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Intensification and Sustainability of Production Systems—A Bibliometric Analysis

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Abstract: Conventional intensification of agriculture has contributed to climate change and consequently influenced the food security of a growing global population. Sustainable cultivation alternatives are a viable means of overcoming this problem; however, the literature lacks studies that demonstrate the extent of these practices at a global level. One of the ways to observe research behavior in an area of knowledge is through bibliometric analysis. The objective of this work was to carry out a bibliometric analysis of the intensification and sustainability of production systems between 2013 and 2023. For this, a final set of data with 480 files was used to carry out analyses to identify the evolution and exploration of the theme, keywords and scientific relevance and prominence in the theme. The results demonstrated an increase in the number of publications, highlighting Asian countries as the most influential on the subject and an evolution in trending keywords within the topic. Through bibliometrics it was possible to understand the evolution of intensification and sustainability of production systems, offering valuable perspectives on improving productivity in conjunction with environmental conservation.

Keywords: sustainable intensification; agriculture; food security; bibliometrics

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1. Introduction

The challenges for the food system in the following decades comprise a series of factors, including population growth and demographic changes, the increase in average purchasing power and expectations resulting in dietary modifications, scarcity of resources, the consequences of global environmental changes (including climate change) and the urgency of mitigating greenhouse gas emissions (GHG), while simultaneously adapting to their consequences [1]. Projections indicate that the global population is expected to reach almost 10 billion by the year 2050, which will result in an increase of approximately 50% in agricultural demand [2].

The availability of food and other agricultural products is conditioned by ease of access to land and water. However, production often faces limitations due to the degradation of soil fertility, water scarcity and the adoption of inappropriate technologies associated with unskilled labor. Furthermore, climate change and extreme natural events have an impact on agricultural production. On the demand side, population growth, urbanization and changes in income and eating habits are determining factors that contribute to food insecurity, especially in certain regions [3]. Thus, food production and productivity as well as the continuity of these traditional intensive farming systems are threatened, due to their inefficiency in the use of practices that minimize the degradation of soil, water and air, natural resources essential for maintenance of agricultural activity in the world [4]. Among some harmful effects of this practice on the soil, we can mention the reduction in fertility and organic carbon. Traditional intensive production systems use a high number of inputs, mainly chemicals, which in many situations do not promote growth in productivity or an increase in crop yields. Contrary to this, these systems have contributed to large levels of GHG emissions from agriculture [5].

For this reason, agricultural science has faced the challenge of reconciling the demand for increased productivity in agricultural systems, in terms of food security, with the need to prevent environmental degradation and promote the restoration of ecosystems [6]. The main question, however, lies in how to increase food production using fewer resources. It is necessary to develop agricultural systems that are more resilient to the impacts of climate change, such as the greater frequency of extreme events and the emergence of new biotic stresses. In the poorest countries, where a significant increase in population and demand for food is expected, the challenge is to reduce the gap between potential income and actual income in a sustainable way, even with limited access to inputs. In richer countries, although this income gap is less of a concern, the challenge remains in protecting soils and maintaining income using fewer inputs [7].

Sustainable intensification thus emerges as an alternative that aims to increase agricultural production while minimizing the ecological footprint. This approach is considered a crucial feature of sustainable agriculture, especially given the predominant focus on productivity over sustainability [8]. Sustainable agricultural intensification can enable increased productivity per hectare; an increase in crop diversity per unit of land; water efficiency and the reallocation of land use from lower value crops or products to crops that have higher market prices or have a superior nutritional composition [9]. Furthermore, the practical results of sustainable agricultural intensification of production systems have been observed through their significant benefits to the economy, food and nutritional security, employment, decision-making, division of tasks, local institutions and leadership. Therefore, this approach offers a method to evaluate and balance the environmental, economic and social goals of agriculture, representing a superior solution for agricultural sustainability in general [10].

Given this context, understanding research related to intensification and sustainability of production systems is essential to generating new ideas and guiding the choice of journals or directing the public and those interested in the area to the main authors who contribute to this topic. Bibliometric methods have been used to provide quantitative analyses of written publications [11–13]. The data that form the basis of bibliometric analysis are generally voluminous and objective in nature, although their interpretations often depend on both objective assessments and subjective assessments established through informed techniques and procedures. In other words, bibliometric analysis is a tool useful for deciphering and mapping the accumulated scientific knowledge and evolutionary nuances of established fields, providing robust understanding of large volumes of rigorously unstructured data [14].

