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REVIEW

The Potential of Pig Slurry Application on Pasture Production: A Systematic Approach

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Abstract
Livestock production is fundamental to agricultural systems, particularly in communal farming contexts where it directly influences rural livelihoods. This study investigates the application of pig slurry as a natural fertilizer on pasture production, focusing on its impact on both forage quantity and quality. Through a comprehensive bibliometric analysis using the Web of Science and Scopus databases, we identified key research trends, spatial distributions, and collaboration networks within the field from 1975 to 2024. Our findings reveal that Brazil leads in publications, followed by the USA, Canada, China, and Australia, with significant international collaboration primarily among developed nations. The average annual growth rate of publications was found to be 2.32%, demonstrating exponential growth ($R^2 = 0.44$) in the scientific output, aligning with Price's Law of bibliometrics. Keywords such as "pig slurry," "nitrous oxide," and "soil" emerged as prominent themes, indicating a strong focus on nutrient management and environmental impacts. Notably, the top 10 cited documents emphasized greenhouse gas emissions and nitrogen dynamics, reflecting significant environmental concerns related to pig slurry's application. Despite substantial advancements in research, a considerable gap persists in research activity from developing nations, particularly in Africa, where only Senegal has shown engagement in this area. This highlights a need for enhanced collaboration and investment in research to optimize the use of pig slurry in pasture systems, thereby promoting sustainable agricultural practices and improving livestock productivity. By addressing these research gaps, future studies could contribute to effective nutrient management strategies, fostering resilience in communal farming systems.

Keywords Nutrient Management · Pasture Productivity · Pig Slurry · Sustainable Agriculture

1 Introduction

Livestock production is a cornerstone of agriculture, particularly in rural areas, where it plays a vital role in sustaining livelihoods (Mapiye et al. 2020). According to Taruvinga et al. (2022), it is a key source of income for communal farmers in South Africa. Livestock also provides essential animal-derived foods, such as meat and milk, which are important protein sources for human diets (Henchion et al. 2021). However, Livestock producers frequently encounter several challenges, with the use of low-quality animal feed being a major constraint (Kamalzadeh et al. 2008). Forage scarcity, particularly during the winter, significantly hampers livestock production in communal farming systems. This scarcity often results in compromised animal health, reduced productivity, and economic difficulties for farmers (Magawana et al. 2021). To maintain livestock productivity, some communal farmers resort to costly supplements, such as commercial protein and mineral licks, as well as high-protein forage like lucerne (Mthi et al. 2017). Resource-limited farmers rely on rangelands, while those engaged in summer crop production utilize post-harvest residues (Descheemaeker et al. 2016).

The increasing demand for livestock products suggests a corresponding rise in the demand for animal feed (Kamalzadeh et al. 2008). Organic amendments, such as pig slurry(PS), offer a promising alternative to synthetic fertilizers, with the potential to enhance soil fertility and improve

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forage production (Garbowski et al. 2023; Brustolin-Golin et al. 2016). Studies have consistently demonstrated that pig slurry positively impacts soil fertility and the quantity and quality of forage due to its rich content of essential macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium) and micronutrients (manganese, boron, iron, nickel), with notable levels of copper (Cu) and zinc (Zn) (Grohskopf et al. 2016). Moreover, pig slurry contains trace elements such as cobalt (Co), chromium (Cr), and lead (Pb), which, while not essential for plant nutrition, are present in small amounts (Shakoor et al. 2022). These nutrients play critical roles in various stages of plant development, including growth, flowering, and fruiting, further demonstrating the value of pig slurry as a natural fertilizer.

For instance, Shakoor et al. (2022), assessed the impact of pig slurry on soil properties and nutrient accumulation in barley plants over a seven-year field study. Their findings indicated that increasing slurry doses enhanced organic carbon, phosphorus, and potassium levels in the soil without elevating heavy metal concentrations. Notably, while higher slurry rates led to increased copper, manganese, and zinc levels in straw, the lowest slurry rate achieved the highest grain yields and improved soil fertility. Also, Bertici et al. (2022), evaluated pig sludge's effect on soil quality and pasture variability in Ciacova, Timiș County, Romania. Their study revealed that pig sludge application improved soil fertility, with increased phosphorus and potassium levels and optimal pH values over time. The variability of the pasture's NDVI index decreased from 2013 to 2019, reflecting enhanced pasture quality.

Furthermore, Brustolin-Golin et al. (2016), investigated the response of carpet grass to pig slurry fertilization, assessing agronomic efficiency and plant-available nitrogen from the manure. Their results showed a linear increase in dry matter yield with higher slurry doses, particularly notable in the second year of the study. However, the agronomic efficiency of pig slurry was lower compared to ammonium nitrate, with plant-available nitrogen fractions estimated at 0.64 in 2008–2009 and 0.60 in 2009–2010. Similarly, Albuquerque et al. (2017), examined the residual effects of pig slurry on carpet grass pasture, finding that dry matter yield increased by 398 kg ha^{-1} per 100 m^3 of pig slurry applied. This was comparable to increases of 317 and 564 kg ha^{-1} for each 100 kg ha^{-1} of inorganic and organic nitrogen, respectively. The residual effect of pig slurry on dry matter yield and forage-nitrogen uptake ranged from 11 to 45% and 8–40%, respectively, indicating a gradual release of nitrogen from the slurry. These findings suggest that pig slurry is a valuable resource for enhancing forage yield and improving soil fertility. Therefore, this study aims to explore the impact of pig slurry application on pasture production. Additionally, the study will conduct a bibliometric analysis to review and synthesize the existing research on this topic. The objective is to identify trends, gaps, and key findings in the literature, providing a comprehensive overview of how pig slurry affects pasture productivity and highlighting areas for future research. By building upon previous studies, this research seeks to contribute to the development of sustainable and effective nutrient management strategies for communal farming systems.

2 Application of Pig Slurry on Pasture Production

The application of pig slurry (PS) to pastures has been widely documented to enhance plant growth and productivity due to its rich content of essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K). This nutrient-rich slurry supports improved plant development, increased biomass production, and overall pasture quality (Nekesa et al. 2024). Research consistently demonstrates the positive effects of PS on various pasture parameters, including plant height, stem diameter, leaf count, and biomass yield. For example, Berenguer et al. (2008), investigated the impact of different PS and mineral N fertilization rates on maize yield, biomass, and soil nitrate ($NO3^{-}$-N) content in the Ebro Valley, Spain. Their study revealed that maize grain yield and biomass increased significantly with higher PS and mineral N applications. However, they also observed that optimal N rates varied annually, influenced by the initial soil $NO3^{-}$-N content before planting, with lower N rates reducing post-harvest soil $NO3^{-}$-N content and thereby minimizing environmental impact.

