis

At this stage, the program offers several forms of analysis, including performance assessment, co-occurrence of events, co-authorship, and citation analysis. The visual outputs are then categorized into three types for each analysis: network visualization, density mapping, and trend representation. This study adopts a bibliometric analysis framework, following five stages outlined in previous research (Ulker et al., 2023; Malanski et al., 2021). In these phases, the term biopore is defined and applied as the primary search keyword. The procedure involves four main steps: compiling search results, verifying the completeness of the data obtained, generating preliminary statistical information, and conducting further analytical interpretation.

2.2 Classification of essential terms and their definitions

This stage emphasizes additional details and specific features that may not be immediately visible to observers. The program groups significant terms into undefined clusters using related datasets, while the proposed classification scheme organizes these words based on their semantic relevance. All keywords associated with "data" are categorized through frequency analysis and relational connections. This category encompasses core concepts such as big data, data mining, satellite-based data, data collection, data processing, data acquisition, data fusion, databases, metadata, open data, database visualization, and data integration (Ulker et al., 2023; Malanski et al., 2021).

3. RESULTS AND DISCUSSION

This paper reviews the contributions of numerous scholars in integrating recent advancements and potential applications of biopores to support sustainable development and food security. The analysis indicates a consistent upward trend in indexed publications from 1985 to 2024, with 208 records retrieved via the Scopus database (Figure 1a). Over the last several decades, biopores have become increasingly relevant as an approach to address urgent environmental challenges. Research from multiple fields has demonstrated their effectiveness, particularly in flood management by enhancing groundwater infiltration. Biopore holes enable rainfall to penetrate the soil more rapidly, minimizing surface runoff and reducing flood hazards. Additionally, biopores contribute to sustainable farming by recycling organic residues into compost. Within the biopore cavities, organic waste undergoes natural decomposition, producing nutrient-rich material that lessens dependence on chemical fertilizers. Beyond waste management, biopores improve soil quality by enhancing soil structure and raising organic carbon concentrations. Accordingly, biopores are considered a vital strategy for advancing ecological sustainability and promoting greener landscapes. This practice also facilitates the transformation of degraded or underutilized land into productive agricultural areas capable of mitigating environmental risks.

The earliest recorded study covering this theme dates back to 1878, titled "Development of the Water Resources of Bali: A Master Plan, Volume 2: Technical Report" by Walker et al. (1980) (Figure 1a). The three main subject areas contributing to this body of research are agricultural and biological sciences, medicine, and earth and planetary sciences (Figure 1b). Major funding institutions include the Deutsche Forschungsgemeinschaft (German Research Foundation), the National Eye Institute, and the Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research) (Figure 1c). Prominent publication outlets are the IOP Conference Series: Earth and Environmental Science, Soil and Tillage Research, and Geoderma (Figure 1d). In terms of document types, the majority consist of journal articles, conference proceedings, and review papers (Figure 1e). The leading nations contributing to biopore development are Germany, the United States, and Indonesia (Figure 1f). Among research institutions, the University of Bonn, the Leibniz Centre for Agricultural Landscape Research (ZALF e.V.), and the University of Copenhagen (Københavns Universitet) stand out as the most influential affiliations in advancing biopore studies (Figure 1g).

3.1 Network Analysis Using The Term "Primary Research"

The network analysis demonstrates how frequently used terms in biopore-related studies are interlinked. By applying VOSviewer software, the most common keywords were mapped and grouped, showing not only their relationships but also the strength of their associations within the field. This visualization provides a comprehensive understanding of how different aspects of biopore research are interconnected across scholarly publications.

The initial method applied in this study analyzed the occurrence of all keywords found in the selected dataset. A minimum threshold of three occurrences was set to include only the most relevant terms. From 2,242 keywords generated by the software, 276 satisfied the occurrence and link strength criteria, appearing in association with other terms. This process identified five clusters (Figure 2a). The first cluster, consisting of 93 items marked in red, includes terms such as human, animal, and adult. The second cluster, with 86 items in green, contains terms like agriculture, water flow, and soil organic matter. The third cluster, comprising 65 items in blue, features terms such as organic carbon, root growth, and nutrients. The fourth cluster, shown in yellow, has 29 items related to climate change, carbon, and soil.

Biopore Effectiveness In Increasing Soil Organic Carbon And Addressing Environmental Issues