By providing an overview of the current state of knowledge, employing bibliometrics to explore the intensification and sustainability of production systems could offer valuable insights for researchers, practitioners and policymakers interested in the sustainable management and yield of agricultural production systems. In this sense, this work aimed to carry out a bibliometric analysis of the intensification and sustainability of production systems in the period 2013–2023.

2. Materials and Methods

2.1. Data Collection

The analysis of scientific literature and trends related to the intensification and sustainability of production systems consisted only of articles in the Scopus database. The data collection technique was carried out by searching the following strings: (sustainabilit* OR "enhance sustainability in cropping system") AND (cropping AND system* OR "rice" OR "soybean" OR "maize" OR "sorghum" OR "wheat" OR "bean" OR "sugarcane") AND (production* OR yield). The search was limited to only scientific and review articles that presented these terms in their titles, abstracts or keywords. The search considered a period of one decade, between 2013 and 2023. The search resulted in a total of 697 files published in the selected period. Subsequently, the documents that effectively dealt with intensification and sustainability in production systems were filtered through the analysis of the titles and abstracts of all articles, resulting in a final dataset consisting of 480 articles.

2.2. Knowledge Extraction and Analysis

After downloading the final dataset, the bibliometric analysis was developed in the software R version 4.3.3 [15], the first procedures being the conversion and joining of the files, as the download was carried out in parts. This step resulted in the creation of a single file in R language with all the data, consisting of 32 variables, created using the Bibliometrix package. This package provides a comprehensive set of tools for quantitative research in bibliometrics and scientometrics using the R language, an open-source environment and ecosystem. The R language stands out in scientific computing due to its vast collection of efficient statistical algorithms, access to high-quality numerical routines and robust data visualization tools. These characteristics make R a preferred choice for work in this area [16]. After viewing these preliminary results, the analysis was conducted in the "biblioshiny" bibliometrix web application, also operated by the R software, where the graphs were created and the tables were exported. To present the data, the research results were divided into three sections: analysis of identification of the evolution and exploration of the theme, of keywords used in the theme and of scientific relevance and prominence in the theme.

3. Results

3.1. Analysis to Identify the Evolution and Exploration of the Theme

Between 2013 and 2023, a total of 480 articles were published on intensification and sustainability in production systems. The publication of works on this topic increased by more than 300% in the last year evaluated (2023) in relation to the first year (2013). However, in the first five years (2013–2017), there was an increase followed by a drop in the number of publications, but in the following years (2018–2023) the growth of articles published on this topic was exponential (Figure 1).

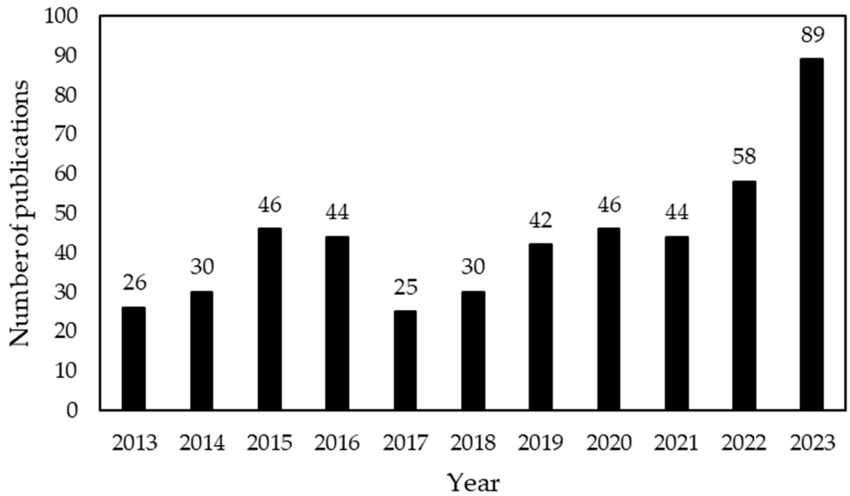

Figure 1. Number of publications in the final dataset between 2013 and 2023.

