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A bibliometric analysis of biochar for sustainable soil fertility management in Africa

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ABSTRACT

Biochar has gained popularity as a potential strategy to enhance soil fertility and sustainability in Africa. The link between biochar and soil fertility management has not been well defined in terms of development, thematic direction, and collaborative structure. The paper aims to analyze the research trends in biochar to address sustainable soil fertility management in Africa from 2015 to 2025, tracing scientific publications, productivity, growth mapping, evolution, conceptual structure, and international collaboration network. A total of 561 papers were kept after retrieval from the Dimensions.ai database. A bibliometric technique using the R tool was used for the analysis in the Biblioshiny package. The findings showed that annual publications rose from 12 in 2015 to over 150 in 2025 at an average annual rate of 27%. The International Journal of Plant and Soil Science has the most publications (21 documents), with Agronomy having the most citations per paper (h -index = 10; 440 citations). Marschner B. is the most productive author with 10 publications (h -index = 8; 237 citations), and Cornelissen G. has the most citations per article (74.7; h -index = 6; 523 citations). Nigeria was the country with the most citations (847). A document by Button ES had the highest number of citations globally (293). The co-occurrence analysis identified charcoal and soil as the central connecting terms, and thematic evolution revealed a shift from general soil and biomass research toward input-specific research (maize, fertilizers, and agriculture). Collaboration analysis showed that there were very strong partnerships, including the United States, Germany, and Norway with Nigeria, Ghana, and Kenya. Overall, the field is growing in size and scope but remains thematically weak and highly reliant on international research networks, with a need for more intra-African collaboration and greater international awareness of regional research.

Keywords: Biochar, Soil fertility management, Africa, Bibliometric analysis, Biblioshiny, Sustainable agriculture

1. Introduction

Approximately 33% of the world's soil suffers from moderate to high degradation, driven by erosion, organic carbon loss, acidification, salinization and nutrient imbalance (Lal, 2015) [1]. Climate change has an impact on these losses, as changes in precipitation and heat stress erode the soil's ability to support crop production. The Food and Agriculture Organization identified Soil fertility as one of the direct threats to food security, as fertile soil cannot be replenished in any time scale appropriate to agricultural planning (FAO, 2015) [2].

Biochar is a carbon-rich material, produced by heating biomass like crop residues, wood chips, and manure in the presence of little or no oxygen (pyrolysis) (Lehmann *et al.*, 2009) [3]. The concept of biochar dates back to the pre-Columbian Amazonians (Wang *et al.*, 2020) [4], and is a response to this challenge. It has a high surface area and cation exchange capacity (CEC), and can hold the nutrients that would otherwise wash out of coarse soils, including potassium, calcium, and magnesium (Glaser *et al.*, 2002; Ding *et al.*, 2016) [5, 6]. It is usually alkaline, which buffers acidic soils and optimizes the availability of phosphorus to plants, and its porosity results in an increase in water-holding capacity (FAO *et al.*, 2023) [7]. Effects on yield are real but variable: a meta-analysis found an average 10% productivity gain, ranging from a 28% loss to a 39% gain depending on soil and application conditions (Jeffery *et al.*, 2011) [8]. The recalcitrant carbon is also a long-term sink (Hou, 2021) [9].

The global interest has been increasing quickly since the founding of the International Biochar Initiative in 2006 to encourage sustainable biochar systems. A total of 2,756 biochar results were returned for 2019 alone from Web of Science, while the number of publications that mention sustainability increased by 108% from 2018 to 2019 (Hou, 2021) [9]. Over 7,000 records between 2007 and 2023 were analyzed through a bibliometric approach, and 71% of the produced items were published in the last five years, with 95 different subjects in which soil amendment, water treatment and water remediation appeared (Ngaba *et al.*, 2025) [10].

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This is reflected in industry growth; global production reached 520,810 metric tonnes in 2025, compared to 180,150 in 2023, and they go up to 9.3 million tonnes by 2030 (IBI, 2025) [11].

Africa's soils are low in organic matter, hold few nutrients, and are very acidic, limiting productivity in the smallholder farming systems that dominate African farming (Iwuozor *et al.*, 2025) [12]. These constraints combine with demographic pressures: Africa's population is expected to grow to approximately 2 billion by 2050, and still more than 900 million people in Africa rely on biomass as their primary source of cooking energy, consuming it inefficiently, which contributes to deforestation (Iwuozor *et al.*, 2025) [12].

Although the use of Africa's abundant underused biomass (agricultural residues, wood waste, invasive biomass, and animal manure) is high, the production of biochar is still the traditional way, which shows a low efficiency of 9-30% compared to engineered systems (Iwuozor *et al.*, 2025) [12]. The applications include soil fertility, water treatment, and energy generation, with Egypt, Nigeria, and South Africa (Iwuozor *et al.*, 2025) [12]. Africa recorded the fastest regional production growth surveyed in 2025, representing a 183% compound annual growth rate (IBI, 2025) [11]. However, low public awareness, inconsistent quality of biochar, poor financing, and inadequate infrastructure continue to hinder widespread adoption (Iwuozor *et al.*, 2025) [12].