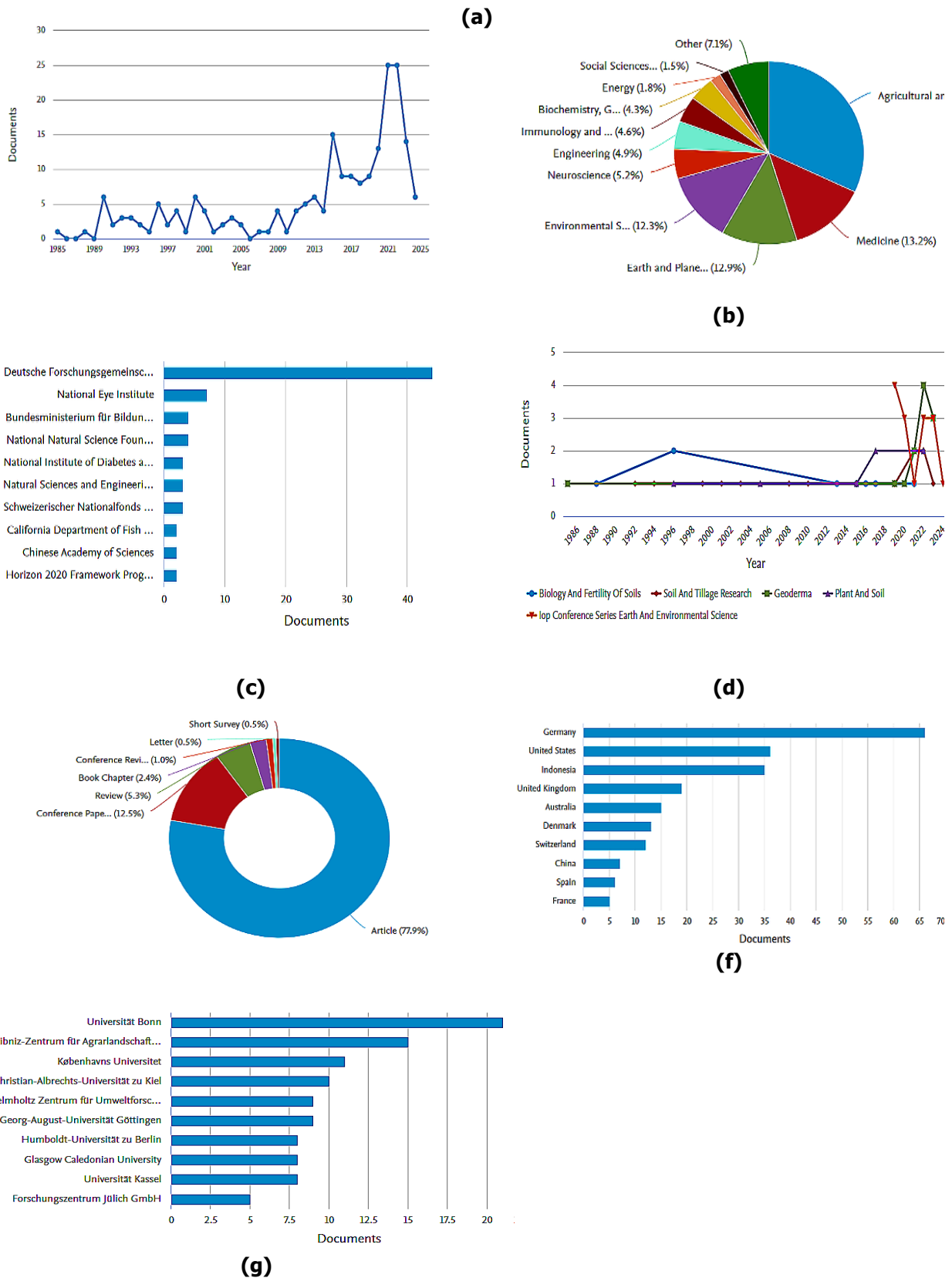


Figure 1. Structure of biopore research based on 208 documents published between 1985 and 2024: (a) publication trends during the study period; (b) subject area classifications; (c) main funding agencies; (d) key publication outlets; (e) document types; (f) leading contributing countries; (g) most influential research affiliations.

The second approach, Overlay Visualization in VOSviewer, highlights the contribution of biopore systems to soil fertility enhancement and their role in solving problems such as household waste management and surface runoff caused by heavy rainfall. Poorly structured soils, which are often dense and brittle, have long posed challenges in assessing biopore distribution (Phalempin et al., 2022). Nevertheless, biopore systems facilitate effective surface water drainage, preventing stagnation and compensating for limited water storage. Functional drainage infrastructure is crucial for managing runoff intensified by land-use changes in watershed areas (Mariyono, 2024; Setiadi et al., 2021). Moreover, biopores enriched with organic materials improve soil water retention during dry periods, thereby supporting crop growth (Putra et al., 2024) (Figure 2b). Lastly, Density Visualization in VOSviewer reflects increasing societal awareness of sustainable biopore practices as a strategy to improve soil fertility and reduce flooding hazards (Figure 2c).

