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Crop-livestock-forest integration systems: A scientometric analysis[1]

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Abstract: Scientometrics studies a specific discipline of science through quantitative indicators. Integrated production systems are a scientific knowledge area aimed at developing sustainable rural production. These systems require adequate and thorough planning of agricultural, forestry and livestock components in order to adequately protect natural resources. Scientometric studies help to quantitatively analyze these studies and generate more accurate instruments to formulate and adopt public and scientific policies. The objective of this work was to carry out a scientometric analysis of knowledge production for crop-livestock-forest integration (CLFI) systems worldwide, in order to identify the following: (a) the most productive authors; (b) the historical evolution of the number of publications and journals that publish the most on the topic; (c) the countries that produce the most scientific knowledge on the topic; and (d) the main approaches that cover the topic. A total of 1,592 studies were retrieved from the Web of Science and Scopus databases, covering the period from 1983 to August 2020. Brazil had the largest number of publications on crop-livestock-forest integration systems. Most articles were characterized in the sustainability, biodiversity and conservation knowledge areas. Our results indicate that scientific efforts have been devoted to studies related to sustainable production practices and integrated systems have been pointed out as a potential production system that meets the current demands for sustainable development, especially in tropical developing countries.

Keywords: Agrosilvopastoral; Sciencemetrics; CLFI systems; Sustainable.

Produção de conhecimento em sistemas de integração Lavoura-Pecuária-Floresta: uma análise cienciométrica

Resumo: A cienciometria estuda, através de indicadores quantitativos, uma disciplina específica da ciência. Sistemas integrados de produção são uma área do conhecimento científicos voltados para o desenvolvimento da produção rural sustentável. Estes sistemas demandam um planejamento adequado e minucioso dos componentes agrícolas, florestais e pecuários, para assim, proteger adequadamente os recursos naturais. Estudos cienciométricos auxiliam na análise quantitativa destes sistemas e geram instrumentos mais precisos para adoção de políticas públicas e científicas. O objetivo do presente trabalho foi realizar uma análise cienciométrica da produção de conhecimento para sistemas de integração Lavoura-Pecuária-Floresta (ILPF), a nível mundial, de forma a identificar os (a) autores mais produtivos; (b) a evolução histórica do número de publicações e os periódicos que mais publicam sobre o tema; (c) os países que mais produzem conhecimento científico sobre o tema; (d) as principais abordagens que cobrem o tema. Foram recuperados 1592 estudos do banco de dados *Web of Science* e *Scopus* compreendendo o período de 1983 a agosto de 2020. O Brasil foi o país com o maior número de publicações sobre sistemas de ILPF. A maioria dos artigos foram caracterizados na área de conhecimento sustentabilidade, biodiversidade e conservação. Os resultados indicam que os esforços científicos têm sido destinados aos estudos referentes às práticas sustentáveis de produção e os sistemas integrados vêm sendo apontados como potenciais sistemas de produção que atendem as demandas atuais de desenvolvimento sustentável principalmente nos países tropicais em desenvolvimento.

Palavras – chave: Agrossilvipastoril; Cienciometria; ILPF; Sustentável.

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Introduction

The generation of scientific knowledge about Crop-Livestock-Forest integration (CLFI) systems is important due to the global appeal for sustainable agriculture, considering the obstacles in producing food, fiber, energy, wood and non-wood products in a way compatible with existing natural resources (CORDEIRO et al., 2015).

It is in this perspective that CLFI systems have been emerging (GIL et al., 2015). These production systems provide numerous provisioning services (food and raw materials), support and regulatory services (control of erosion and carbon sequestration) and biodiversity. Several studies in this area are being developed, and the satisfactory results collaborate with the expectations desired by the sustainability precepts (TORRALBA et al., 2016). However, knowledge about CLFI systems is unevenly distributed and is closely linked to geographic coverage, types of production systems, socio-political incentives, and study topics (SOLER et al., 2017).

Given the above, metric studies collaborate to identify research gaps, update theoretical and methodological models and direct new paths for research. Thus, the objective of the present work was to carry out a scientometric analysis on the generation of scientific knowledge about Crop-Livestock-Forest integration (CLFI) systems worldwide in order to identify: (a) the most productive authors; (b) the historical evolution of the number of publications and the journals that publish the most in relation to the topic; (c) the countries that produce the most scientific knowledge on the subject; (d) the main approaches that cover the topic.