Similarly, Ovejero et al. (2016), conducted a study to evaluate the effects of different N rates from PS on crop yield, N uptake, unrecovered N, and soil nitrate content in a maize-triticale double-annual forage cropping rotation under rainfed conditions. Their findings indicated that higher PS rates improved crop yields but also led to lower N use efficiency and a higher potential environmental impact due to increased levels of unrecovered N. This aligns with the results of Díez et al. (2004), who examined the effects of applying optimal (P1) and excessive (P3) rates of PS on soil salinization, nitrate leaching, and groundwater pollution under Mediterranean conditions. This study. found that excessive PS application (P3) resulted in significantly higher nitrate leaching (329 kg N ha^{-1}) and total dissolved salts accumulation (6058 kg TDS ha^{-1}) compared to optimal rates (P1), without a corresponding increase in grain production.

Further supporting these findings, Díez et al. (2001), evaluated the agronomic and ecotoxicological effects of PS application during a maize crop cycle under forced irrigation conditions. Their study demonstrated that the highest PS dose (P3) led to significant nitrate leaching and increased soil salinity, while chronic ecotoxicological effects observed with both lower and higher doses (P1 and P3) could be due to unidentified contaminants, despite the absence of organic compounds. Moreover, López-Bellido et al. (2006), reported a substantial increase in wheat biomass yield, up to 20%, attributed to the enhanced soil fertility and nutrient availability from PS. These studies collectively highlight that while PS application can enhance crop yield and biomass, the environmental risks associated with excessive application such as nitrate leaching and soil salinization underscore the importance of careful management and adherence to optimal application rates.

Pig slurry, recognized for its richness in essential nutrients, has the potential to enhance various quality parameters of pastures, thus supporting livestock health and productivity, particularly during periods of natural forage scarcity (Ferreira et al. 2022; Scollan et al. 2014). However, there is limited literature evaluating the specific effects of pig slurry on forage or pasture quality. Existing studies primarily address general quality without detailing specific parameters. For instance, Park et al. (2017), compared the nitrogen use efficiency (NUE) of pig slurry with that of chemical fertilizers, focusing on regrowth yield, annual herbage production, and nutritive value. Their results indicated that pig slurry was less effective than urea during early regrowth periods but showed comparable performance during later periods, especially when applied in split doses. Notably, split applications of nitrogen, regardless of the source, reduced nitrate leaching by an average of 36% compared to single applications.

In a related study, Hou et al. (2019), investigated the effects of biogas slurry on the agronomic traits, yield, and forage quality of indica rice. Their findings revealed that biogas slurry applications led to higher protein content in unpolished rice, particularly in treatments N7-N14, compared to the control. Additionally, biogas slurry treatments (N3-N14) resulted in reduced amylose content in unpolished rice relative to conventional chemical fertilizers (N2). The study concluded that biogas slurry improved rice growth and yield, with the optimal application rate being 612 t/hm² (N8).

3 Methodology

This study integrates bibliometric data from two comprehensive scientific literature databases, Web of Science (WOS) and Scopus, to conduct a detailed bibliometric analysis. Data collection was carried out between 20 and 25 June 25, 2024, with the objective of retrieving all relevant open access and English-written publications within the specific niche of interest. WOS and Scopus were selected for their extensive historical coverage, spanning over 15 years (Pranckute, 2021), and their high scientific impact and broad research scope (Gusenbauer and Haddaway 2019). Traditionally, studies have utilized these databases independently due to the challenges and time required for data cleaning. Furthermore, this analysis adopted a more integrated approach using the PRISMA method and leveraged the bibliometric R package (RStudio v4.3.2) alongside the Biblioshiny software to provide an interactive bibliometrix web interface. The search was guided by specific criteria and different combinations of search terms. The criteria included publication years (1975–2023), publication types (research articles, review articles, and conference papers), and language (English). The focus on peer-reviewed articles justified the selection of research articles, review articles, and conference papers. The search strategy included key terms such as “Pasture” OR “Pasture production” OR “Pasture Yield” OR “Pasture quality” OR “Forage quality” OR “grasses” OR “legumes” AND “pig slurry” OR “pig manure.” Fig. 1 illustrates the criteria used for selecting studies on the application of pig slurry in pasture production for this bibliometric evaluation. Additional screening was conducted by reviewing abstracts to ensure that the selected articles focused on the application of pig slurry in pasture production. Furthermore, the contents of the articles were assessed for eligibility using the Critical Appraisal Skills Programme (CASP) tool (CASP, 2018).

4 Results

4.1 Characteristics of WOS and Scopus Indexed Databases

The analysis includes 118 articles published and retrieved from the Scopus and WOS databases, focusing on the use of pig slurry on pastures during the survey period. The Fig. 2; Table 1 summarizes the information retrieved from these databases. For example, an international co-authorship rate of 10.17% was found among 418 authors, and there were 4 single-authored published documents. The average annual growth rate was 2.32%, with an average of 26.53 citations per article recorded during the survey period.

The Fig. 3 shows a relatively low annual production rate of articles recorded from 1975 to 2000. A notable increase in the number of documents occurred during 2005–2008 and 2011–2016, followed by a decline in 2017. It is worth noting that the study observed inconsistency in the growth trends of publications over the past years. The study observed an exponential scientific production trend with an exponential