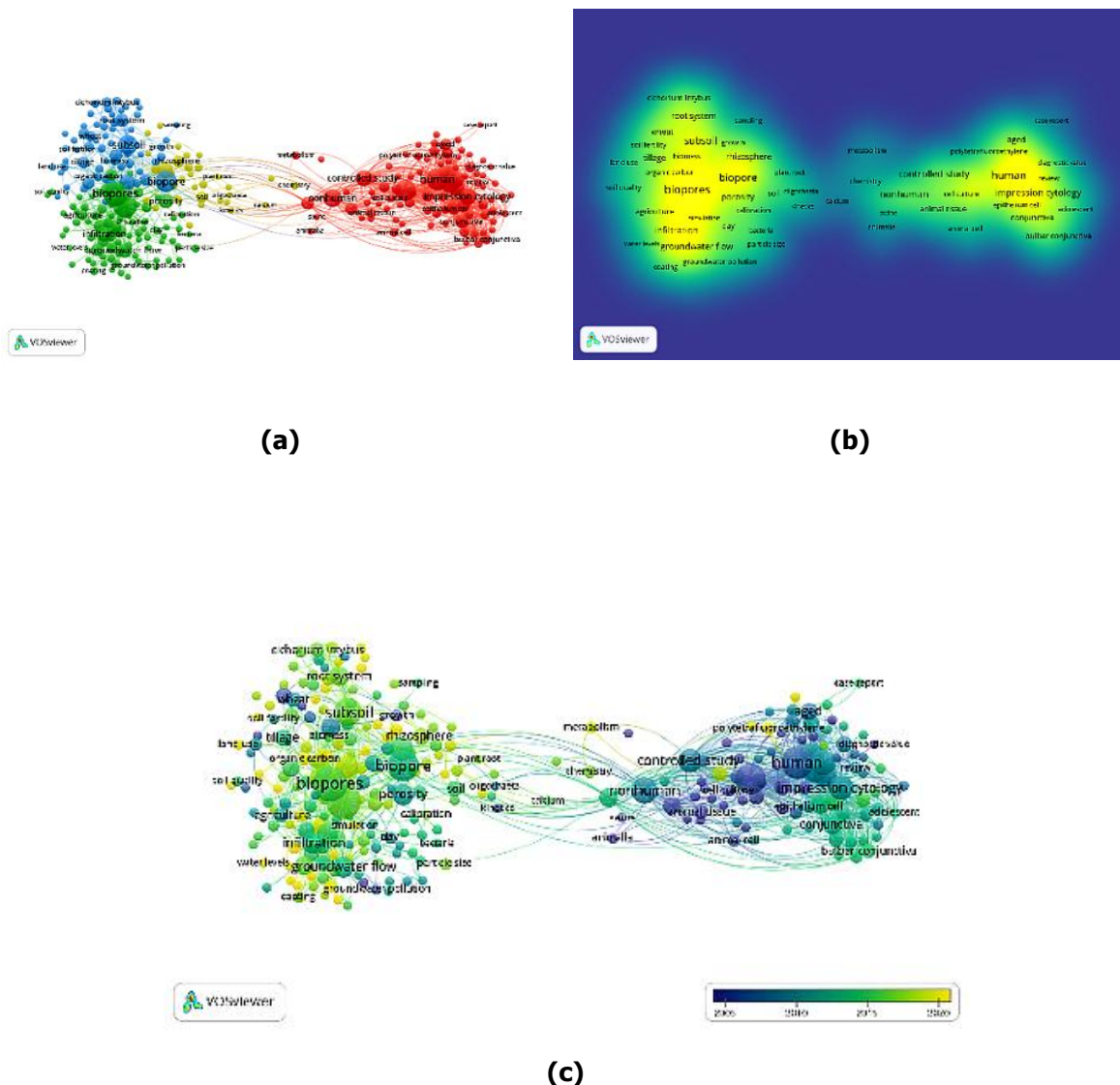


Figure 2. Network analysis of the keyword “Biopore” based on publications from 1985–2024 using VOSviewer: (a) event occurrence and network connections; (b) density mapping; and (c) keyword trend visualization.

3.2 Countries Mapped by Publication Output and Citations

In this section, the analysis focuses on co-authorship, with “country” serving as the unit of measurement. The calculation method applies the full counting approach, with a minimum threshold of 25 documents per country. For selected documents, however, the minimum requirement is five publications. Out of 34 contributing countries, only 11 met the set threshold. For each of these, the total strength of collaborative links with other nations was also calculated. The maximum number of countries with strong cooperative connections was recorded at 34. Based on the visualization generated through VOSviewer, Indonesia appears as the leading country in terms of research productivity, followed by the United States within the examined domains (Figure 3, Table 1).

Table 1. Five Most Influential Countries, Number Of Documents, Citations And Total Link Strength

Country	Document	Citation	Total Link Strength
United States	82	1744	57
United Kindom	24	597	27
China	65	589	22