In order to present the situation of publications worldwide, only the top ten countries that stood out quantitatively in the period studied were considered (Figure 2). The map of total documents per country shows the number of documents published in each country on a scale of 1 to 120, with the color intensity proportional to the number of articles published. It can be seen that some Asian, American and European countries were the most prominent in disseminating their research compared to African countries (Figure 2a). The map of the number of citations per country shows a scale from 0 to 3669 for the number of times the works were cited. Once again, some Asian, American and European countries stood out in relation to African countries, which, for this variable, had even less participation in relation to the number of publications (Figure 2b). According to Figure 2c, of the ten countries with the highest number of publications in the decade 2013–2023, the five with the highest numbers were India, followed by China, the United States, Brazil and Italy. In terms of the number of citations per country, Figure 2d shows that China, India, the United States, Italy and the United Kingdom comprised the top five. In these last two figures, the absence of African countries in the top ten is notable, highlighting the need for more studies and publications on intensification and sustainability of production systems on this continent.

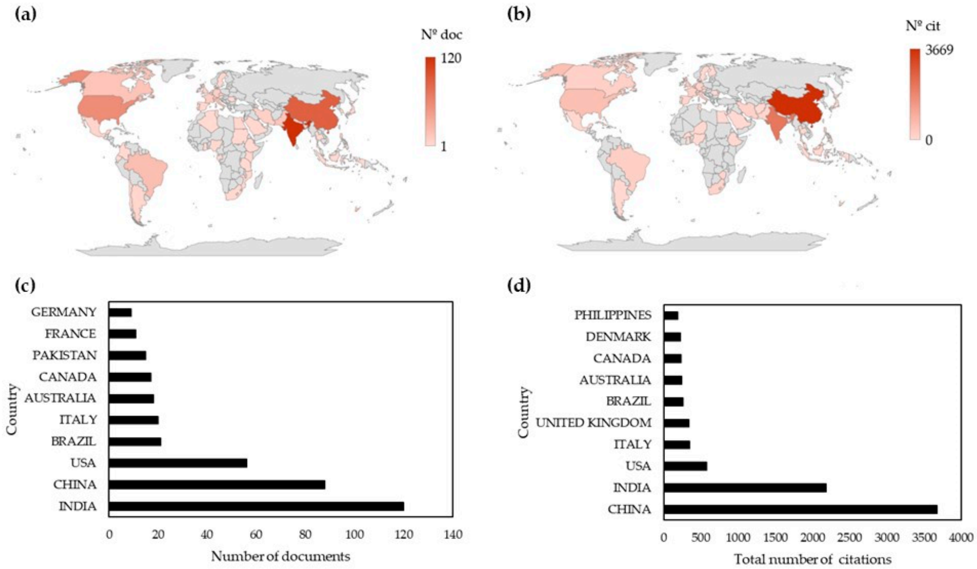

Figure 2. Status of publications worldwide: (**a**) map of total articles produced by country; (**b**) map of the number of citations by country; (**c**) total number of documents presented by the top ten countries; (**d**) total number of citations presented by the top ten countries.

The collaboration between authors was illustrated through the color density map, with the intensity of coloring being proportional to the relationship between the collaboration networks (Figure 3). It is possible to observe that the collaboration networks feature authors mainly with Asian names, subdivided into two well-defined groups, one composed mostly of Chinese and the other, with a strong collaboration network (represented by the greater intensity of coloring), formed by Indian researchers, corroborating the higher values observed in previous results regarding the number of publications and citations in the countries of China and India.