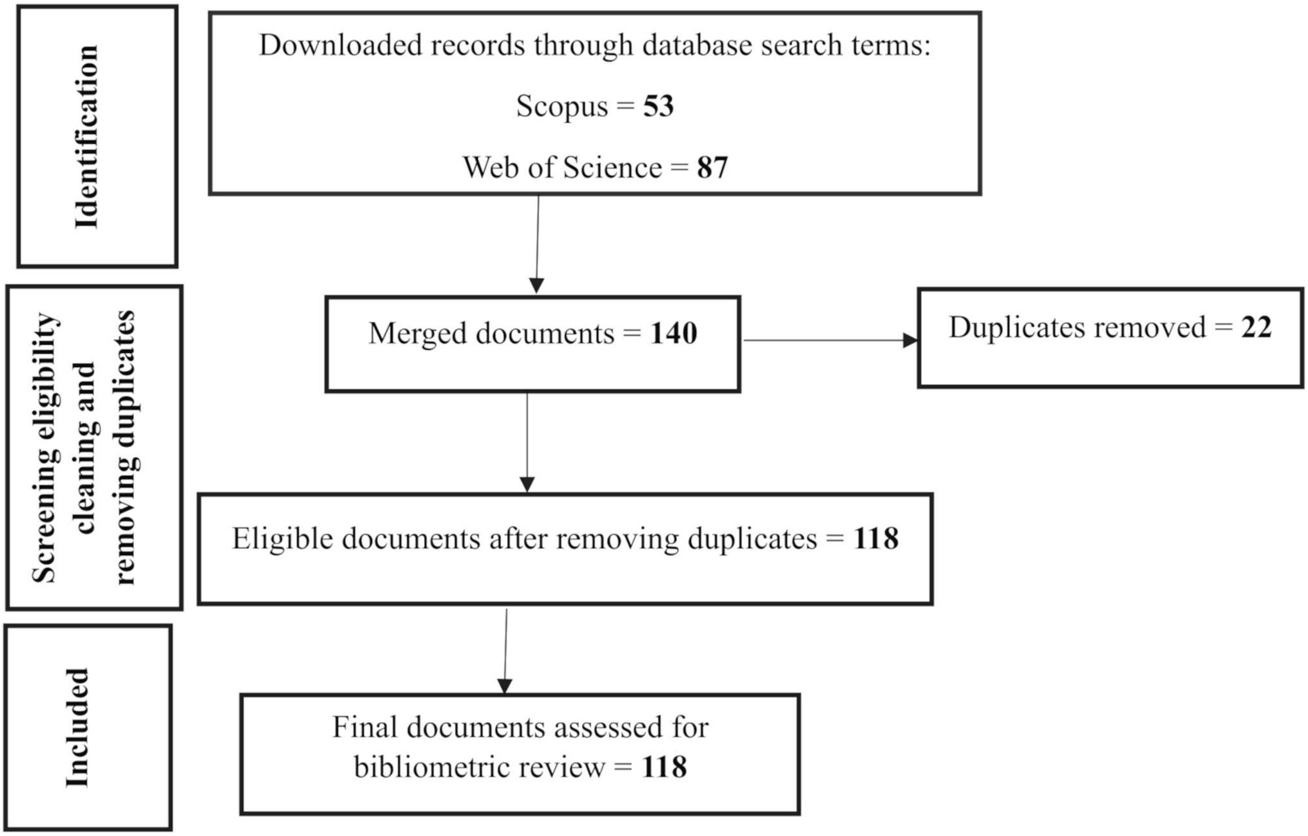

Fig. 1 The PRISMA diagram for document selection criteria

Fig. 2 Main summary information retrieved on the use of pig slurry for pasture production (1975–2024)

model of R2 = 0.44, which aligns with Price's Law of bibliometrics, indicating exponential annual growth in scientific production (Price 1976). This suggests that while there has been significant growth in scientific production over certain periods, the overall trend has been inconsistent. The observed exponential growth, as indicated by the model supports Price's Law of bibliometrics, which predicts exponential growth in scientific output. However, the fluctuations and decline in specific years highlight that this growth is not uniform and can be influenced by various factors. The

Table 1 Overview of information retrieved on the use of pig slurry for pasture production (1975–2024)

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1975–2023
Sources (Journals, Books, etc.)	63
Documents	118
Annual Growth Rate %	2.32
Document Average Age	14.4
Average citations per doc	26.53
References	2385
DOCUMENT CONTENTS	
Keywords Plus (ID)	583
Author's Keywords (DE)	305
AUTHORS	
Authors	418
Authors of single-authored docs	4
AUTHORS COLLABORATION	
Single-authored docs	4
Co-Authors per Doc	5.11
International co-authorships %	10.17
DOCUMENT TYPES	
Article	106
Article; proceedings paper	2
Conference paper	5
Proceedings paper	1
Review	4

relatively low R2 value also indicates that while there is a general trend of exponential growth, other variables and inconsistencies are impacting the overall production rates.

4.2 Spatial Distribution and Collaboration Per Countries

The Fig. 4 depicts the spatial distribution of documents published on the use of pig slurry for pasture production studies from 1975 to 2023. According to the map, Brazil leads in publications in this field. Developed nations have been more productive compared to developing nations. Following Brazil, the USA, Canada, China, and Australia are notable contributors. However, despite expectations, most developing nations in Africa have shown no research output in this area, with only Senegal being active. This can be attributed to fact that the developing nations often face challenges such as limited funding for research, inadequate infrastructure, and fewer opportunities for scientific collaboration and networking. Furthermore, the limited participation of African nations highlights a gap in research efforts and opportunities for collaboration in this field.

Brazil ranked first among the top countries based on the number of published articles exceeding 50 during the survey period. Notably, after Brazil, the top four productive countries reported fewer than <20 single-authored publications (SCP), whereas most countries reported less than <10 multiple-country publications (MCP) in studies on the use of pig slurry for pasture production (Fig. 5). This suggesting there is a limited international collaboration in this specific scientific field.

The Fig. 6 illustrates the key collaborations between countries involved in studies on the use of pig slurry for pasture production. Brazil emerges as the most dominant

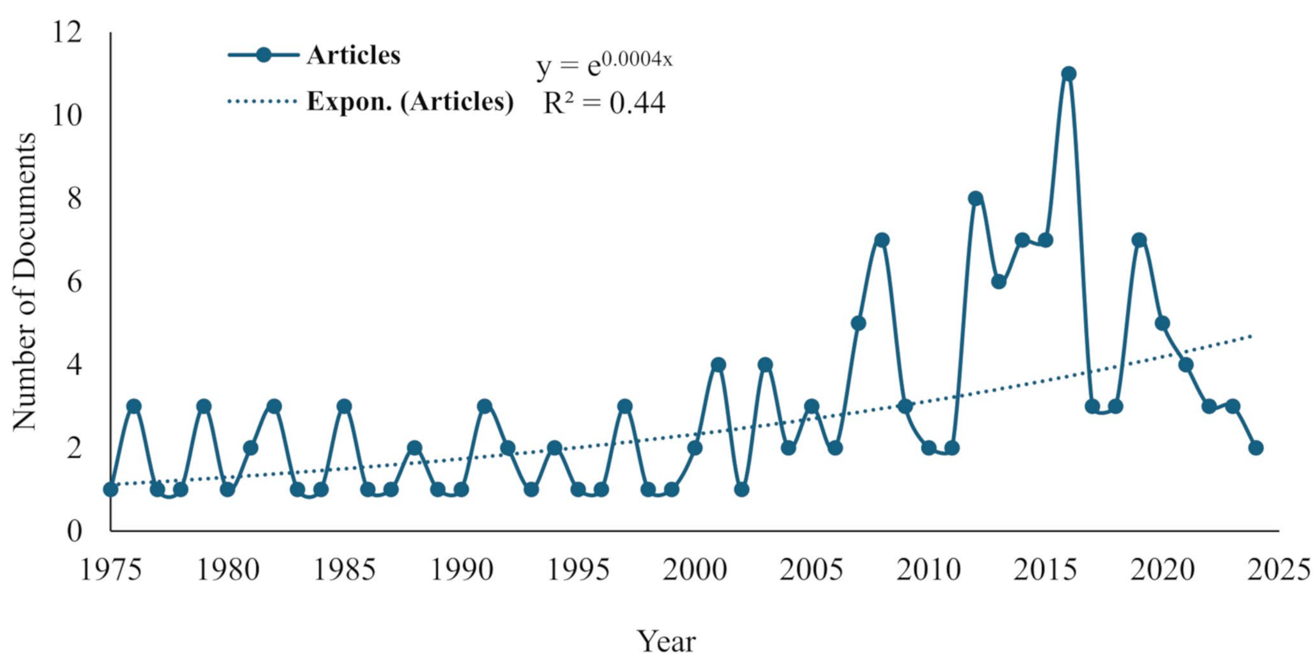

Fig. 3 Annual scientific production on the use of pig slurry in pasture production (1975–2024)