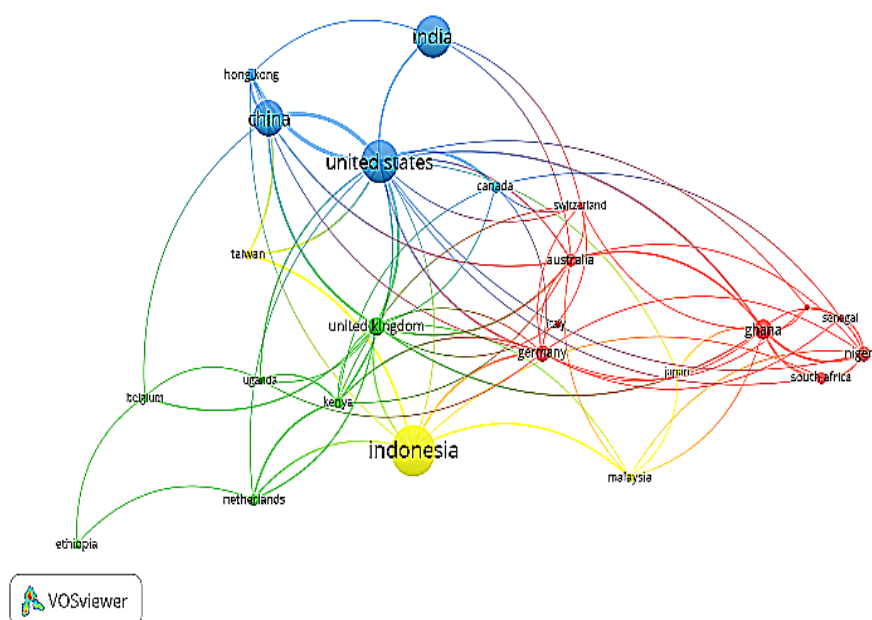


Figure 3. Map of the most influential countries by number of documents published and citations

Several studies have underscored the significance of this emerging topic. Land transfer for tourism can harm ecosystems, reduce food production, and negatively impact the environmental sustainability of agricultural land. Threats posed by the transfer of agricultural

land functions to tourism can reduce the amount of land available for food production, which in turn can lead to a decrease in food production and increased dependence on imports. Furthermore, the transfer can disrupt local ecosystems, damage biodiversity, and reduce soil fertility due to environmentally unfriendly infrastructure development or property development activities. It can also increase pressure on water and energy resources as demand increases to meet tourism needs. Finally, land transfers can interfere with the livelihoods of local farmers and threaten their economic sustainability. Therefore, it is important to plan and manage land transfers wisely, taking into account their impact on the environmental, economic, and social sustainability of local communities.

On the other hand, management efforts to integrate agricultural land alongside tourism using sustainable agricultural practices and green technologies can play an important role in supporting food sustainability. To design solutions that can reduce the impact of transferring agricultural lands to tourism, promote ecosystem balance, and pave the way for sustainable farming and a more environmentally friendly economy, stakeholders, governments, and the agricultural sector must collaborate. We visualised four examples during the period 1985–2024 to illustrate the relationship between the most trending topics: humans (Figure 4a), soils (Figure 4b), biopores (Figure 4c), and earthworms (Figure 4d).