A bibliometric analysis of African biochar research by (Iwuozor *et al.*) [12] revealed that annual output rose significantly from 17 publications during 2008 to 2012 to 2,157 during 2019 to 2024, with citations expanding by 800% between 2018 and 2024. The study identified a distinct international collaboration network and a dataset of 13,289 keywords; its primary thematic focus centered on production and environmental applications rather than social and economic dimensions.

However, this existing mapping remains broad rather than soil fertility specific, as it covers water, energy, and construction. Therefore, specialized bibliometric overviews targeting biochar for sustainable soil fertility management in Africa are limited. This study addresses this research gap by conducting a bibliometric review of literature tracking African biochar application for sustainable soil fertility management in Africa from 2015 to 2025.

2. Materials and methods

2.1 Data source, search strategy and data screening

The research design used in this study is a quantitative bibliometric design to measure the productivity and citation impact of authors, institutions, countries, and journals, and to portray the conceptual structure of a research domain or field, such as keyword co-occurrence and thematic mapping. The data was obtained from the Dimensions.ai database, which was selected due to its ability to gather publications, citations, and other publication-related research outputs from a vast array of sources into one coherent system.

A Boolean query was used to search the records that have been indexed in Dimensions.ai, using the relevant search terms ("Biochar" OR "bio-char" OR biochar OR bio-char OR charred biomass OR "pyrogenic carbon" OR "pyrogenic-carbon" OR pyrogenic carbon OR pyrogenic-carbon) AND (agriculture* OR farm* OR crop* OR soil* OR "soil fertility" OR "soil amendment" OR "soil health" OR agronomy OR horticulture*) AND (Africa OR Algeria OR Angola OR Benin OR Botswana OR "Burkina Faso" OR Burundi OR Cameroon OR "Cape Verde" OR "Central African Republic" OR Chad OR Comoros OR Congo OR "Democratic Republic of the Congo" OR Djibouti OR Egypt OR "Equatorial Guinea" OR Eritrea OR Eswatini OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR "Guinea-Bissau" OR Kenya OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Mali OR Mauritania OR Mauritius OR

Morocco OR Mozambique OR Namibia OR Niger OR Nigeria OR Rwanda OR Senegal OR Seychelles OR "Sierra Leone" OR Somalia OR "South Africa" OR "South Sudan" OR Sudan OR Tanzania OR Togo OR Tunisia OR Uganda OR Zambia OR Zimbabwe") indexed in Dimensions.ai contains. The searched was limited to the information in the Title and Abstract data field from 2015 to 2025, articles, book chapters, and proceedings published in English from peer-reviewed journals were considered, eliminating preprint documents. Following the initial retrieval of 569 records, duplicates were removed, and one editorial 'Expression of Concern' notice was excluded, resulting in a final dataset of 561 documents for study.

2.2 Analytical tools and indicators

Bibliometric methods are quantitative tools for investigating the structure and evolution of scientific literature. (Zupic *et al.*, 2015; Donthu *et al.*, 2021) [13, 14]. Tools used to visualize and quantify the relationships in the literature were: scientific production, citation indicators, source productivity and impact, author productivity and impact, country productivity and citation impact, keyword co-occurrence network, and the international collaboration network. Analysis was carried out in R software using the Bibliometrix package using Biblioshiny interface. (Aria *et al.*, 2017) [15]. Text-mining techniques were used to provide further insight into the conceptual and thematic structure of the literature. These were based on keyword frequency analysis, trend-topic analysis, thematic mapping, thematic evolution, and Multiple Correspondence Analysis (MCA). Frequently occurring and emerging terms of research were determined by keyword analysis, and by thematic mapping, terms were grouped by centrality and density. To analyze the changes in the major research themes, thematic evolution analysis was applied in the following periods: 2015-2021, 2022-2024, and 2025. The MCA approach was used to reveal the conceptual structure and relations between the terms extracted from the publication titles. The network-based visualization was used to explore the relationship of keywords and international research collaboration (van Eck *et al.*, 2014) [16]. Results are summarized using graphs, tables, network visualizations, and frequency analysis to describe the annual growth of publications, influential sources and authors, country-level research productivity and impact, dominant research themes, conceptual clusters and international collaborations.