Material and methods

Bibliographic search and selection of studies

The scientific literature was surveyed in order to identify and extract data on the subject from national and international studies. The main collections from the Web of Science and Scopus databases were used for this critical review. This search strategy had the recommendations of Chadegani et al. (2013) and Santos (2020) as propositions, who advocate the use of these two databases to carry out bibliometric/scientometric research. The databases were searched on August 14, 2020.

The following search strategy was used to select publications in the databases: the search for terms was performed in the topic "advanced searches" in the Title (TI) and Keywords (AK) fields combined using the Boolean operator "OR", as described by Aleixandre et al. (2015). Articles in English, Portuguese and Spanish languages were selected. A specific time frame was not established, as it was sought to understand from which period it started and where the highest frequency of knowledge production about CLFI systems was obtained.

The following descriptors were used: "Agrosilvopastoral system*", "CLFI", "integrated crop-livestock-forest*", "Agrosilvopastoral", "silvopastoral". The selection of these descriptors was based on a previous survey of the terms most used in articles on the topic addressed in the work (Table 1).

Analyses

Data was extracted from the documents of the two databases, merged and the data was verified by identifying duplicate files Using the Bibliometrix package (ARIA and CUCCURULLO, 2017) in the RStudio software program (R STUDIO TEAM, 2019) through statistical methods.

The research data was processed by exporting and tabulating the results. Scientometrics was used through statistical methods to analyze the information in the documents: years of publication, types of published documents, main journals, main authors, citation averages, countries and institutions with the highest number of publications, as well as the most occurring keywords. Techniques and tools such as

Microsoft Excel and Notepad were used, thus allowing to visualize the results and create tables, images and percentage relationships.

Table 1 - Search strategy to obtain the publications analyzed in this study on the crop-livestock-forest integration system theme in the Web of Science and Scopus databases.
Tabela 1 - Pesquisa estratégica para obter a publicação analisada neste estudo com o tema de integração lavoura-pecuária-floresta nos bancos de dados Web of *Science* e *Scopus*.

Database	Crop-Livestock-Forest Integration
Web of Science	((AK="Agrosilv$pastoril system*" OR AK="ICLF" OR AK="integrated crop-livestock-forest*". OR AK="crop-livestock-forest integration system*" OR AK=silv$pastoral) OR (TI="Agrosilv$pastor$l system*" OR TI="ICFL" OR TI="integrated crop-livestock-forest*" OR TI="crop-livestock-forest integration system*" OR TI="silv$pastoral) OR (AB="Agrosilv$patoril system*" OR AB="ICLF" OR AB=integrated crop-livestock-forest*" OR AB="crop-livestock-forest integration system*" OR AB=silv$pastoral))
Scopus	((AUTHKEY ("Agrosilv?pastor?l system*") OR (AUTHKEY ("ICFL") OR (AUTHKEY ("integrated crop-livestock-forest*") OR (AUTHKEY ("crop-livestock-forest integration system*") OR (AUTHKEY (silv$pastoral)) OR (TITLE ("Agrosilv?pastor?l system*") OR (TITLE ("ICFL") OR (TITLE ("integrated crop-livestock-forest*") OR (TITLE (silv$pastoral)) OR (ABS ("Agrosilv?pastor?l system*") OR (ABS ("ICFL") OR (ABS ("integrated crop-livestock-fores*") OR (ABS ("crop-livestock-fores integration system*") OR (ABS (silv?postoral)).

* = any number of characters (letters or numbers) at the end of the word; $ and ? = any character in the middle of the word; TI and TITLE = Title (Title); AK and AUTHKEY= author keywords (Author Keyword); AB and ABS = Abstract.

Keyword co-occurrence network analysis was applied (ARIA and CUCCURULLO, 2017). The keywords in scientific publications refer to important areas of research and demonstrate the interconnection between different scientific fields, also pointing out central areas that researchers seek and study to generate new research (TRIPATHI et al., 2018).

A thematic map was created for thematic analysis of the publications, being formed from frequency analyzes and co-occurrence of keywords, represented in the form of a two-dimensional diagram. This map shows the basic, specialized, emerging and research engines in CLFI systems. Aria and Cuccurullo (2017) demonstrate that thematic maps are intuitive graphics which help to analyze themes according to the quadrant in which they are found. This chart is divided into 4 quadrants, classified as follows: (1) upper right quadrant: engine themes; (2) lower right quadrant: basic themes; (3) lower left quadrant: emerging or declining themes; (4) upper left quadrant: very specialized, niche themes.