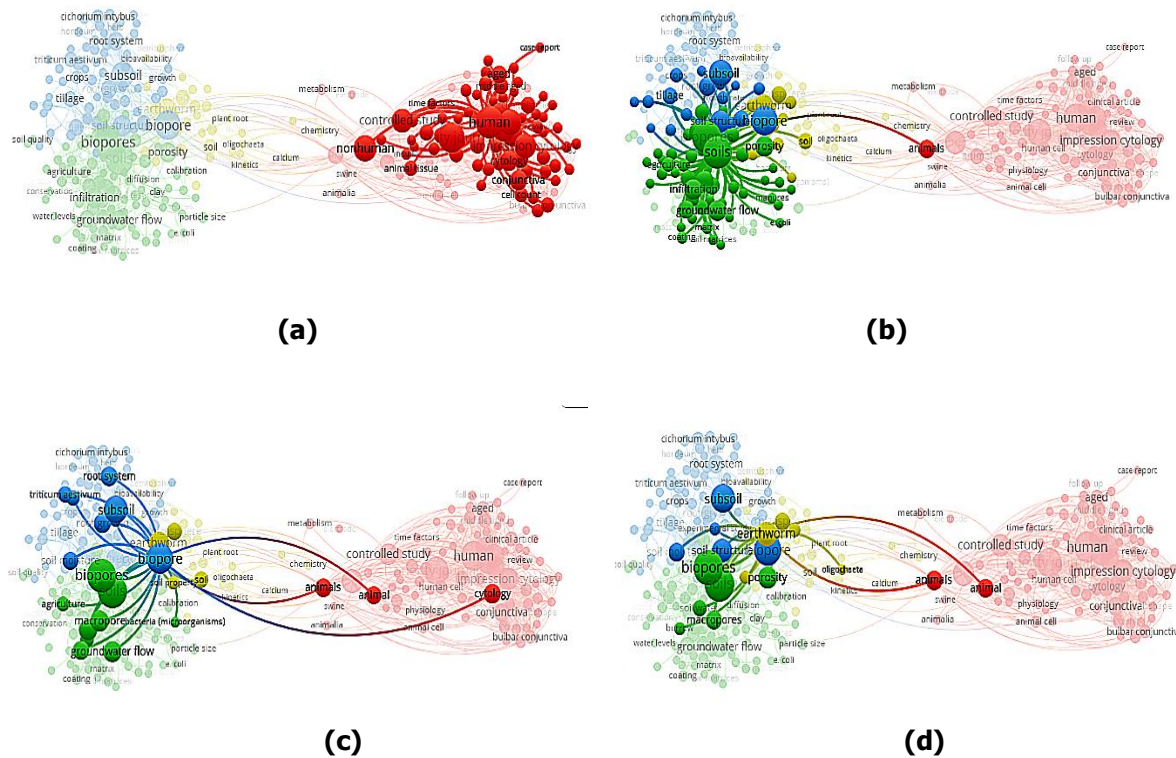


Figure 4. Example network visualisation of the most trending key terms used in current searches in the period 1985–2024: (a) human; (b) soils; (c) biopore; and (d) earthworm.

Biopores is essential in addressing flood issues and conserving groundwater, as highlighted by various studies, including a meta-analysis (Kassam et al., 2021; Ruiz et al., 2021). Drilling these tiny, cylindrical openings into the soil enhances rainfall infiltration, allowing more water to seep into the ground instead of building up on the surface. This procedure is essential in urban areas, where impermeable surfaces such as buildings and roadways have supplanted natural land, resulting in a higher risk of inundation and increased water runoff. Biopores

reduces the likelihood of flooding during periods of heavy rainfall by facilitating water infiltration and alleviating the burden on urban drainage systems (Mariyono, 2024; Setiadi et al., 2021; Putra et al., 2024).

Biopores plays a crucial role in maintaining groundwater levels and mitigating floods, especially in drought-prone areas where groundwater is vital for irrigation and drinking water. It aids in the natural replenishment of groundwater, supporting both urban and agricultural needs. Additionally, biopores improve soil aeration, essential for root respiration and microbial activity, enhancing plant growth and soil structure (Mariyono, 2024; Setiadi et al., 2021; Putra et al., 2024). Managing biopore density and dynamics is key to optimizing soil health and agricultural productivity (Mariyono, 2024; Setiadi et al., 2021; Putra et al., 2024).

In addition to its advantages in water management, biopore is also critical in organic refuse management. Biopores perforations can be employed to decompose household organic waste, thereby transforming it into compost (Lestari et al., 2023; Rahayu et al., 2024). This not only diminishes the quantity of waste that is disposed of in landfills, but it also enriches the soil with nutrients, thereby fostering sustainable agricultural practices and improving soil fertility. The improved soil structure that results from biopores is also beneficial for agriculture and urban greening initiatives, contributing to healthier ecosystems. Additionally, the increased soil porosity is a benefit (Dang et al., 2023). The efficacy of biopores is not limited to their immediate environmental impact. The significance of environmental education is underscored by the increased public awareness and participation in creating biopores. According to (Sidik et al., 2024; Masdar et al., 2024), collective efforts to implement biopores underscore a broader commitment to sustainability and environmental stewardship. These initiatives not only offer tangible benefits, such as the prevention of floods and the reduction of pollution, but they also cultivate a more profound comprehension of the significant impact that minor actions can have when taken collectively to safeguard our planet (Pramanik et al., 2019).

In conclusion, biopores are symbolic and practical solutions to environmental challenges. They are a potent instrument for educating and engaging communities in the broader mission of environmental protection and addressing critical issues such as flood management, groundwater conservation, and waste reduction. As such, biopores serve as a testament to the efficacy of collective action in preserving the planet for future generations.

3.3 Document Citation Map Based on the Number of Citations to a Document

In this subsection, citation analysis was selected as the analysis type, with documents as the unit of analysis. The calculation method used was full counting. A minimum threshold of five citations per document was applied. Out of a total of 664 documents, 12 met the threshold. The total link strength was then estimated for these documents to identify the most influential works in the field. The VOSviewer output shows that the document authored by Kautz received the highest number of citations, indicating its strong influence on subsequent studies. This was followed by a document authored by Athman, which also showed considerable impact within the research domain. The citation network illustrates how these highly cited documents are interconnected with other studies and demonstrates the central role of a few key publications in shaping the biopore research field (Figure 5).