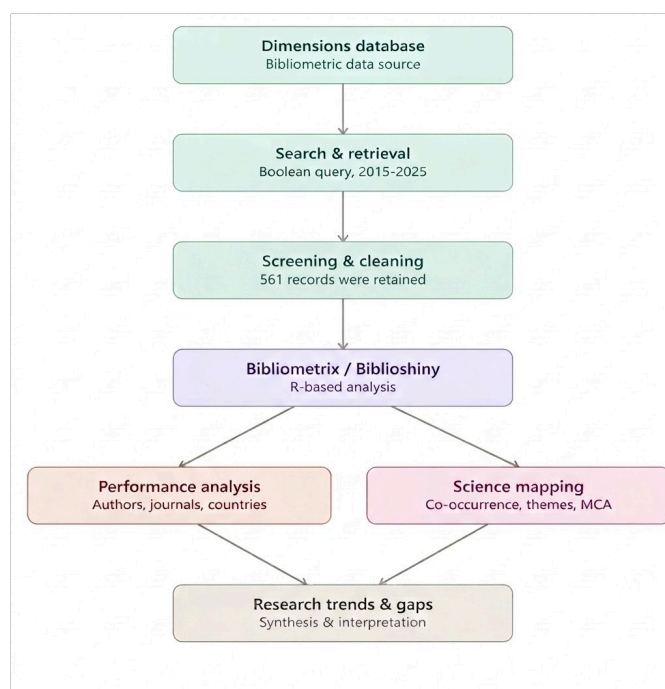


Figure 1. Methodological Framework

3. Results

3.1 Performance analysis

This section includes annual scientific production, average citations per year, Source local impact, Bradford's Law, and the productivity of various authors, as well as paper production by country.

Based on the number of documents published per year, annual scientific production is characterized by the emergence phase, growth

phase, and accelerating phase. The emergence phase (2015-2018) grew steadily from 12 in 2015 to 23 in 2018. The growth phase (2019-2022) rose from 29 and reached a high of 56 documents per year. The number of documents produced increased rapidly from approximately 78 in 2021 to more than 150 in 2025. This represents an annual growth rate of 27% over all 11 years, indicating that the research field of biochar for soil fertility is still an emerging one, but is now growing far faster than it did in the first 6 years.

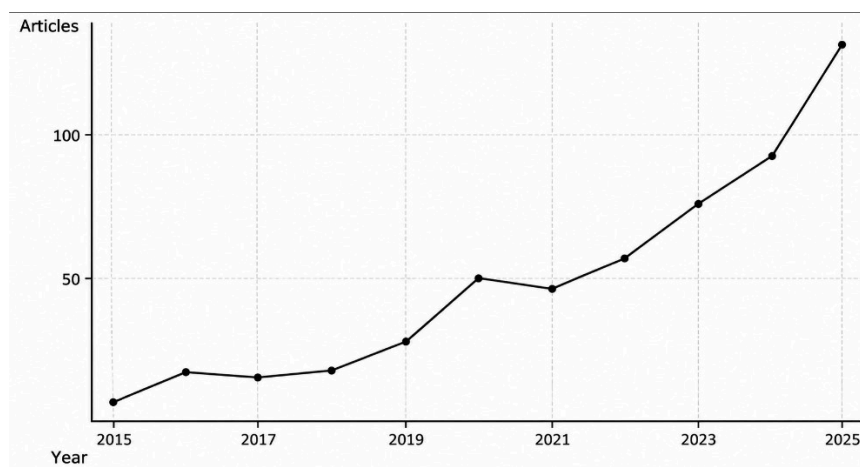


Figure 2. Annual Scientific Production, 2015-2025.

The average citations per year aren't linear, but fluctuate with highs around 2017 (around 4.5) and again around 2022 (around 3.6) before decreasing in more recent years. This decrease is not a measure of in-

ferior quality of research; it is simply the number of papers getting cited being higher when published earlier. This is a normal phenomenon in a rapidly expanding area.

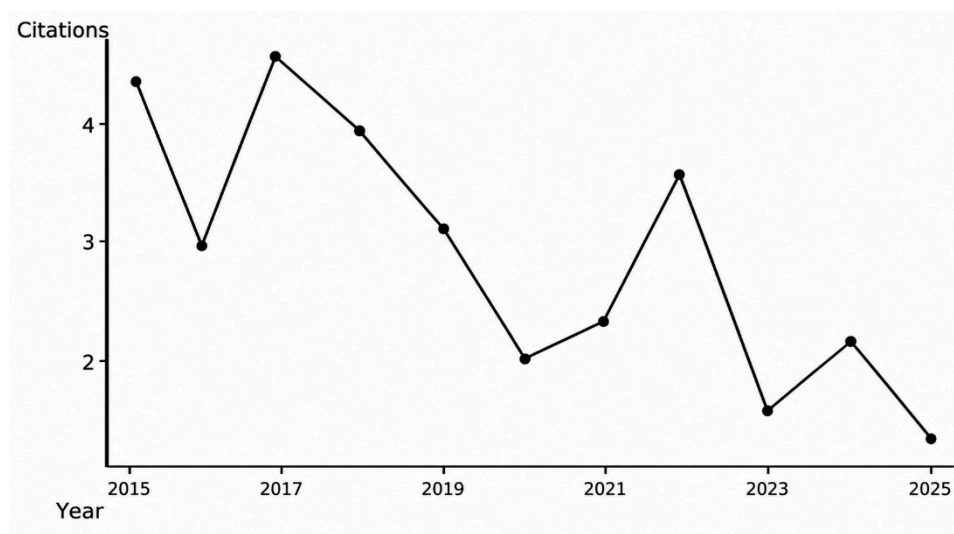


Figure 3. Average Citations per Year.