Results

The total number of documents found from searches in the Web of Science and Scopus databases (after excluding duplicates) was 1,592 documents for the period from 1983 to 2020. Of these, 1,382 (86.81%) are scientific articles, representing most of the studies focused on the crop-livestock-forest integration theme, 50 (3.14%) book chapters, 49 (3.08%) review articles, 26 (1.63%) publications in event proceedings, 3 (0.19%) corrections, and 1 (0.06%) editorial material.

There was an evolution in the number of publications in relation to the annual scientific production. The first publication related to the research theme is from 1983, with 3 documents published, going to a total of 179 in 2019, which represents a significant increase in the number of publications. It should be noted that this growing number of publications came from the year 2008, since 68% of the total scientific production is concentrated from this year onwards. The year 2019 had the highest number

of publications (N=179) (Figure 1).

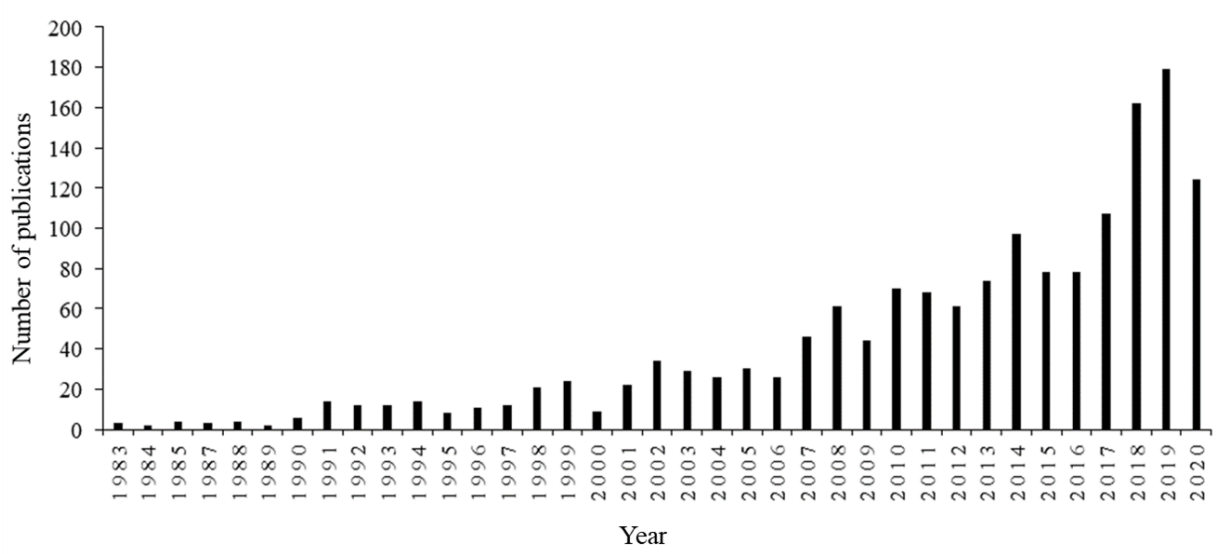

Figure 1 - Number of annual publications on the topic of crop-livestock-forest integration research, from 1983 to 2020 in the Web of Science and Scopus databases.
Figura 1 - Número de publicações anuais do tópico de pesquisas de integração lavoura-pecuária-florestal de 1983 a 2020 no banco de dados do *Web of Science* e *Scopus*.

Next, the 10 journals with the highest number of publications were ranked in descending order: Agroforestry Systems, Cuban Journal of Agricultural Science, Livestock Research for Rural Development, Forest Ecology and Management, Brazilian Agricultural Research, Agriculture Ecosystems & Environment, Tropical Grasslands-Forrajes Tropicales, Tropical Animal Science, Tropical and Subtropical Agroecosystems, Brazilian Archives of Veterinary Medicine and Animal Science, Journal of Tropical Biology (Table 2). These have a knowledge field focused on the agroforestry, agriculture, zootechnics, sustainable agriculture, forest ecology and tropical pasture areas.