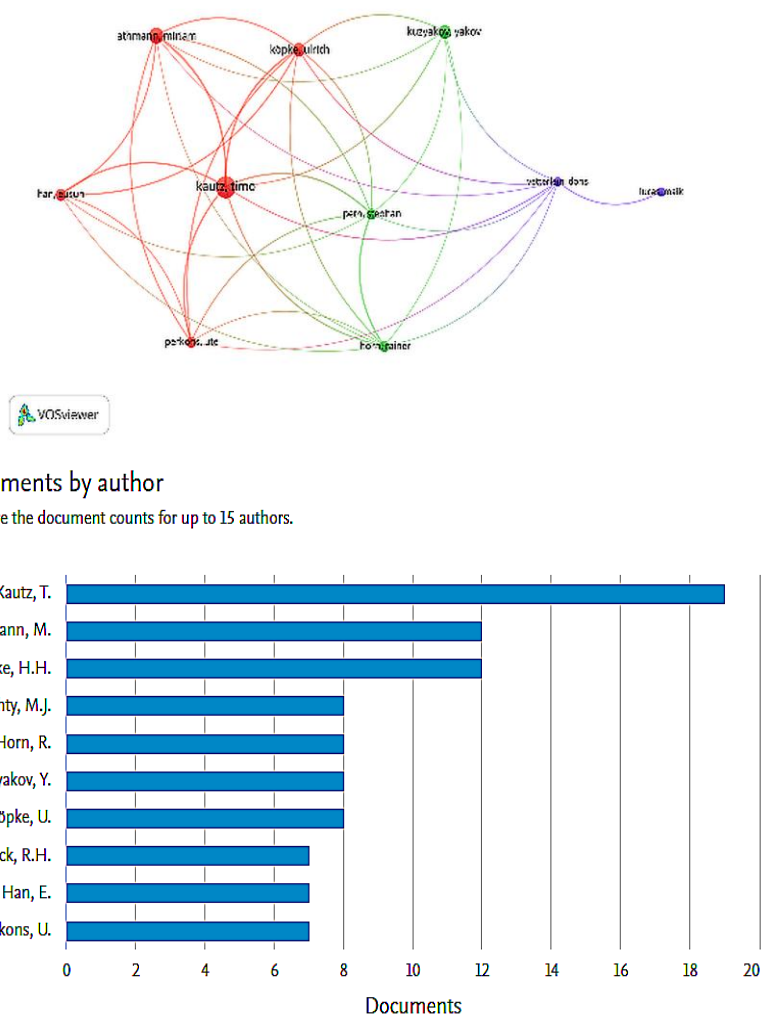


Figure 5. Citation analysis Most cited documents

3.4 Technical Synthesis: Quantitative Effects of Biopores on Soil Organic Carbon and Related Parameters

Beyond bibliometric patterns, the indexed literature reveals consistent quantitative findings regarding the technical performance of biopores. Studies on soil organic carbon (SOC) enhancement through biopore-based composting report average SOC increases ranging from 15% to 40% compared to control plots without biopore treatment, depending on soil type, organic material input, and duration of application (Setiadi et al., 2021; Sharma et al., 2023). In urban settings, biopore infiltration holes (BIH) have been shown to increase water infiltration rates by an average of 30–60%, with reported values reaching up to 15.6 cm/hour in loamy soils, compared to 2–4 cm/hour in untreated compact soils (Naharuddin et al., 2024; Hutabarat and Simanjuntak, 2022). With respect to flood mitigation, surface runoff volume has been reduced by approximately 20–35% in watersheds where biopore systems were implemented at sufficient density (Mariyono, 2024).

With regard to organic waste management, studies indicate that household organic waste placed in biopore holes decomposes into compost within 4–8 weeks under tropical conditions, producing compost with nitrogen (N) content of approximately 1.5–2.5%, phosphorus (P) 0.5–1.2%, and potassium (K) 0.8–1.5%, comparable to commercial organic fertilizers (Rahayu et al., 2024; Lestari et al., 2023). Furthermore, earthworm-formed biopores have been documented to increase macropore density by 20–50 per square meter in agricultural soils, contributing to enhanced gas exchange and root penetration depth (Kuz'yakov and Kooch, 2024; Petzoldt and Kautz, 2021). These quantitative findings collectively affirm that biopore systems deliver measurable and substantial environmental engineering benefits, making them a technically sound strategy for sustainable land and water management.

4. CONCLUSION

In general, biopore has emerged as a significant and growing research topic due to its essential role in addressing pressing environmental concerns, including the management of organic waste, the conservation of groundwater, flood mitigation, and the improvement of soil organic carbon. This bibliometric analysis of 208 Scopus-indexed publications (1985–2024) reveals that biopore research is dominated by contributions from Indonesia, Germany, and the United States, with Kautz identified as the most cited author and the University of Bonn as the most influential institution. The main thematic clusters identified through VOSviewer encompass soil organic carbon, water infiltration, earthworm activity, organic waste management, and climate change mitigation—reflecting the multidisciplinary nature of biopore science. Biopore is a potent instrument for fostering community engagement and environmental consciousness in Earth conservation initiatives, in addition to its practical engineering advantages. With continued research and broader implementation, biopores have strong potential to become a fundamental component of sustainable green infrastructure solutions worldwide. Despite the growing body of literature, this analysis reveals several important research gaps that warrant future investigation. First, there is a notable lack of standardized protocols for measuring and reporting biopore-related SOC gains across different climate zones and soil types, making cross-study comparisons difficult. Second, while Indonesia is the leading contributor in terms of document volume, most Indonesian studies focus on urban flood mitigation rather than agricultural SOC improvement, suggesting a need for more field-based experimental research in tropical agroecosystems. Third, the long-term persistence of engineered biopore systems (i.e., biopore infiltration holes) beyond one to two growing seasons has been rarely studied, and the maintenance requirements for sustained hydrological function remain poorly understood. Fourth, the potential of biopores for carbon sequestration and climate change mitigation at landscape or watershed scale has not been adequately quantified. Future research should also explore the integration of biopore technology with precision agriculture tools and digital monitoring systems to optimize implementation at scale. Addressing these gaps will significantly advance both the theoretical understanding and practical application of biopore-based green infrastructure.