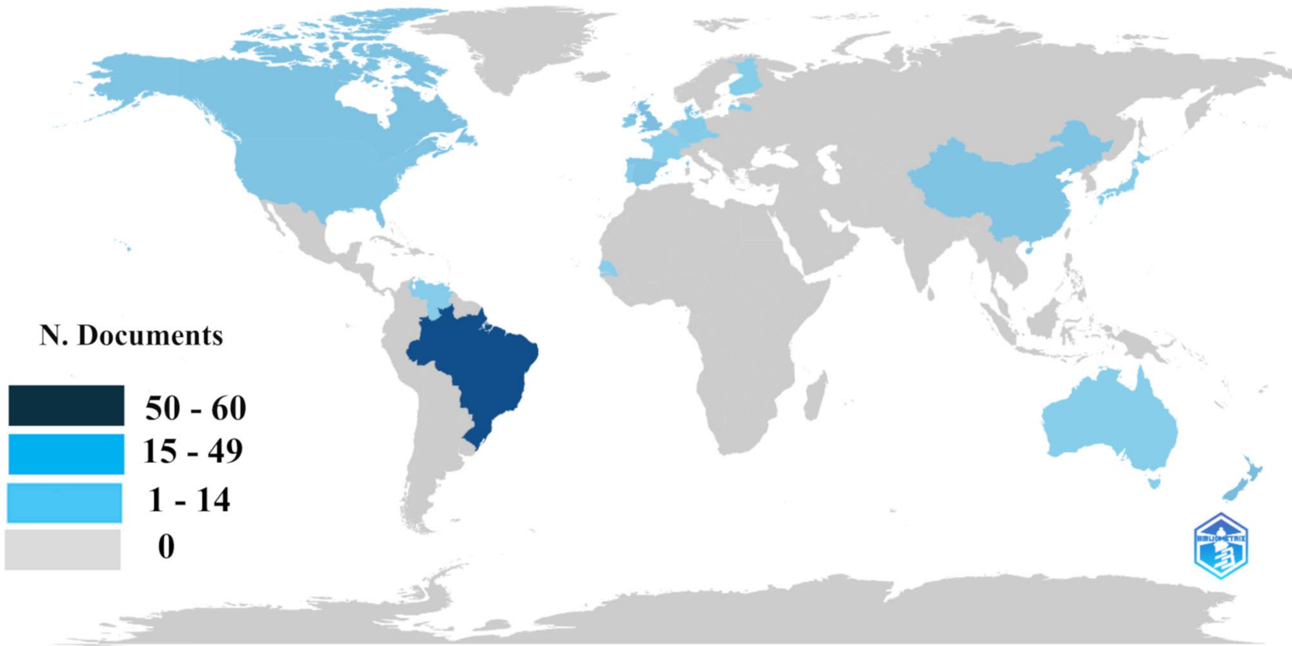

Fig. 4 Spatial distribution map where pig slurry was used in pastures from 1975–2024 (Note: grey- coloured regions have no data captured)

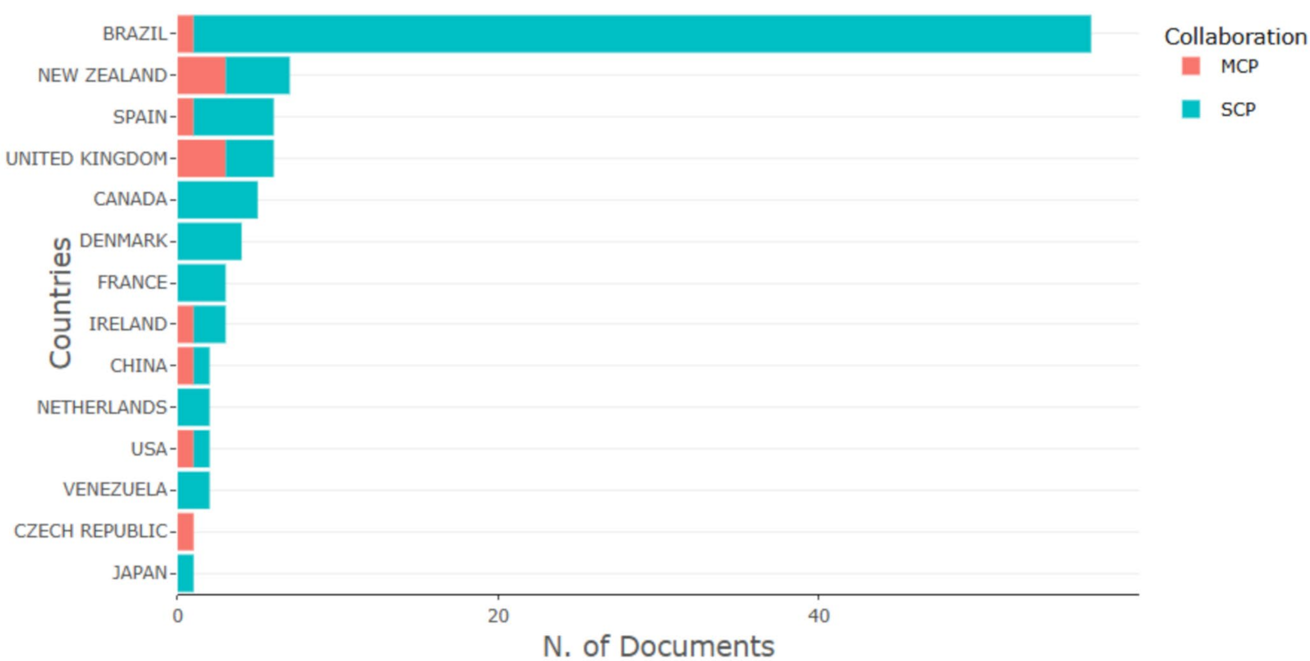

Fig. 5 Top countries in pig slurry use for pasture production
NB: single country publications (**SCP**) and multiple country publications (**MCP**)

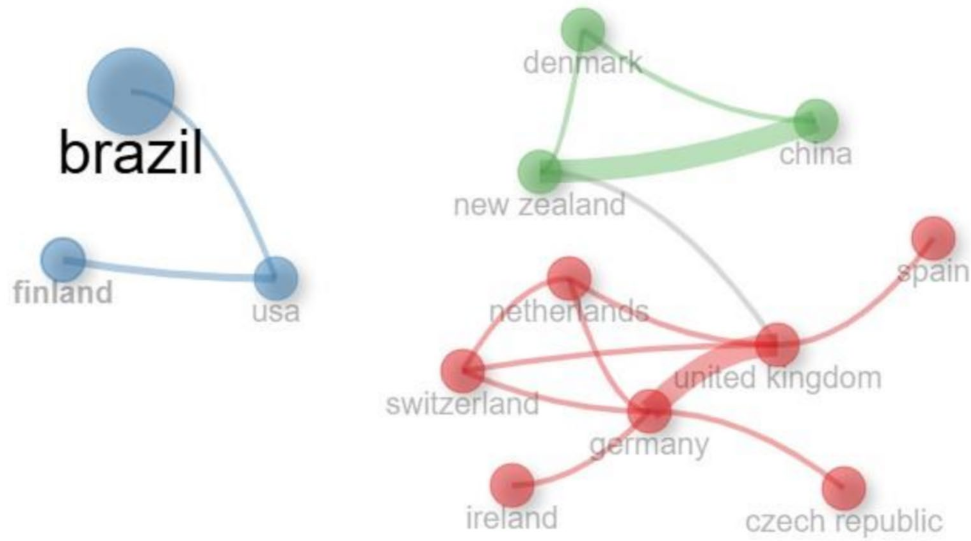

Fig. 6 Collaboration network among countries in studies on using pig slurry for pasture production