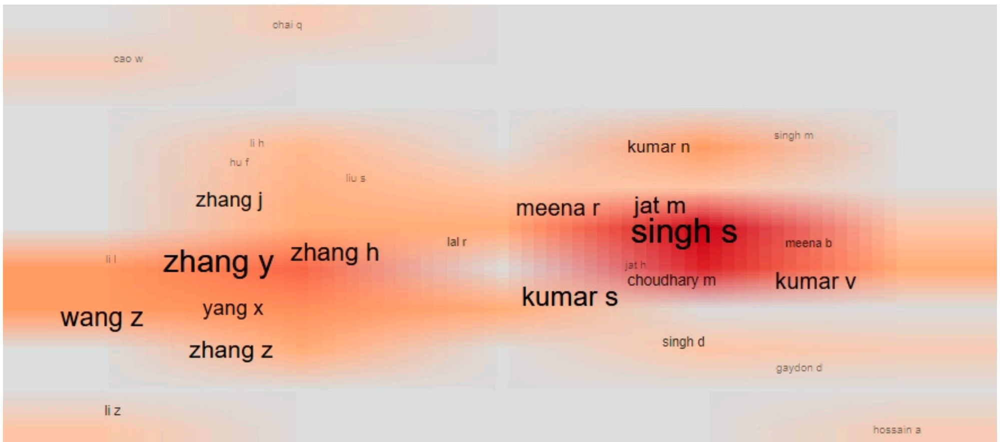

Figure 3. Collaboration density map between authors.

Figure 4 shows the collaboration network between research institutions that stood out for articles published on the topic of this study between the years 2013 and 2023. The color indicates the clusters for each network and the size of the circle and line intensity of collaboration. As demonstrated in this figure, it was found that China Agricultural University was the institution that presented the greatest number of collaborations with other centers in the preparation and dissemination of articles on intensification and sustainability in production systems, followed by the Icar-Indian Agricultural Research Institute, again highlighting the countries China and India and corroborating the results obtained in previous evaluations.

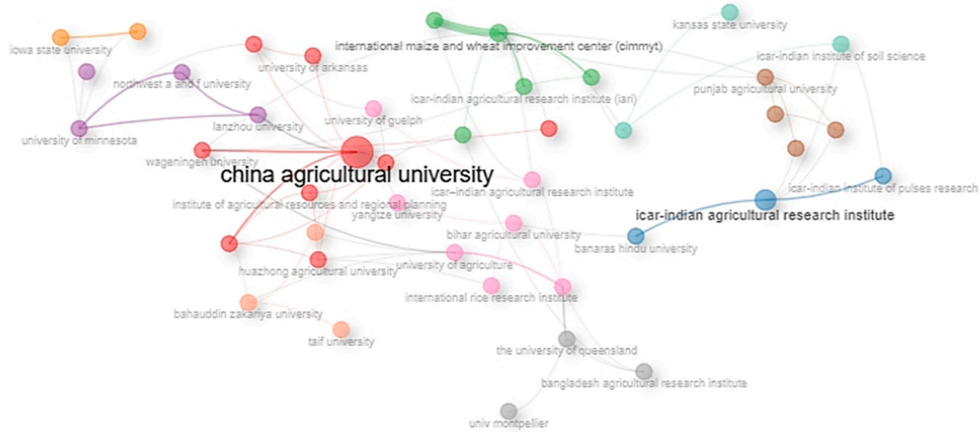

Figure 4. Network collaboration on publications between institutions.

3.2. Analysis of Keywords Used in the Theme

The font size in the keyword cloud indicates the frequency of use of each term in the collected articles. For this analysis, only the 100 words that stood out most in the works published in the period established by this study were considered. It was observed that keywords such as sustainability, crop yield, crop production, cropping practice, wheat, China, maize, rice and agriculture and terms that characterize the sustainable intensification of production systems such as intercropping, tillage systems, conservation tillage, crop rotation, soil conservation, water use efficiency and double cropping were some of the most used in articles published on this topic in the period from 2013 to 2023 (Figure 5).

Figure 5. Cloud of keywords presented in papers on intensification and sustainability of production systems published between 2013 and 2023.

The keyword tree map diagram highlights the frequency of use of each term, by identifying the number of uses and its respective percentage in the dataset, thus making it possible to complement the information obtained in the keyword cloud analysis through numerical demonstration of the participation of each term covered in published studies. To facilitate visualization of the results obtained, in this analysis only the 50 most frequent terms in the collected works were considered. Among the five most frequently used terms, sustainability, used in 157 works, was the most used in articles on intensification and sustainability in production systems, followed by the terms crop yield (144), crop production (136), cropping practice (135) and wheat (112) (Figure 6).