The most relevant source and source local impact indicate that the International Journal of Plant & Soil Science publishes the highest number of papers on this topic (21 documents), followed by the Journal of Soil Sciences (Donthu *et al.*, 2021) [14] and Scientific Reports (Zupic *et al.*, 2015) [13]. It's a different story altogether for Impact. The highest h-index (Ngaba *et al.*, 2025) [10] is in Agronomy, which has 12 documents and 440 citations, followed by Heliyon with 10 documents and 304 citations. PLOS ONE is different: it has 5 articles with 528 citations, an average of more than 100 per article; several citations are not high, but they indicate that a small number of papers are cited many.

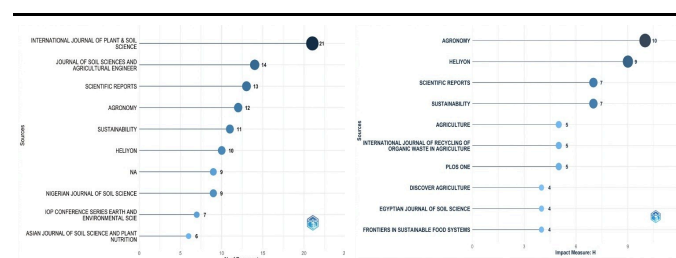


Figure 4. Most Relevant Sources

Figure 5. Source Local Impact by H-index

For this study, the 304 different sources fall into a Bradford multiplier, k , of 2.71, with an R^2 value of 0.947, a strong fit, which can be divided into a Zone 1, 27 journals; a Zone 2, 91 journals; and a Zone 3, 186 journals. This is consistent with findings across most research

areas, which tend to follow the pattern that a small number of journals generate most of the work in the field, as predicted by Bradford's Law.

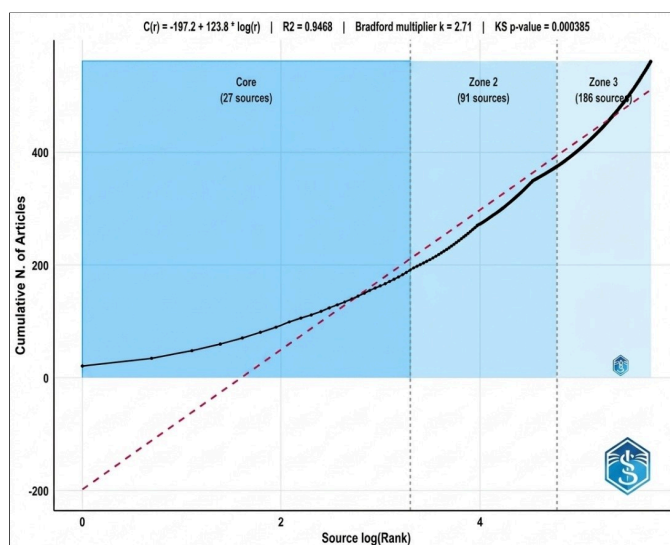


Figure 6. Core Sources by Bradford's Law.

Table 1. Ten Most Productive Authors, with Local H-index.

Author	Articles	Total Citations	TC/Article	H-index
Marschner B	10	237	23.7	8
Mulder J	9	385	42.8	7
Frimpong KA	8	437	54.6	7
Martinsen V	8	395	49.4	7
Obia A	8	338	42.2	6
Cornelissen G	7	523	74.7	6
Sato S	7	62	8.9	4
Sundberg C	6	169	28.2	5
Steiner C	6	146	24.3	5
Werner S	6	137	22.8	5

At the country level, Nigeria, Egypt and Ethiopia are the top three producers, while Ghana, Kenya, Uganda and South Africa are clearly in a second tier (Figure 6). The number of citations also has a similar, but not the same, distribution. Nigeria again leads (847 citations), followed by Germany (695), Norway (551), Ghana (530), and Ethiopia (458) (Figure 7). Germany and Norway do not fall into this study's search space at all, and so their performance is worth consideration: it seems that a lot of literature that is about Africa is actually produced in conjunction with researchers in European universities, rather than by researchers based in Africa alone.