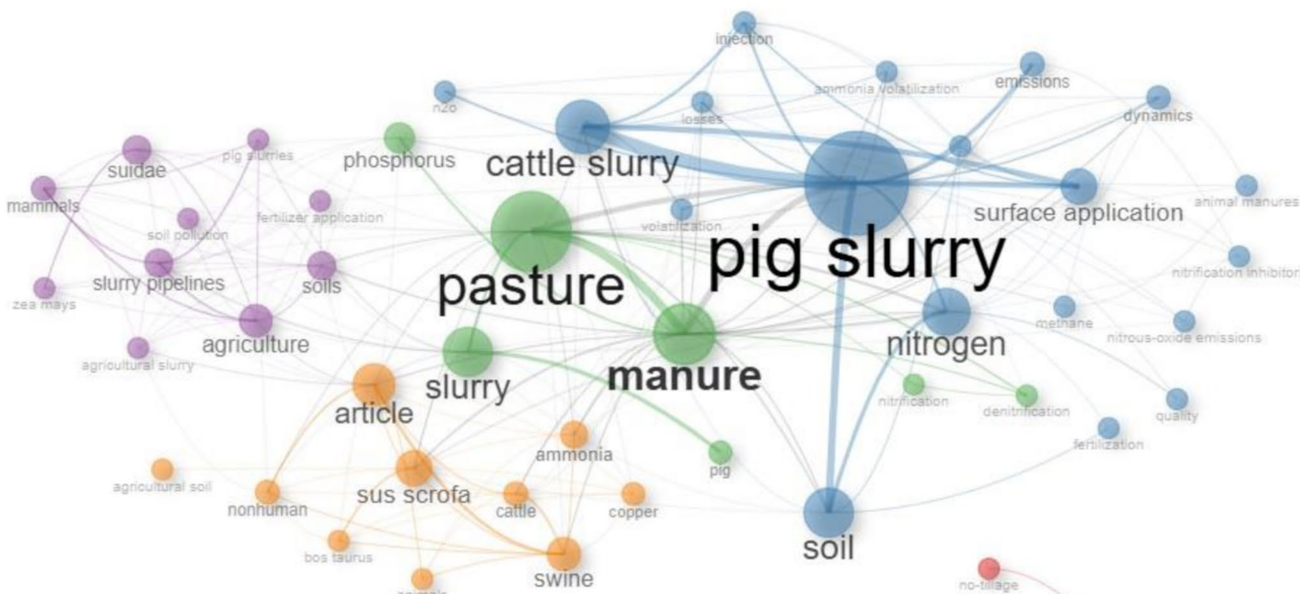

Fig. 7 Authors' keywords co-occurrence network on the use of pig slurry on pasture production

country, indicated by the size of its node, reflecting both the number of article publications and its extensive links with other countries. Following Brazil are New Zealand, China, England, Germany, Spain, and Switzerland, each contributing significantly to the field. This dominance underscores the importance of enhancing research capabilities and fostering collaboration networks in advancing studies related to pig slurry application in pasture production. Strengthening these partnerships could lead to broader insights and innovations beneficial to agricultural practices worldwide.

4.3 Top Authors Keywords and Co-Occurrence Network

The Fig. 7 illustrates the top keywords' co-occurrence in studies on the use of pig slurry in pasture production. The size of the nodes indicates the frequency of each keyword; larger nodes like "pig slurry" and "pasture" signify higher keyword frequency. Key terms such as cattle slurry, slurry, manure, nitrogen, and soil are prominently featured, highlighting their significant influence in the research on pig slurry utilization in pasture production. Meanwhile, other important variables like surface application, swine, phosphorus, and agriculture are represented by smaller nodes, indicating a lower frequency of these keywords. This suggests a potential area for further research to advance the understanding and application of pig slurry in pasture production.

Figure 8 shows that the most frequently used words in studies on the use of pig slurry for pasture production are "manure" (14 times), "ammonia" (9 times), "pig slurry" (9 times), and "nitrous oxide" (8 times). Other commonly used keywords include "nitrogen," "organic fertilizer," and "soil quality" (7 times each). Additionally, terms such as "organic manure" (6 times), "swine manure" (5 times), and "chemical composition" (4 times) are also used in these studies. This suggests that researchers studying the use of pig slurry for pasture production focus primarily on topics related to manure management, nitrogen cycling, and soil quality. The frequent use of keywords such as "manure," "ammonia," "pig slurry," and "nitrous oxide" indicates a strong interest in understanding the nutrient composition and environmental impacts of pig slurry. Additionally, the emphasis on "organic fertilizer" and "soil quality" suggests that researchers are exploring the benefits of using pig slurry as a sustainable agricultural practice to enhance soil health. Overall, the keyword analysis highlights key areas of interest and concern in the field of pig slurry application in pasture production.

The word cloud in Fig. 9 visualizes the most frequently mentioned words in papers on the topic of using pig slurry in pasture production. Words appear in varying sizes based on their frequency. While the placement of words is somewhat random, predominant words are centered for greater visibility due to their larger size. The most commonly occurring word was "pig slurry," followed by "pasture," "manure," "cattle slurry," "nitrogen," and "nitrogen." Less frequently used terms in these studies included "surface application," "phosphorus," "swine," and "ammonia." This reflects current scientific interests and priorities in researching the use of pig slurry in pasture production, emphasizing nutrient management, productivity enhancement, and potentially highlighting areas needing further exploration or refinement in agricultural practices.

4.4 Trend Topics Per Year

The Fig. 10 illustrates the most preferred trend topics by researchers in studies on the use of pig slurry in pasture production. The analysis shows that the trend topics varied throughout the years. The keyword "swine" has been used since 1975, while most other terms, such as "pig slurry," "nitrogen," "manure," "pasture," and "soil," emerged between 1990 and 2005. These trends highlight the progression of scientific inquiry from broader studies on swine farming to more detailed and specialized research on optimizing the use of pig slurry in pasture production.

4.5 Top Global Cited Published Documents on the Use of Pig Slurry for Pasture Production

Table 2 presents the most cited international studies on the application of pig slurry for pasture production outlining treatment used, parameters measured, and findings for each case study within the research development scope.