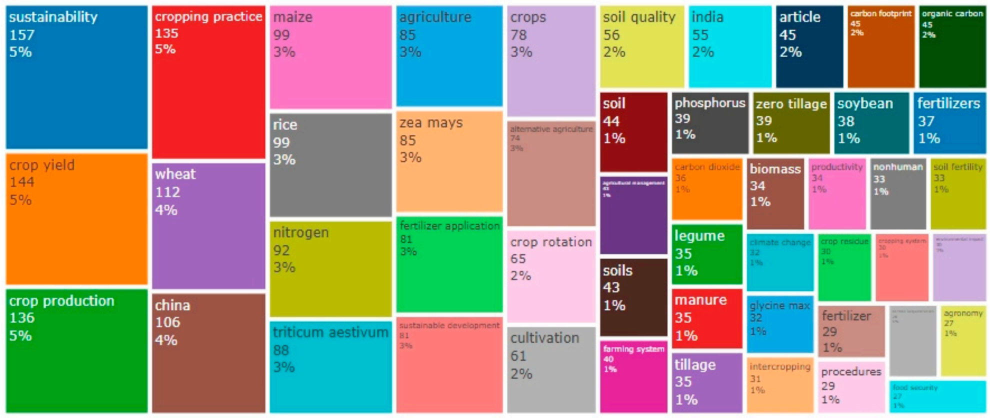

Figure 6. Tree diagram of keywords used in papers on intensification and sustainability of production systems published between 2013 and 2023.

The analysis of trend keywords shows the evolution of the use of terms over the studied period, with the size of the circle proportional to the frequency of use of each word and the color of the horizontal bar being the period of the trend. This analysis revealed 28 trending terms used in studies published during the period of this research. As shown in Figure 7, it is observed that the keywords sustainability, crop yield and crop production were frequently used in scientific articles; however, in more recent years, there has been a tendency to use words more related to system management, such as biodiversity, life cycle, evapotranspiration, soil and carbon footprint.

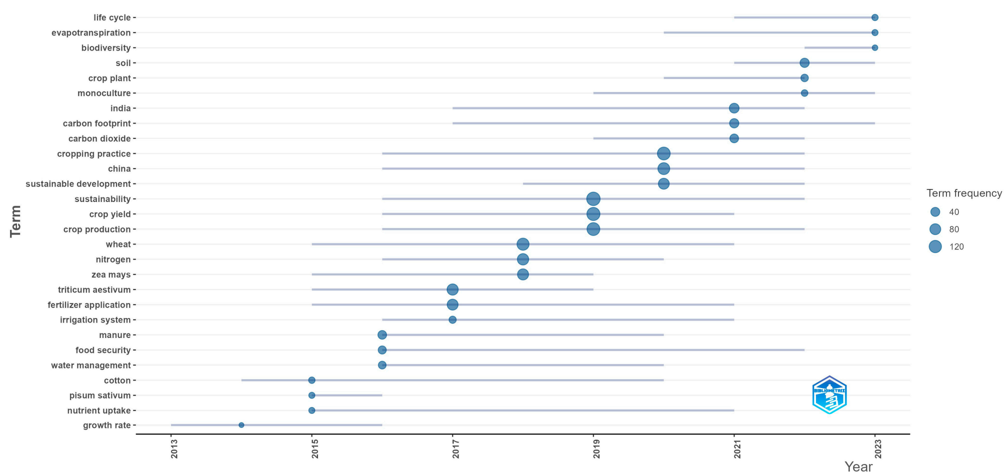

Figure 7. Trending keyword analysis referring to studies on intensification and sustainability of production systems published between 2013 and 2023.

3.3. *Analyses of Scientific Relevance and Emphasis on the Topic*

Among the most cited works in the dataset, the first five were authored by Munkholm et al. [17], Rowe et al. [18], Wei et al. [19], Hussain et al. [20] and Huang et al. [21]. The number of citations of these works ranged from 167 to 219. The article "Long-term rotation and tillage effects on soil structure and crop yield" published in the journal *Soil* *and Tillage Research* in 2013 by Munkholm et al. [13] had the highest number of citations (Table 1).

Table 1. Most cited articles in the final dataset.