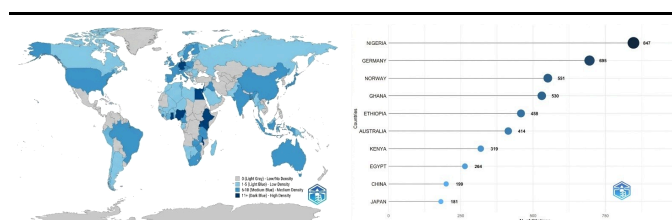


Figure 7. Country Scientific Production

Figure 8. Most Cited Countries

The top 10 most cited documents for this study are listed in Table 2. Button *et al.* (2022) leads with 293 citations, ahead of Kätterer *et al.* (2019) with 240 citations and Mensah *et al.* (2018) with 202 citations. Six of the top ten most cited papers are in large international journals, not regional and/or African journals.

Table 2. Most Globally Cited Documents.

Document	Source	Year	Citations
Button ES.	Soil Biology and Biochemistry	2022	293
Kätterer T.	Field Crops Research	2019	240
Mensah AK.	International Journal of Agronomy	2018	202
Abiven S.	Plant and Soil	2015	182
Adekiya AO.	The Scientific World Journal	2020	171
Obia A.	PLOS ONE	2015	169
Tadele Z.	Agronomy	2017	157
Bashagaluke JB.	PLOS ONE	2018	151
Yang G.	PLOS ONE	2016	147
Brown DM.	The Science of the Total Environment	2017	131

3.2 Co-occurrence network and thematic mapping

The co-occurrence network divides the charcoal and soil literature into four clusters, with two of the nodes holding nearly the entire structure. There are two terms, charcoal and soil, that are connectors, with nearly every other term passing through them (betweenness values shown: 226.30, 182.53; PageRank values shown: 0.169, 0.167). Agriculture is the third in line (betweenness 18.06), and leads into the rural population and special settings in Africa back to that core. Another smaller cluster of fertilizers, N and P, is tied to nutrient management, and another cluster of carbon around material characterization (pH, FTIR, kinetics). All the rest (soil contaminants, microbiology, zeolites, country-specific terminology) exists as a periphery, bound to the core but not closing the gap.

The thematic map divides the same literature into seven clusters, and in this case, the frequency is not the same as betweenness. The basic theme is clearly charcoal, with a total of 13 terms and 119 combined occurrences; charcoal occurs 30 times alone, and soil occurs 30 times alone. Fertilizers is the second largest cluster by PageRank (0.293), and is the smallest of the raw counts, making it a tightly developed motor theme by itself. Smaller clusters that have not yet expanded into branches are applied clusters, such as humans, soil microbiology, and soil pollutants. The highest PageRank scores for any group (0.333) go to the single-term cluster of Zeolites; this is a self-contained topic that's sitting right on the edge of the field, and a sign of this, as both analyses show, is the field's next trajectory: charcoal and soil are what anchor it, while remediation, microbiology, and zeolite treatment are what drive it forward.

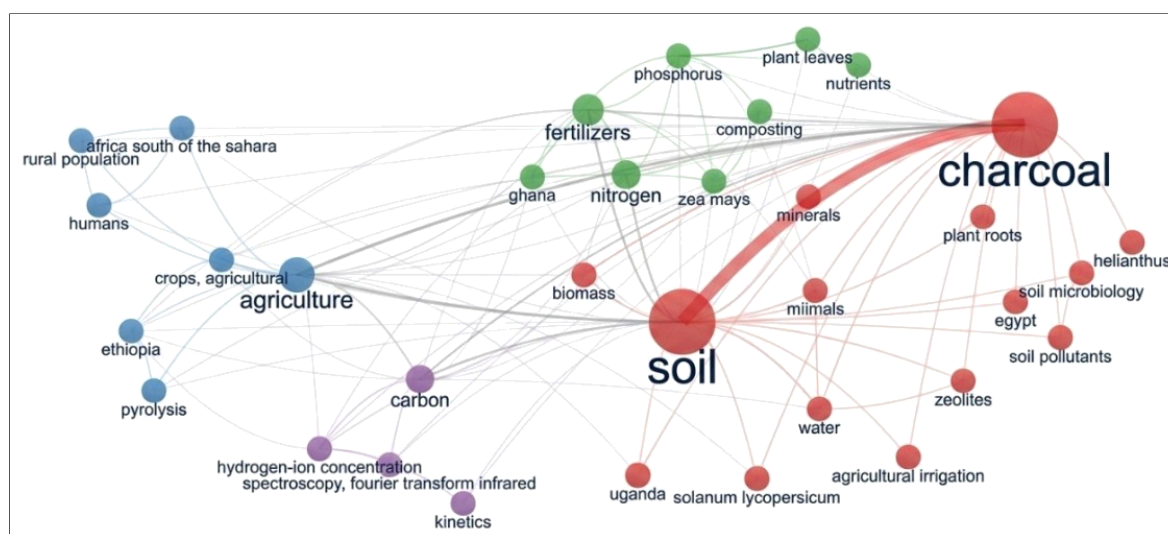
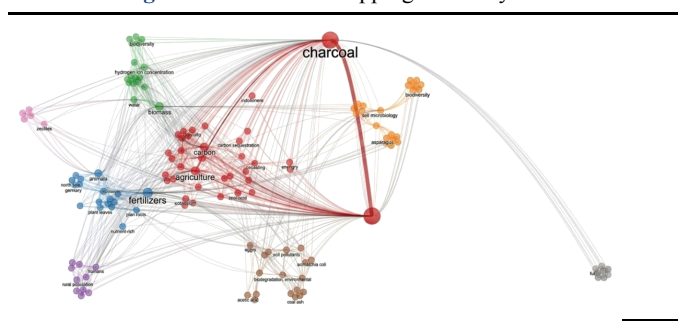