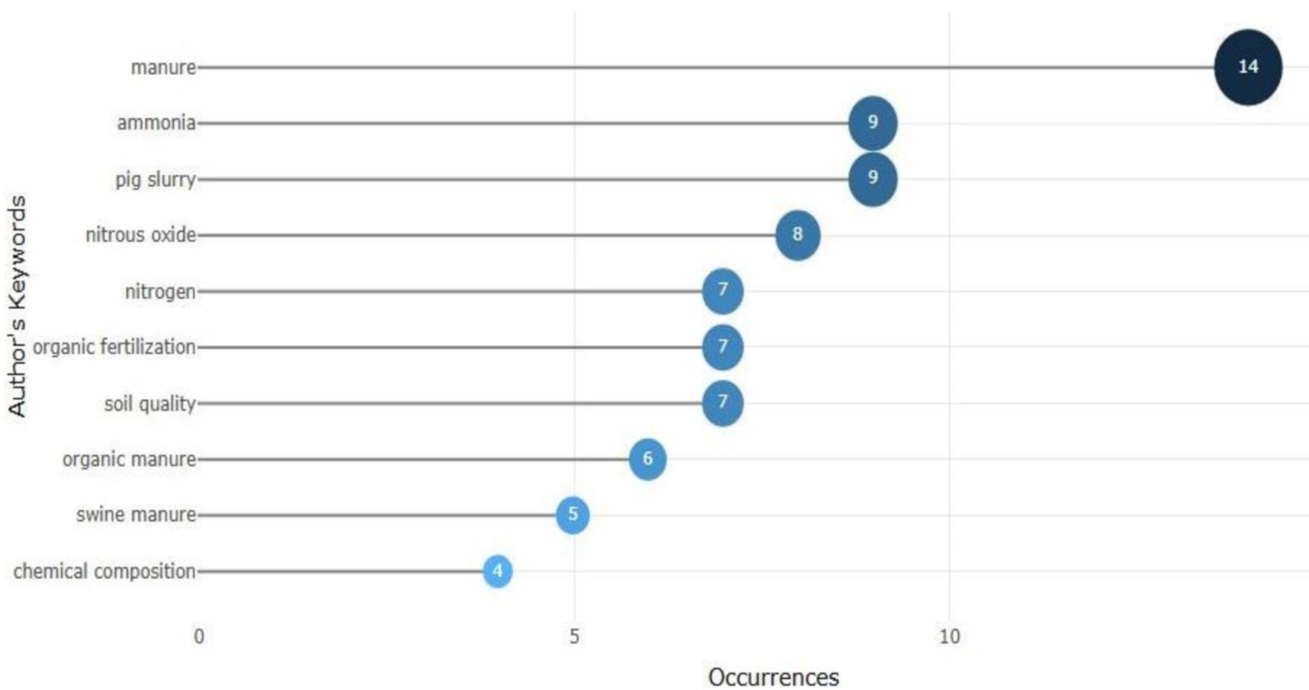

Fig. 8 Most frequently used and top words in the use of pig slurry in pasture production

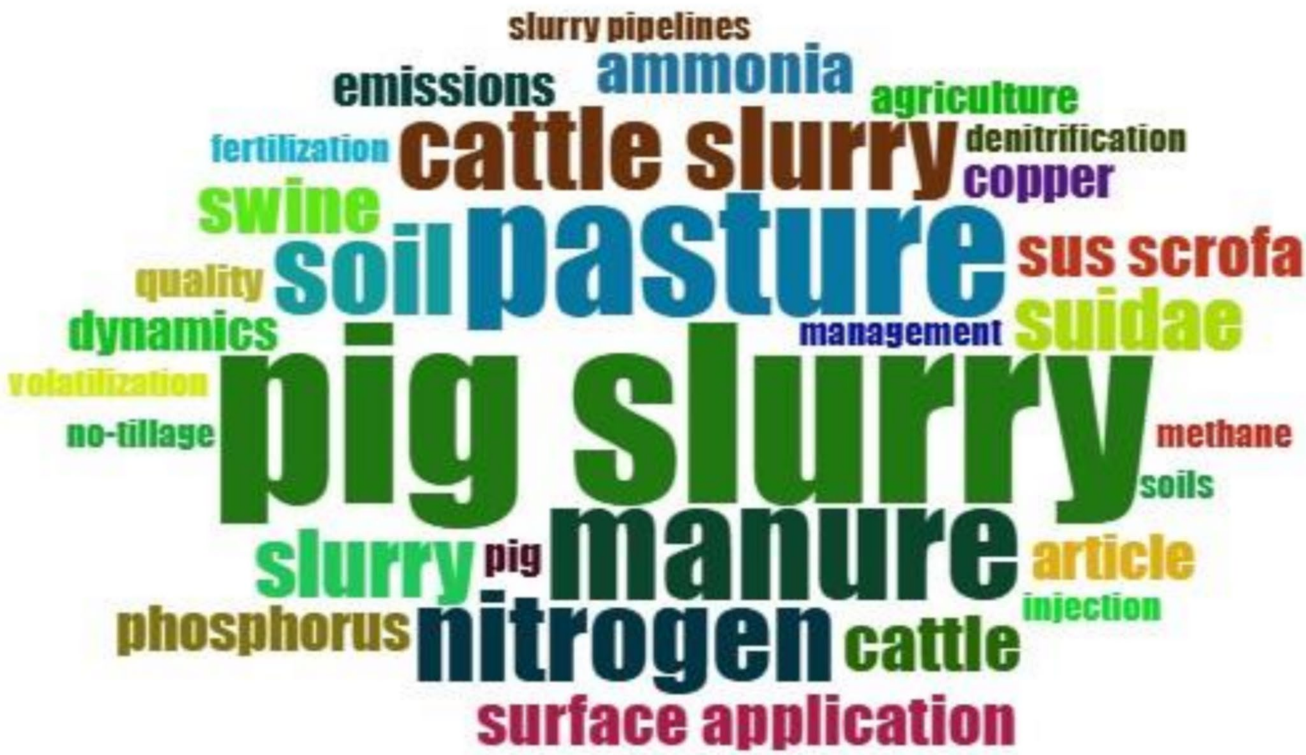

Fig. 9 Visualization of the most frequently mentioned words in papers on the use of pig slurry in pasture production