C	Authors	Title	Journal	Year	TC
1	Munkholm et al. [17]	Long-term rotation and tillage effects on soil structure and crop yield	Soil and Tillage Research	2013	219
2	Rowe et al. [18]	Integrating legacy soil phosphorus into sustainable nutrient management strategies for future food, bioenergy and water security	Nutrient Cycling in Agroecosystems	2016	208
3	Wei et al. [19]	Effects of combined application of organic amendments and fertilizers on crop yield and soil organic matter: An integrated analysis of long-term experiments	Agriculture, Ecosystems & Environment	2016	185
4	Hussain et al. [20]	Rice management interventions to mitigate greenhouse gas emissions: a review	Environmental Science and Pollution Research	2015	174
5	Huang et al. [21]	Effect of crop residue retention on rice yield in China: A meta-analysis	Field Crops Research	2013	167

Note: C: classification; TC: total citations (corresponding date until the year 2023).

Regarding the most relevant journals, ranked according to the impact factor of the Journal Citation Reports, the five most prominent journals in the period from 2013 to 2023 in publishing works on intensification and sustainability in production systems were *Agricultural Systems*, *Field Crops Research*, *Agricultural Water Management*, *European Journal of Agronomy* and *Agriculture Ecosystems & Environment*. Of these, the highest impact factor (2.3) is presented by the *Agricultural Systems* journal; however, *Field Crops Research* has the highest total of publications (Table 2).

Table 2. Most relevant journals in publications on intensification and sustainability of production systems.

Classification	Journal	FI	TP
1	Agricultural Systems	2.3	20
2	Field Crops Research	1.96	39
3	Agricultural Water Management	1.93	10
4	European Journal of Agronomy	1.83	23
5	Agriculture Ecosystems & Environment	1.71	14

Note: FI: impact factor; TP: total publications (corresponding date until the year 2023).

4. Discussion

4.1. Evolution and Exploration of the Theme

It is likely that the frequent concern with sustainability and increased production in cultivation systems as a result of climate change and food security (imposed by growing demand for food) has contributed to stimulating more research and, consequently, an increase in publications on this topic over the last ten years. Climate change can interfere with crop productivity in several ways, including lengthening the cycle and increasing atmospheric CO_2 levels, which can have positive impacts to a certain extent. However, negative effects can also occur, such as an increase in maximum temperature during the growing season. Furthermore, changes in the spatial and temporal distribution and amount of precipitation may also be highly uncertain and significantly affect crop yields [22]. Agriculture is identified as one of the main human activities that contributes to climate change [23–25]. Finding ways to reduce the environmental impact of production systems has been crucial to ensuring the sustainable development of agricultural ecosystems [26]. Sustainable intensification in production systems is an alternative to increase both productivity and profits without generating negative impacts on the environment [27,28], and the benefits of this type of management for the environment and food security are already seen in practice. Between the years 2000 and 2020, greenhouse gas emissions reduced by 4% in agricultural crops [29]. The sustainable intensification of cropping systems differs from traditional agricultural intensification. This aims exclusively at increasing productivity on land and does not consider the sustainability of the agricultural environment; thus, it is predominantly associated with the loss of biodiversity and the use of chemical inputs, damaging the environment and compromising the continuity of agricultural production in the same area of cultivation. Sustainable intensification, in turn, respects the environment and promotes greater crop diversification during harvests, ensuring the maintenance of food supply in production areas and optimizing the use of available resources [30–32]. Several studies have been carried out and presented good results in reducing environmental impacts through the implementation of more sustainable intensified production systems and, consequently, have made viable alternatives available to provide a greater supply of food [33–38].