Figure 9. Co-occurrence Network of all keywords

Figure 10. Thematic Mapping of all keywords



3.3 Thematic evolution

Change over time was studied across three periods: 2015-2021, 2022-2024, and 2025. Focus was well distributed between soil microbiology and soil and biomass in the earliest time. Much had changed by 2022-2024: the soil microbiology is now almost confined to the charcoal and *Zea mays*, while soil and biomass are distributed over charcoal, *Zea mays*, fertilizers and agriculture. There is a real move away from a general, process-based early literature to a crop- and input-specific literature that focuses on one named crop (maize) and named farm inputs. At the latest time (2025), charcoal is very dominant, and the directions of flow are that of feed into charcoal and also to nitrogen and agriculture, while *Zea mays* and fertilizers flow into agriculture.

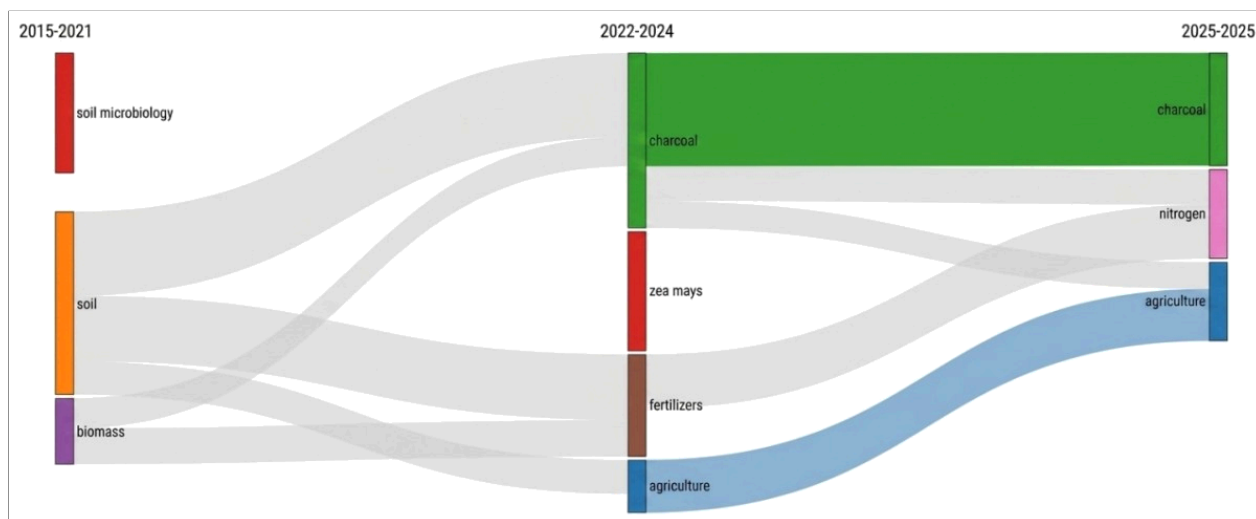


Figure 11. Thematic Evolution, 2015-2025.

3.4 Factorial analysis (MCA)

The Multiple Correspondence Analysis based on the words retrieved from the titles of the papers in this study reveals the existence of two well-defined clusters of documents along Dimension 1. The majority of the documents are grouped broadly around the keywords Nigeria, poultry and manure with the principal focus of most of the literature being the use of organic inputs and manure for soil treatment, pre-

dominantly in Nigeria. Far to the other side, much further apart is a small dense cluster of spectroscopy and Fourier transform infrared in addition to kinetics, which represent a separate set of lab-based tests. There is a significant difference between the two dimensions, as the former accounts for 14.66% of the variation and the latter for 10.76%, but the difference in the two means that they have very little in common at the level of paper titles.