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REFERENCES

- Brata, K. R. (2008). Lubang resapan biopori untuk mitigasi banjir, kekeringan dan perbaikan lingkungan. In *Prosiding Seminar Lubang Resapan Biopori (LRB) untuk Mitigasi Banjir, Kekeringan dan Lingkungan*. Bogor: Institut Pertanian Bogor.
- Behrend, D., Athmann, M., Han, E., Küpper, P. M., Perkons, U., Bauke, S. L., & Seidel, S. J. (2025). Do biopores created by perennial fodder crops improve the growth of subsequent annual crops? A synthesis of multiple field experiments. *Field Crops Research*, 322, 109687.
- Dang, Z., Guo, N., Li, S., Degen, A. A., Cao, J., Deng, B., & Shang, Z. (2023). Effect of grazing exclusion on emission of greenhouse gases and soil organic carbon turnover in alpine shrub meadow. *Science of the Total Environment*, 858, 1-9.
- Durán-Sandoval, D., Durán-Romero, G., & Uleri, F. (2023). How much food loss and waste do countries with problems with food security generate?. *Agriculture*, 13(5), 966.
- Eck, N.J. V., and L. Waltman. 2017. Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics* 111, 1053–1070
- Geng, X., Yang, H., Gao, W., Yue, J., Mu, D., & Wei, Z. (2024). Greenhouse gas emission characteristics during kitchen waste composting with biochar and zeolite addition. *Bioresource Technology*, 399, 130575.
- Hassan, N. Y. I., Badawi, E. Y. M., Mostafa, D. E. A. S., Wahed, N. A., Mohamed, M. S., Abdelhamid, A. N., and Bassiony, D. (2023). Composting: An eco-friendly solution for organic waste management to mitigate the effects of climate change. *Innovare Journal of Social Sciences*, 11(4), 1-7.
- Hutabarat, L. E., & Simanjuntak, I. V. (2022). Using bio-pore infiltration hole to reduce flooding in densely population communities of Jakarta and surrounding area. *IOSR Journal of Engineering*, 12(8), 1-9.
- Kanna, V., Roseline, S., Balamurugan, K., Jeeva, S., & Augustin Santhiyagu, I. (2024). The effects of greenhouse gas emissions on global warming. *Encyclopedia of Renewable Energy, Sustainability and the Environment*, 1, 143-154.
- Karmaoui, A. (2022). Ordovician-Cambrian palaeontological heritage of Zagora Province: a bibliometric analysis from 1984 to 2020 (Anti-Atlas, Morocco). *Geoheritage*, 14(2), 55.
- Kassam, A., Gonzalez-Sanchez, E., Carbonell-Bojollo, R. M., Friedrich, T., & Derpsch, R. (2021). Global Spread of Conservation Agriculture for Enhancing Soil Organic Matter, Soil Health, Productivity, and Ecosystem Services. In *Soil Organic Matter and Feeding the Future* (pp. 91-126). CRC Press.
- Kuzyakov, Y., and Kooch, Y. (2024). Earthworm Biopores for Transport and Nutrient Cycling. In *Earthworms and Ecological Processes* (pp. 417-432). Cham: Springer Nature Switzerland.
- Lestari, R. S. D., Lestari, D. K., Barleany, D. R., Suhendi, E., & Jayanudin, J. (2023). Training on making composters and biopore holes as a solution to the organic waste problem. *Journal of Community Service in Science and Engineering (JoCSE)*, 2(2), 45-48.
- Malanski, P. D., Dedieu, B., & Schiavi, S. (2021). Mapping the research domains on work in agriculture. A bibliometric review from Scopus database. *Journal of Rural Studies*, 81, 305-314.
- Mariyono, J. (2024). Sustainable intensification practices of fish-rice co-culture in Java, Indonesia: technical, socio-economic and environmental features. *Journal of Agribusiness in Developing and Emerging Economies*, 14(5), 1015-1032.