Asian, American and European countries stood out in terms of the number of publications and citations on work on the subject when compared to African countries. Africa suffers from a low availability of resources for investment in research and development, and this limits its scientific competitiveness with countries on other continents [39]. Furthermore, researchers on the African continent suffer from inadequate infrastructure and national support to conduct their research, most often seeking international collaboration to continue their work [40]. Africa's low participation in research on intensification and sustainability of production systems may predispose the countries of this continent to greater environmental impacts and food vulnerability of their inhabitants. African countries face a series of challenges related to agriculture and food and nutrition security. These include low land productivity and high vulnerability to climate change [41], making it therefore crucial to adopt adaptation and mitigation strategies to protect agriculture and ensure food security in its regions [42]. Thus, encouraging research on the intensification and sustainability of production systems on the African continent can be essential to ensuring food security for its population, optimizing the use of available resources and reducing environmental impacts [43–46]. On the other hand, in the American, European and Asian continents, the research incentive is notable, justified by the greater participation of their countries in the publication of works on the subject, mainly from China and India. These Asian countries constitute the two countries with the largest number of inhabitants in the world [47]. Developing countries with high purchasing power like China and with a large population like India may be extremely interested in encouraging research to provide, above all, food security for their inhabitants. Studies have demonstrated China's role in implementing sustainable intensified systems to reduce the harm from conventional agriculture to the environment and at the same time increase crop yields [48–50]; similarly, India has also developed several works on the same topic [51–53]. These two countries were also highlighted in relation to collaboration networks between authors. It is known that scientific research requires increasing levels of collaboration between authors to achieve its objectives. To this end, it is in the interest of countries to encourage cooperation in scientific work, especially at an international level, as this facilitates access to international funds and consequently improves the development of institutional partnerships [54]. China is known as one of the countries that offers the most financial support for research [55]. Financial support from a country has a positive effect on increasing citation impact. However, the effect of international collaboration can vary, being positive, negative or neutral depending on the country of origin of the publications [56].

India has recently been identified as the country with the highest population density in the world. Indian agriculture is largely dominated by smallholders who depend on subsidized irrigation and rainfed practices, comprising approximately 78% of the agricultural population. Inadequate market infrastructure and limited ability to adapt to extreme weather conditions increase the agricultural sector's vulnerability to climate change. Furthermore, lack of preparation, scarcity of adequate storage facilities and the adoption of monocultures with single varieties contribute significantly to losses [57]. This increase in population size and, consequently, in the demand for food will lead to a sharp increase in the need to intensify agricultural production in order to achieve higher yields in Indian production systems [58]. It is clear that agricultural research has significant potential to increase productivity and growth in the sector, which is crucial for long-term development in food supply and prices. In India, since the early 1990s, agricultural growth has lagged considerably behind the non-agricultural sector, worsening a growing disparity. Although there has been an increase in agricultural growth recently, it has not yet reached the 4% growth target. The difficulty in improving agricultural productivity in a sustainable manner is aggravated by the growing pressure of the population on resources, the vulnerability of agriculture to external shocks and the fragmentation of small properties. In this restrictive context, the future growth of agriculture will increasingly depend on continuous advances in technological and institutional innovations to increase and sustain productivity [59]. Therefore, it is likely that the prominence of these two countries in the number of published works, citations, co-authorship and institutional collaborations is key to these efforts to expand the sustainable intensification of their production systems.

4.2. Keywords: Topic Breakdown

A keyword analysis allows the identification of the most prevalent themes covered by the bibliometric analysis [11]. The keywords sustainability, crop yield, crop production, cropping practice, wheat, maize and rice were the most used in published works on intensification and sustainability in production systems. Wheat, corn and rice play key roles in food security as the three most produced crops globally [60]. These grains are essential components of diets in many countries, providing vital nutrients and calories for billions of people. Wheat (*Triticum aestivum*) is the most cultivated cereal globally, with more than 220 million hectares planted annually in diverse climatic conditions and varied geographic regions. Annual production reaches around 670 million tons, depending on specific agro-climatic conditions [61], and with its versatility, it is a staple food in various forms, such as bread, pasta and bakery products [62]. Corn (*Zea mays*) serves as the main ingredient in countless food products, from corn flour to sweeteners and cooking oils, in addition to being a crucial food for animal feed [63]. Rice (*Oryza sativa*), a dietary staple for more than half of the world's population, offers a significant source of energy and nutrition [64]. Their widespread cultivation and consumption contribute significantly to combating hunger and malnutrition, making them indispensable for meeting the nutritional needs of populations globally. As pillars of agriculture, wheat, corn and rice highlight the importance of diversifying food systems and ensuring their sustainable production to protect food security in the face of constantly evolving challenges, such as climate change and population growth [65]. It is also important to highlight the presence of some terms that characterize the intensification and sustainability of production systems such as intercropping, tillage systems, conservation tillage, crop rotation, soil conservation, water use efficiency and double cropping. One of the main objectives of the intensification and sustainability of production systems is to increase agricultural productivity and sustainability. In these systems, the presence of agronomic practices such as mixed cropping systems, tillage systems and cover cropping is crucial. Mixed cropping systems allow the integration of crops with different root depths, providing bioirrigation and oxygenation throughout the soil profile as well as the association of legumes with non-legumes, improving nutrient availability and mainly benefiting non-legumes through nitrogen fixation. Legumes can also promote an environment that favors beneficial microorganisms, increasing ecosystem services [66]. Tillage systems include conservation tillage, which is a sustainable approach that balances the need for efficient agricultural production with the conservation of natural resources. In this practice, soil disturbance is minimal, maintaining crop residues and thus providing greater carbon stock in the soil and reducing CO_2 emissions [67]. Cover cropping refers to the cultivation of plants between harvests of two main crops and is known to provide numerous benefits to the production system such as improving soil quality, availability of nutrients and water, suppression of weeds, reduction in erosion and farming costs [68–70].