Table 2 - Ranking of the 10 most relevant journals for publications on crop-livestock-forest integration systems according to the Web of Science and Scopus databases.
Tabela 2 - Ranqueamento dos dez mais relevantes jornais para publicação de integração lavoura-pecuária-floresta de acordo com o banco de dados do *Web of Science* e *Scopus.*

Ranking	Journals	Number of documents
1	Agroforestry Systems	272
2	Cuban Journal of Agricultural Science	51
3	Livestock Research for Rural Development	43
4	Forest Ecology and Management	29
5	Pesquisa Agropecuária Brasileira	25
6	Agriculture Ecosystems & Environment	24
7	Tropical Grasslands-Forrajes Tropicales	21
8	Zootecnia Tropical	21
9	Tropical and Subtropical Agroecosystems	20
10	Arquivo Brasileiro de Medicina Veterinária e Zootecnia	19
Total		**525**

More than 50% of publications are concentrated in 37 journals from 440 sources, meaning more than 50% of articles are published in less than 10% of sources. The 10 most relevant sources have 525 published documents, representing 32.97%, and only the first source (Agroforestry System) has 272 of these publications, representing (17.08%) of the total number of publications. A total of 667 documents were published only in the first 20 sources, which represents 41.9% of the total documents published.

The entire dataset had a total citation number of 14,279, an average of 8.96 per document. Of this total, the 10 works with the highest number of citations account for more than 9% of the total (Table 3). The dataset presents a dispersion in the number of citations, containing 407 documents that do not have any citations. Thus, it can be said that this set of 10 articles are influential in research related to Crop-Livestock-Forest integration systems.

Table 3 - The most-cited documents globally in relation to the topic of crop-livestock-forest integration systems according to the Web of Science and Scopus databases.
Tabela 3 - Documentos mais citados globalmente em relação ao tópico integração lavoura-pecuária-floresta de acordo com o banco de dados do *Web of Science* e *Scopus*.

Ranking	Article	Total citations	Annual citations	Themes approached
1	BELSKY, AJ et al. Comparative effects of isolated trees on their undercanopy environments in high- and low-rainfall savanas. Journal of Applied Ecology, v. 30, p: 143-155, 1993.	227	8.1	Synergism between arboreal, herbaceous and shrub species.
2	MURGUEITIO, E et al. Natives trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. Forest Ecology and Management, v. 261, n. 10, p: 1654-1663, 2011.	158	15.8	Recovery of degraded areas
3	BERGMEIER, E; PETERMANN, J; SCHRODER, E. Geobotanical survey of wood-pasture habitats in Europe: diversity threats and conservation. Biodiversity and Conservation, v. 19, n. 11, p: 2995-3015, 2010.	150	15.0	Diversity and conservation
4	NAIR, PKR. Classification of agroforestry systems. Agroforestrey Systems, v. 3, n. 2, p: 97-128, 1985.	136	3.7	Agroforestry systems
5	SOTO-PINTO, L et al. Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. Agroforestry Systems, v. 78, n. 1, p: 39-51, 2009.	131	11.9	Carbon sequestration
6	HARVEY, CA; HABER, WA. Remnant trees and the conservation of biodiversity in Costa Rican pastures, Agroforestry Systems, v. 44, n. 1, p: 37-68, 1998.	125	5.4	Conservation and biodiversity
7	DIXON, RK; Agroforestry systems: sources or sinks of greenhouse gases? Agroforestry Systems, v. 31, n. 2, p: 99-116, 1995.	125	4.8	Carbon sequestration
8	PAGIOLA, S et al. Paying for the environmental practices in Nicaragua. Ecological Economics, v. 64, n. 2, p: 374-385, 2007.	123	8.7	Environmental services
9	TORRALBA, M et al. European agroforestry systems enhance biodiversity and ecosystems e services? A meta-analysis. Agriculture Ecosystems & Environment, v. 230, p: 150-161, 2016.	118	23.6	Biodiversity and ecosystem services
10	PLIENINGER, T; PULIDO, FJ; KONOLD, W. Effects of land-use history on size structure of holm oak stands in Spanish dehesas: implications for conservation and restoration. Environmental Conservation, v. 30, n. 1, p: 61-70, 2003.	115	6.3	Biodiversity and soil conservation

Among the 10 most cited documents, four are aimed at conservation and biodiversity areas (Table 3). All works address themes about sustainable management and practices, aiming at the developing local agriculture and mitigating the effects of environmental degradation.

Brazil stands out as the country with the highest number of scientific publications regarding the countries that developed the most scientific research on the Crop-Livestock-Forest integration system topic, totaling 715 documents, followed by Mexico with 256 documents and the United States with 220 documents (Figure 2).