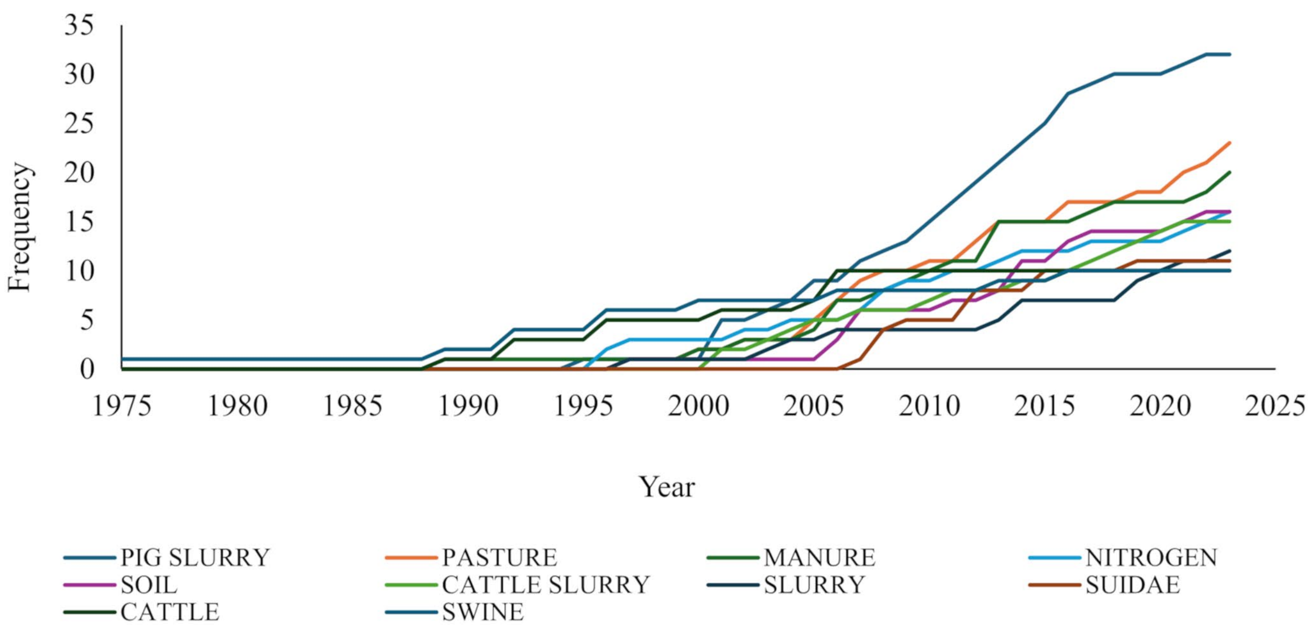

Fig. 10 The Most Preferred Trend Topics

Various studies have investigated the impact of pig slurry and other animal manures on soil and environmental parameters. Schmitt et al. (2006), identified a diverse array of resistance genes in soils affected by pig manure, suggesting a potential link to agricultural practices. Chadwick et al. (2000), found that pig slurry and layer manure resulted in significant nitrogen mineralization, with nitrogen uptake rates varying between 37% and 56% of the added organic nitrogen. Saggar et al. (2010), highlighted the substantial emissions of ammonia (NH3), nitrous oxide (N2O), and

Table 2 Top 10 most globally cited documents on the use of pig slurry for pasture production studies from 1975–2024. (**TC** = Total Citations)

Rank	Treatment	Parameters measured	Findings/Research gaps	Reference	TC
1	Pig manure	Diversity of resistance genes	The study found a high diversity of resistance genes in soils influenced by manure, with regional differences, but could not determine whether this diversity was due to long-term antibiotic use or natural soil resistance.	Schmitt et al., (2006)	213
2	Layer manure, pig slurry, cow slurry and a beef farm yard manure	Organic N fraction	The findings showed that the highest levels of nitrogen mineralization occurred in layer manure and pig slurry, where nitrogen offtake represented 56% and 37% of the added organic nitrogen, respectively.	Chadwick et al. (2000)	205
3	Animal manure	Methane, ammonia, and nitrous oxide	The main findings indicate that animal manure is a significant source of ammonia (NH3), nitrous oxide (N2O), and methane (CH4) emissions in New Zealand's agricultural sector, highlighting its environmental impact and the need for management strategies to mitigate these emissions.	Saggar et al. (2010)	190
4	Manure stages	Ammoniacal nitrogen (total ammoniacal-nitrogen, TAN)	The main finding is that rapid incorporation of manure into arable land and specific manure application techniques are cost-effective measures to significantly reduce NH3 emissions from pasture-based livestock production.	Webb et al. (2005)	159
5	Pig slurry	Nitrogen oxide	The study found that dicyandiamide significantly reduced both N2O and NO emissions from pig slurry, highlighting its potential as an effective inhibitor in mitigating atmospheric pollutants during maize cultivation.	Meijide et al. (2007)	153
6	Pig slurry	Nitrous oxide (N2O)	The study found that nitrous oxide (N2O) emissions were significantly higher than methane (CH4) emissions following pig slurry application to pasture, highlighting N2O as the predominant greenhouse gas pollutant in this agricultural context.	Sherlock et al. (2002)	126
7	Animal waste	Nitrous oxide (N2O)	Findings show that agricultural soils are significant sources of nitrous oxide (N2O) emissions, with herbivore excrement identified as the largest single anthropogenic source, comprising approximately 50% of total emissions	de Klein et al. (2001)	118
8	Pig slurry	Nitrous oxide (N_2O) and nitric oxide (NO)	The results show varying emissions of nitrous oxide (N_2O) and nitric oxide (NO) from different pig slurry application methods under Mediterranean conditions.	Vallejo et al. (2005)	107
9	Pig slurry	Pore morphology, infiltration and earthworm community	The study highlights significant differences in soil pore morphology and hydraulic conductivity influenced by earthworm activity and agricultural management.	Lamande et al., (2003)	100
10	Pig slurry	Soil chemical properties and maize yield	The results indicate that application of pig slurry biofertilizer up to 240 m3 ha-1 did not significantly impact soil chemical properties, corn yield, or nutrient concentrations in leaves and kernels.	Bócoli et al. (2016)	73

methane (CH4) from animal manure emphasizing the need for emission management strategies. Webb et al. (2005), demonstrated that rapid incorporation of manure into arable land can effectively reduce ammonia emissions. Meijide et al. (2007), and Sherlock t et al. (2002), separately investigated nitrous oxide (N2O) emissions from pig slurry, noting its significant environmental impact compared to methane (CH4). de Klein et al. (2001), identified herbivore excrement, including pig slurry, as a major contributor to global nitrous oxide emissions. Vallejo et al. (2005), studied emissions of N2O and nitric oxide (NO) under different application methods of pig slurry in Mediterranean conditions. Lamande et al. (2003), explored the influence of pig slurry on soil pore morphology, infiltration rates, and earthworm communities, revealing significant alterations due to agricultural practices. Bócoli et al. (2016), evaluated the impact of pig slurry biofertilizer on soil chemical properties, corn yield, and nutrient concentrations in leaves and kernels. Their findings revealed that doses of pig slurry biofertilizer up to 240 m^3 ha^{-1} had no effect on soil chemical properties or corn yield. Additionally, the application of the biofertilizer did not influence nutrient concentrations in corn leaves and kernels. Overall, these findings underscore the complex interactions between pig slurry application, soil health, and environmental sustainability in agricultural systems. Most studies predominantly investigated parameters related to greenhouse gas emissions (especially nitrous oxide), nitrogen mineralization, and soil health indicators influenced by pig slurry application. This focus suggests a significant concern and interest in understanding the environmental and agronomic impacts of pig slurry on agricultural ecosystems and global climate change mitigation efforts. However, there is limited investigation into pasture production and other potential environmental impacts beyond greenhouse gas emissions and nitrogen dynamics, such as the effects on soil microbiota diversity, water quality, or long-term soil fertility under sustained pig slurry application.

5 Discussion

The study evaluated global research history and current data advancements to identify potential future research developments and planning in the use of pig slurry for pasture production field. he reviewed publications were indexed in databases such as ScienceDirect, the WOS, and Scopus from 1975 to 2024. The study utilises bibliometrics and the PRISMA method to analyse the use/application of pig slurry for pasture production research field, examining trends, countries contributions, Scientific Collaboration, author keywords, and top global cited articles. The assessment of studies on the use of pig slurry on pasture production shows an inconsistency in the growth trends of publications over the past years with annual rate of 2.23% with exponential growth ($R2=0.44$). These results were aligning with Price's Law of bibliometrics, indicating exponential annual growth in scientific production (Price 1976).