The increased use of trending keywords such as biodiversity, life cycle, evapotranspiration, soil and carbon footprint suggests a growing concern with issues related to environmental management and sustainability in production systems. This trend can be attributed to several factors that reflect changes in research priorities and societal demands regarding agriculture and the environment [71–73]. As the demand for food is growing in the face of increasing population density, traditional practices of intensifying production systems lead to an increase in GHG emissions. The need to implement more sustainable systems that at the same time promote the intensification of food production is pressing, given that one of the main threats to conventional farming systems is the presence of agriculture's carbon footprint [74]. It is known that intensive conventional agriculture increased the carbon footprint and caused uneven climate patterns, generating a range of adverse effects that have a significant influence on agricultural production [75]. For this reason, one explanation for the trend in the use of these terms is the increased awareness of environmental issues and sustainability, leading researchers to explore and emphasize aspects such as biodiversity, the length of the growing season, management of natural resources and the reduction in the environmental impact in agricultural production.

4.3. Scope of Publication and Reference in Disseminating the Topic

A citation establishes a relationship between the referenced literature and the literature that references it, whether partially or in full. The frequency with which an article is cited in other academic articles is an indicator of the substantial influence that the author or journal exerts on specific knowledge [76]. The work Long-term rotation and tillage effects on soil structure and crop yield [17], most cited between 2013 and 2023 in publications on intensification and sustainability in production systems, can offer valuable perspectives on how agricultural practices can be adjusted to promote better soil structure and increase crop yields in a sustainable way. This is relevant not only to researchers interested in effective soil management but also to scholars of sustainable intensification of production systems as an alternative to promoting food security and environmental protection.

Agricultural Systems has the highest impact factor among the journals with the largest number of publications on intensification and sustainability in production systems, followed by *Field Crops Research*. Together, these two journals are well known for disseminating knowledge in the area of cropping systems. The quality and reputation of a journal play a significant role in determining the impact of the articles published in it. To assess whether the publication of an article in a specific journal will increase its influence on certain knowledge, researchers adopt a series of approaches [77]. Quality indicators for a journal can range from the frequency of citation of articles published in the journal in other publications, to the comparative analysis of the journal's position in relation to its peers within the same area of study [12]. From the editors' point of view, it is essential to implement strategies that improve the quality and visibility of journals, with the aim of expanding their reach and attracting authors in search of excellent publications. To this end, it is crucial to obtain a high rating in evaluation systems, which contributes significantly to the lasting success of the journal [78].

5. Conclusions

Bibliometric analysis was fundamental to observing the evolution of intensification and sustainability of production systems, providing valuable perspectives on improving productivity combined with environmental preservation. Given the advancement of climate change and population growth, it is likely that interest in exploring this topic will only grow.

The limited participation of African countries in research on the intensification and sustainability of production systems highlights a significant problem on this continent characterized by facing major challenges such as food and nutritional vulnerability, intensified with climate change. Therefore, it is essential that incentives are created to promote and finance research in this area, integrating them into current and future national and international development programs. This would not only improve food and nutritional security but would also increase crop productivity and contribute to the sustainability of production systems, reducing environmental impacts.

It is important to highlight that this study's main limitations were the use of only quantitative data and exploration in a single language. However, the information obtained was valuable in demonstrating the importance and evolution of the subject, in addition to directing the reader to the main researchers, countries, journals and institutions.

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