With regard to authorship, 3,921 authors were found who produced scientific knowledge on the subject, 92 of whom produced documents of single authorship. Of this total, the 10 authors who published the most contributed 268 documents, which represents 8.14% of the total. The authors with the most scientific research on the topic were Pablo L. Peri, with 45 published documents, followed by Maria Rosa Mosquera-Losada, with 41 documents, and Antonio Rigueiro Rodriguez with 36 published documents (Table 4).

Among the most cited authors, the author Pablo L. Peri (who had the largest number of articles published) is linked to the Universidad Nacional de la Patagonia Austral located in Argentina, and has worked on projects aimed at sustainable management. Maria R. Mosquera-Losada and Antonio Rigueiro-Rodrigues are affiliated with the Universidad de Santiago de Compostela, Spain. The author Domingos Sávio Campos Paciullo is fourth in the ranking of authors who generated the most scientific knowledge on the subject (Table 4) and is affiliated with Embrapa Gado de Leite, in Minas Gerais, Brazil. Then we have Fernando Casanova Lugo in Mexico, Hector Bahamonde and María Vanessa Lencinas who work in Argentina, Muhammad Akbar Ibrahim in Costa Rica, Enrique Muergueitio Restrepo from Colombia, and José Ricardo Macedo Pezzopane from Embrapa, Brazil.

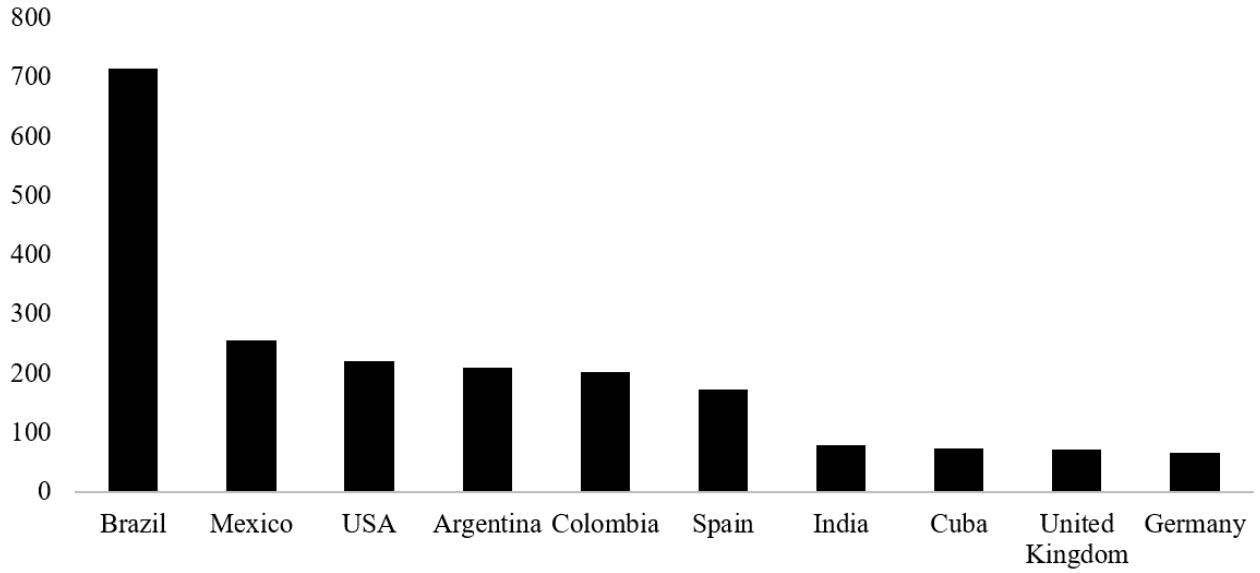

Figure 2 - Ranking of scientific production in the 10 countries with the highest number of publications on the Crop-Livestock-Forest integration system topic.
Figura 2 - Ranqueamento de produção científica nos dez países com maior número de publicações sobre o tópico de integração lavoura-pecuária-floresta.

Table 4 - Ranking of the authors who published the most scientific articles on the crop-livestock-forest integration system topic.
Tabela 4 - Ranqueamento de autores que publicaram mais artigos científicos do tópico integração lavoura-pecuária-floresta.