The results revealed that Brazil, the USA, Canada, China, and Australia ranked as the most productive countries in terms of publications and its extensive links with other countries. However, the limited participation of African nations highlights a gap in research efforts and opportunities for collaboration in this field, despite expectations, with only Senegal being active. This disparity might be attributed to several factors. One significant reason is the limited research funding and infrastructure in African countries compared to more developed nations. Many African countries face economic challenges that restrict their ability to invest in research and development (Möykkynen and Pantelias, 2021; Sawyerr 2004). Additionally, there is often a lack of access to advanced technologies and resources necessary for conducting high-quality research. The educational systems in some African nations may not be as strong as those in developed nations, leading to fewer opportunities for training and developing skilled researchers. Furthermore, political instability, public policy priorities for agricultural practices and social issues in certain regions can further hinder academic progress and international collaboration. As noted by Zuniga (2024) and Yi et al. (2020), that politics and public policies can be important instruments in facilitating the process of catching up with developed countries. Therefore, Africa and international organisations must put more effort into and invest in research on the use of pig slurry on pasture production. As Beaudry and Mouton (2017), highlighted, the influence of funding organizations, beyond merely providing funds for publication, is crucial for the continuity of research programs in countries regions like Africa. Increased investment in research can improve forage availability for livestock production within the region. The role of donors in research and development projects is vital, as they function as the overarching body for within- and intercontinental collaboration (Arvanitis and Mouton 2018; OECD 2016). Enhanced support from funding bodies could significantly boost research capabilities and foster sustainable agricultural practices in Africa.

The study identified several vital themes influencing changes in the use of pig slurry for pasture production. Keywords such as "pig slurry", "pasture", "nitrous oxide," "ammonia", "cattle slurry" "slurry", "manure", "nitrogen", "soil", "swine manure" and "chemical composition" were noted for their higher frequency. This suggests a focus on the ecological and agronomic aspects of using pig slurry for pasture production, highlighting concerns related to nutrient management and emissions. They indicate key areas of research such as the impact on soil health, nitrogen cycling, and the potential for greenhouse gas emissions like nitrous oxide and ammonia. The top 10 globally cited documents highlight key limitations in the use of pig slurry for pasture production, particularly in terms of both pasture quality and quantity. Beyond the well-documented concerns related to greenhouse gas emissions and nitrogen dynamics, these studies also emphasize broader environmental impacts. Notably, they reveal potential risks to soil microbiota diversity, which can alter essential microbial processes that support soil health and nutrient cycling. Additionally, pig slurry application has been linked to water quality degradation through nutrient runoff and leaching, contributing to eutrophication in nearby water bodies (Marszałek et al. 2019). Furthermore, concerns are raised about the long-term effects on soil fertility, as continuous slurry application may lead to nutrient imbalances, soil acidification, or heavy metal accumulation depending on soil type and production practice (Qaswar et al. 2020). For example, Schmitt et al. (2006), identified a diverse array of resistance genes in soils affected by pig manure, suggesting a potential link to agricultural practices.

Similarly, Chadwick et al. (2000), found significant nitrogen mineralization from pig slurry and layer manure, with nitrogen uptake rates ranging from 37 to 56% of the added organic nitrogen. Saggar et al. (2010), highlighted substantial emissions of ammonia (NH_3), nitrous oxide (N_2O), and methane (CH_4) from animal manure, emphasizing the need for emission management strategies. Webb et al. (2005), demonstrated that rapid incorporation of manure into arable land can effectively reduce ammonia emissions. Meijide et al. (2007) and Sherlock et al. (2002), investigated nitrous oxide (N_2O) emissions from pig slurry, noting its significant environmental impact compared to methane (CH_4). de

Klein et al. (2001), identified herbivore excrement, including pig slurry, as a major contributor to global nitrous oxide emissions. Vallejo et al. (2005), studied emissions of N2O and nitric oxide (NO) under different application methods of pig slurry in Mediterranean conditions.

Additionally, Lamande et al. (2003), explored the influence of pig slurry on soil pore morphology, infiltration rates, and earthworm communities, revealing significant alterations due to agricultural practices. Bócoli et al. (2016), evaluated the impact of pig slurry biofertilizer on soil chemical properties, corn yield, and nutrient concentrations in leaves and kernels, finding that doses up to 240 m^3 ha^{-1} did not affect soil properties or corn yield, and had no detectable impact on nutrient concentrations in corn leaves and kernels. Overall, pig slurry application has complex implications for soil health, nutrient cycling, and greenhouse gas emissions. Potential risks include nitrogen imbalances, soil acidification, and heavy metal accumulation. The environmental impact varies depending on soil type, climate, and management strategies, influencing water quality and microbial diversity. To mitigate negative effects while sustaining pasture productivity, optimized application methods and robust emission management strategies are crucial. Enhanced research and investment in sustainable agricultural practices can contribute to better management of pig slurry, ensuring environmental and agricultural benefits for future food production systems.

6 Conclusion

This study highlights the significant role of pig slurry in improving pasture production, both in terms of forage quality and quantity. Through a bibliometric analysis, we identified key research trends, major contributors, and critical knowledge gaps, particularly in developing countries. The findings emphasize that pig slurry enhances soil health and nutrient cycling, which, in turn, directly influences pasture productivity. However, despite these promising benefits, long-term studies are still necessary to assess its effects on forage quality, soil microbiota diversity, and water quality. Moreover, the environmental sustainability of pig slurry application remains a crucial area for further investigation. Furthermore, this study reveals a major challenge: the disparity in research activity between developed and developing nations. In particular, limited funding and infrastructure in regions such as Africa have significantly restricted progress in studying pig slurry applications in pasture systems. As a result, an important opportunity is being missed, since improving research capacity in these areas could lead to enhanced sustainable forage production and better livestock management. To bridge this divide, it is essential for international organizations and funding agencies to increase their support for research initiatives focused on nutrient recycling in livestock systems. In addition, future studies should consider implementing case studies in developing countries to assess both the potential and challenges of pig slurry applications in real-world pasture systems. These case studies could evaluate variations in soil type, climate, and livestock management, thereby providing practical insights into optimizing slurry use for maximum benefit while mitigating environmental risks. Moreover, developing predictive models is strongly recommended to assess the environmental impact of pig slurry under different scenarios. Such models would help policymakers and researchers design sustainable nutrient management strategies that minimize negative effects on soil and water resources. Finally, the insights gained from this study underscore the urgent need for a coordinated effort among researchers, policymakers, and funding bodies to advance knowledge on pig slurry applications in pastures. By encouraging collaboration, enhancing research infrastructure, and prioritizing sustainable nutrient management strategies, we can improve pasture productivity while ensuring long-term environmental sustainability. These efforts are crucial for supporting smallholder farmers and livestock systems worldwide, thereby contributing to resilient and sustainable agricultural practices.

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Data Availability Data will be made available on request.

Declarations

Declaration of Competing Interest The authors declare that they have no conflict of interest.

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