- Masdar, M., Nurdin, K., & Kamal, H. (2024). The Performance of the Adiwiyata Program: An Evaluation Study at Madrasah Tsanawiyah Negeri. *International Journal of Asian Education*, 5(4), 349-362.
- Ministry of Environment and Forestry 2022 [Online]. Available at: www.sipsn.menlhk.go.id [Accessed on 29 May 2024]
- Naharuddin, N., Massiri, S. D., Pribadi, H., Maiwa, A., & Ihsan, M. (2024). Evaluation of rainwater harvesting and bio-pore infiltration holes for flood mitigation and soil conservation. *J. Civ. Hydraul. Eng*, 2(3), 142-150.
- Neelam, S., & Sood, S. K. (2020). A scientometric review of global research on smart disaster management. *IEEE Transactions on Engineering Management*, 68(1), 317-329.
- Nespoulous, J., L. M. Martín, Y. Monnier, D. C. Bouchet, M. Ramel, R. Dombey, G. Viennois, Z. Mao, J. L. Zhang, K. F. Cao, Y. L. Bissonnais, R. C. Sidle, A. Stokes. (2019) Tropical forest structure and understorey determine subsurface flow through biopores formed by plant roots. *Catena*, 181, 104061.
- Parfitt, J., Croker, T., & Brockhaus, A. (2021). Global food loss and waste in primary production: a reassessment of its scale and significance. *Sustainability*, 13(21), 12087.
- Passioura, J. B. (2002). Soil conditions and plant growth. *Plant Cell Environ*, 25, 311–318.
- Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G. P., & Smith, P. (2016). Climate-smart soils. *Nature*, 532(7597), 49-57.
- Petzoldt, L., & Kautz, T. (2021). Root Distribution of Brassica napus and Vicia faba within the Sheath of Root or Earthworm Biopore. *Agriculture*, 11(1), 61.
- Phalempin, M., Landl, M., Wu, G. M., Schnepf, A., Vetterlein, D., & Schlüter, S. (2022). Maize root-induced biopores do not influence root growth of subsequently grown maize plants in well aerated, fertilized and repacked soil columns. *Soil and Tillage Research*, 221, 105398.
- Pramanik, S. K., Suja, F. B., Zain, S. M., & Pramanik, B. K. (2019). The anaerobic digestion process of biogas production from food waste: Prospects and constraints. *Bioresource Technology Reports*, 8, 100310.
- Putra FA 2021 Maintaining food security by innovating in the digital era to become a driver of the national economy towards a golden Indonesia 2045 Semagri, 2(1).
- Putra, D. E., Randika, Y., Randika, I., Inamullah, H., Rusdiansyah, A., & Raharjo, W. (2024). Enhancing grounding system efficiency through biopore technique in seasonal soil conditions. *International Journal of Advanced Technology and Engineering Exploration*, 11(113), 516.
- Rahayu, L., Kamardiani, D. R., & Nurusman, A. A. (2024). Application of Biopori Technology for Sustainable Management of Household Organic Waste. In *BIO Web of Conferences* (Vol. 137, p. 03013). EDP Sciences.
- Ruiz, S. A., Bickel, S., & Or, D. (2021). Global earthworm distribution and activity windows based on soil hydromechanical constraints. *Communications biology*, 4(1), 612.
- Schotten, M., Meester, W. J., Steiginga, S., & Ross, C. A. (2017). A brief history of Scopus: The world's largest abstract and citation database of scientific literature. In *Research analytics*, 31, 31-58.
- Setiadi, A., Santoso, S. I., & Setiawan, B. M. (2021). Performance Of Soybean Farming In Java-Indonesia: Determinants And Improvement. *Academy of Strategic Management Journal*, 20(4), 1-14.
- Sharma, P., Bano, A., Verma, K., Yadav, M., Varjani, S., Singh, S. P., & Tong, Y. W. (2023). Food waste digestate as biofertilizer and their direct applications in agriculture. *Bioresource Technology Reports*, 23, 101515.
- Sidik, A. D. W. M., Edwinanto, E., Padilah, A., Hak, A., Gulo, M., Aghniya, G. I., ... & Agustin, Y. P. (2024). Empowering Communities through Enhancing Environmental Awareness:

- A Case Study of Cikelat Village, Sukabumi, West Java in Community Service Activities. *Journal of Innovation and Community Engagement*, 5(1), 18-34.
- Stolze, K., Barnes, A. D., Eisenhauer, N., & Totsche, K. U. (2022). Depth-differentiated, multivariate control of biopore number under different land-use practices. *Geoderma*, 418, 1-13.
- Sun, J., and Yuan, B. Z. (2020). Mapping of the world rice research: A bibliometric analysis of top papers during 2008–2018. *Annals of Library and Information Studies ALIS*, 67, 55-66.
- Ülker, P., Ülker, M., & Karamustafa, K. (2023). Bibliometric analysis of bibliometric studies in the field of tourism and hospitality. *Journal of Hospitality and Tourism Insights*, 6(2), 797-818.
- Walker, S. H., Eavis, B. W., Harriss, J. C., Laurence, J. F., Moffatt, D. J., & Robertson, C. A. (1980). Development of the water resources of Bali: a master plan. Volume 2. Technical Report.
- Wendel, A. S., Bauke, S. L., Amelung, W., and Knief, C. (2022). Root-rhizosphere-soil interactions in biopores. *Plant and Soil*, 475(1), 253-277.
- Zhang, J., Chen, H., Wang, M., Liu, X., Peng, C., Wang, L., & Zhu, Q. (2024). An optimized water table depth detected for mitigating global warming potential of greenhouse gas emissions in wetland of Qinghai-Tibetan Plateau. *Iscience*, 27(2). 1-13.