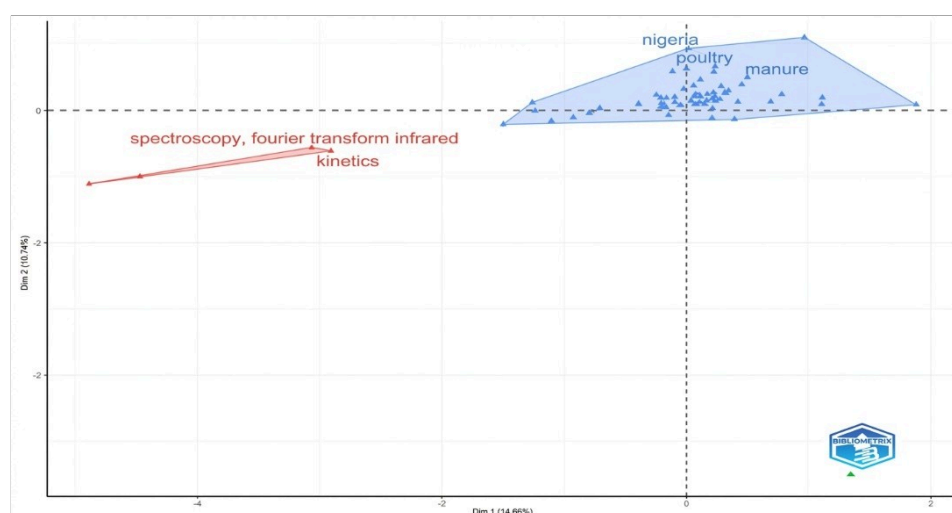


Figure 12. Conceptual Structure Map (MCA).

3.5 Collaboration networks

The story continues on a country level in the country collaboration map. It demonstrates that the United States, Germany, and Norway are the most strongly connected countries outside Africa, all with very thick lines connecting them with Nigeria, Ghana, and Kenya. This brings the North-South research collaborations to a small number, and

the South-South research collaborations (e.g., between Nigeria, Ghana and Kenya) are relatively sparse. This is consistent with the country citation results in the most globally cited document, Germany and Norway had a larger portion of the total citations than expected, but not due to independent research on African soils, but rather due to a strong collaboration between relatively few highly productive researchers, and other researchers working on African case studies.

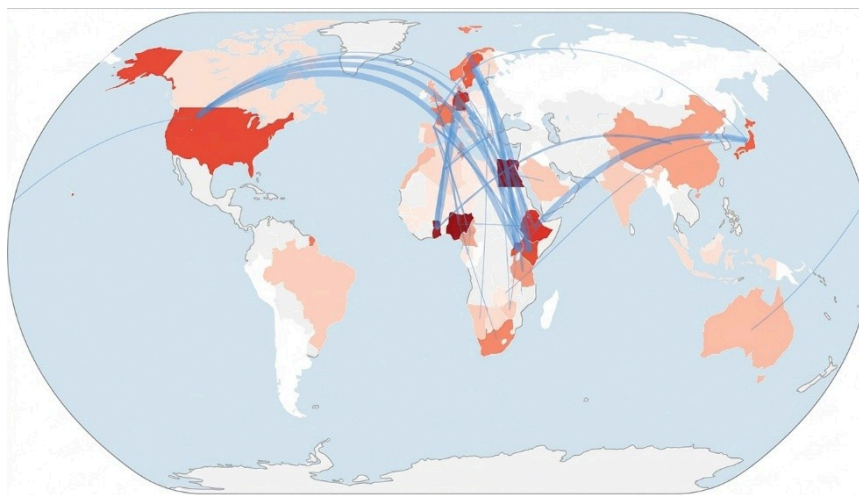


Figure 13. International Collaboration Network.

4. Discussion

The study, taken together paint a picture of a field characterized by rapid production growth, a consolidation towards crop-specific cohorts of ideas, and a model of collaboration dominated by partnerships with scientists outside Africa. The growth trajectory in [Figure 2](#) indicates where this literature lies with respect to the turning point of the global biochar field, which is about four to five years behind. The study by [Wu et al.^{\[17\]}](#) also revealed a significant increase in publications on biochar papers through 2021, mostly in China and the United States, confirming the observation made by [Ahmed, Vanga and Raghavan^{\[18\]}](#) for 2000-2015. In this study, the pattern is very similar, except that the initial levels of the graph are lower, and the pattern starts a few years later. It corresponds to [\(Sanchez's\)^{\[19\]}](#) long-held tenet that research on soil fertility in Africa has historically not kept pace with the problem it wants to address. In addition, the pattern is similar to that reported by [\(Iwuozor et al.\)^{\[12\]}](#) continent-wide as they found that the number of articles published on biochar research in Africa overall rose steeply from 17 articles in 2008-2012 to 2,157 articles in 2019-2024, with citations increasing by approximately 800% during the last five years of the same period that this chapter covers. The soil-fertility strand explored here is therefore not seen as under-developed, but rather partaking in the African literature, although somewhat behind the pace of the global literature as a whole.

Among the most influential peer-reviewed journals that were locally available, *Agronomy* and *Heliyon* led in the number of papers published, and the *International Journal of Plant & Soil Science* was among the regionally hosted journals, with *Nigerian Journal of Soil Science (NJS)* far outpacing the rest. This separation is a high impact, international publication cluster with a close relationship to research capacity abroad, and an alternative, high volume regional cluster of publications with a close relationship to research capacity at home is similar to [Arfaoui, Ibrahim and Trabelsi's^{\[20\]}](#) findings related to the specific biochar research context in the Middle East and North Africa under dry soil conditions, where output continued to rise but remained strongly coupled to research capacity abroad rather than locally.

The authors listed in [Table 1](#) similarly are limited to a few high productivity and high citation authors, with several of the most productive and cited authors ([Marschner, Mulder, Martinsen, Cornelissen and Sundberg](#)) working at German or Norwegian institutions, and it is the joint work of these authors with African researchers, rather than independent African-led work, that helps to account for the high citations of these two countries in [Figure 8](#).

Add to this the collaboration-network results. [Figure 12](#) reveals that the most productive authors in this field are primarily working in small groups of discrete and cohesive networks, rather than a large, cohesive research community, and [Figure 13](#) indicates the same pattern at country level, with strong links between North-South countries, but weak links between African countries. Several different

groups of researchers working independently on similar topics are not unusual for a young and rapidly developing field, but are also a factor that could cause ideas, methodology and results to flow through the field more slowly than they would in a more cohesive community of researchers.

As demonstrated in [Figures 11 and 12](#), the development of ideas and the factorial analysis demonstrate that the ideas in this field are not yet in line with its output. The strategic thematic map created as part of this study left the *Motor Themes area* empty as there is no single topic that is both central to the field and well developed as a distinct area of study. It helps to explain this because of the conceptual structure map shown in [Figure 12](#), where the applied, farm-practice literature (manure, poultry, Nigeria) is virtually separated from the laboratory-based testing literature (FTIR spectroscopy, kinetics). This gap is just starting to narrow in the most recent period in the thematic evolution results, with the field converging towards charcoal use in maize-based farming systems. This trend has been observed in other emerging and rapidly expanding research areas, and represents a shift from a diffuse early literature to a more focused and applied, crop-specific literature that becomes concentrated, rather than dilapidated, after the research output has increased.

All of this does not weaken the merits of biochar for African agriculture. It has demonstrated its ability to boost yields on the acidic, low-productivity soils used by many people across the continent ([Jeffery et al., 2011\)^{\[8\]}](#), and the capacity to lock up carbon in a manner that is beneficial to climate change ([Woolf et al., 2010\)^{\[21\]}](#) is well documented in the broader research landscape. This study provides a more detailed image of the progress made in Africa, and the potential yet to be made in the field of research. The relatively small number of journals revealed by [Bradford's Law \(Figure 6\)](#) and the relatively large number of cited papers revealed by [Table 2](#) suggest a down-to-earth next step: increasing the number of journals would probably not increase the impact of citations to this field of study as much as making the small, tight group of regional journals more accessible and better indexed internationally.

5. Policy recommendation

The growing use of crop-specific and input-focused terms in the 2022-2025 literature shows that Africa's biochar research community is moving away from broad, exploratory soil-microbiology work and toward the kind of applied, yield-linked evidence that extension services and policymakers can actually use. This shift deserves active support, especially through funding for field trials across several sites and several crops that go beyond the maize-heavy evidence base available today. The strength of the Nigeria-Germany and Nigeria-Norway collaboration ties points to research partnerships that are already working well and could be made more formal through joint research grants or researcher-exchange programs. At the same time, funders should invest in building independent African research capac

ity, so that the field's best work depends less on partnerships with researchers outside the continent. National agricultural research bodies and regional organizations should also work to fix the indexing and visibility problems affecting the regional core of journals found through Bradford's Law, and should fund studies that directly link biochar's lab-tested properties, such as surface area, ion-holding capacity, and chemical make-up, to real field results, since these two research communities currently work largely apart from each other. Lastly, because biochar can be made from crop leftovers that would otherwise be burned or thrown away, and because bought fertilizer stays expensive compared with income across much of the continent (Sanchez, 2002) [19], national extension programs should test cheap, farmer-friendly ways of making biochar alongside these research goals, so that research findings turn into soil treatments that farmers can actually use.

6. Conclusion

The research into soil fertility using biochar in Africa is accelerating, but the concepts are yet to catch up with the research products, and the best pieces of research rely heavily on international collaborations with scientists outside Africa. The increased number of articles since 2021, as well as the recent shift of the field toward questions of maize-specific and input-focused research, has suggested a shift in the literature from an early exploration phase to a phase of application. There is need for greater independence in the African research enterprise, increased recognition of the regional journals, and greater collaboration between field trial and lab-based testing researchers.

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