Ranking	Authors	Number of articles
1	Pablo L. Peri	45
2	Maria R. Mosquera-Losada	41
3	Antonio Rigueiro-Rodrigues	36
4	Domingos Sávio Campos Paciullo	28
5	Fernando Casanova Lugo	21
6	Hector Bahamonde	20
7	Muhammad Akbar Ibrahim	20
8	María Vanessa Lencinas	19
9	Enrique Muergueitio Restrepo	19
10	José Ricardo Macedo Pezzopane	19
Total		**268**

The keyword co-occurrence analysis identified the main themes related to the Crop-Livestock-Forest integration system theme. Groups that contained words which were most associated were identified, being dominated by terms of higher frequency. Thus, 5 groups were identified. The first group, which is green in color, comprises the word "Silvopastoral" which is most frequently associated with themes such as greenhouse gases, regeneration, pastures and livestock. The second group is identified with the color red has the central theme of "Carbon Sequestration" associated with soil conservation, nutrient cycling and climate change. The third group has an blue color and the central theme "Livestock", and has themes related to pasture production associated with frequently researched species and biomass production. The fourth group comprises the word "Agroforestry" which is associated with diversity, conservation and production. The fifth group has an orange color and has "Competition" as its central theme associated with the words pasture and tropical forest. The fact of being allocated in groups does not mean that they are not related to the other words, only that the association between them is smaller; however, they are interconnected to a lesser degree with distinct groups. Thus, we identified 5 groups, which are (1) "Silvopastoral", (2) "Carbon Sequestration", (3) "Livestock", (4) "Agroforestry", and (5) "Competition".

The keywords extracted from the data set are grouped in these diagrams, and the main research themes in the area under study are identified from this cluster. Groups are identified by co-occurrence analysis, where keywords which occur frequently in a search domain are grouped together.

Thus, the driving or highly developed themes in research on Crop-Livestock-Forest integration systems are related to sustainability and carbon sequestration (Q1) (Figure 4). Just below (Q2) we have the most relevant basic themes in the research area which are agroforestry and silvopastoral, competition and biomass, and agroforestry system shading (Figure 4). "Leucaena leucaphala" and "carbon" are themes which show decline in scientific research and a decrease in this specific area (Q3) (Figure 4). The themes integration, organic matter and ecosystem services are specialized themes in this research niche (Q4) (Figure 4).

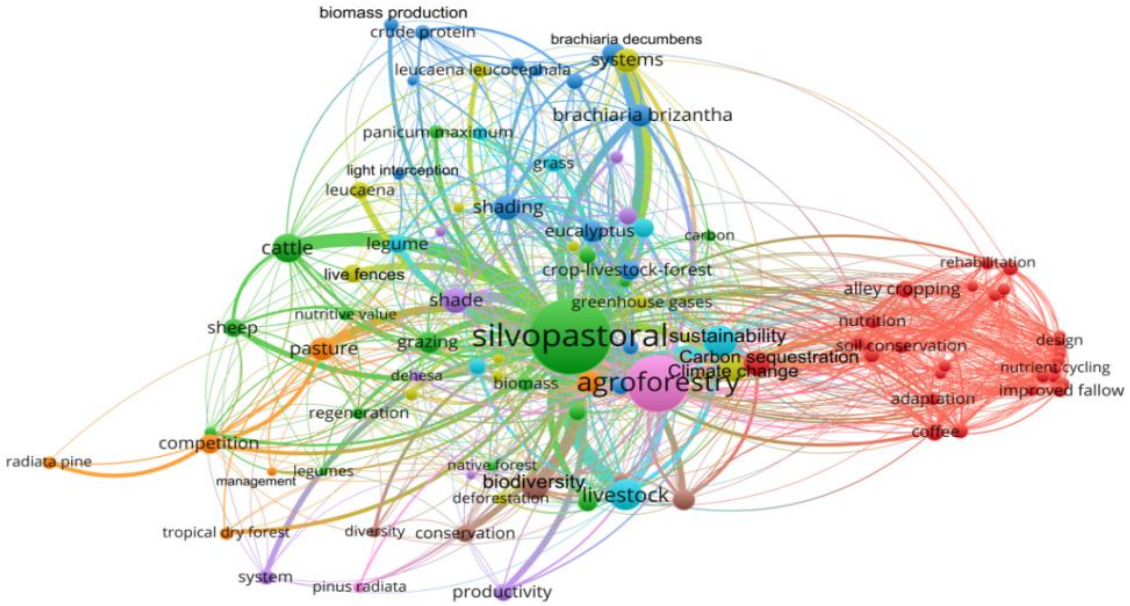

Figure 3 - Keyword co-occurrence network in the analyzed publications.
Figura 3 - Rede de interação de palavras-chave nas publicações analisadas.

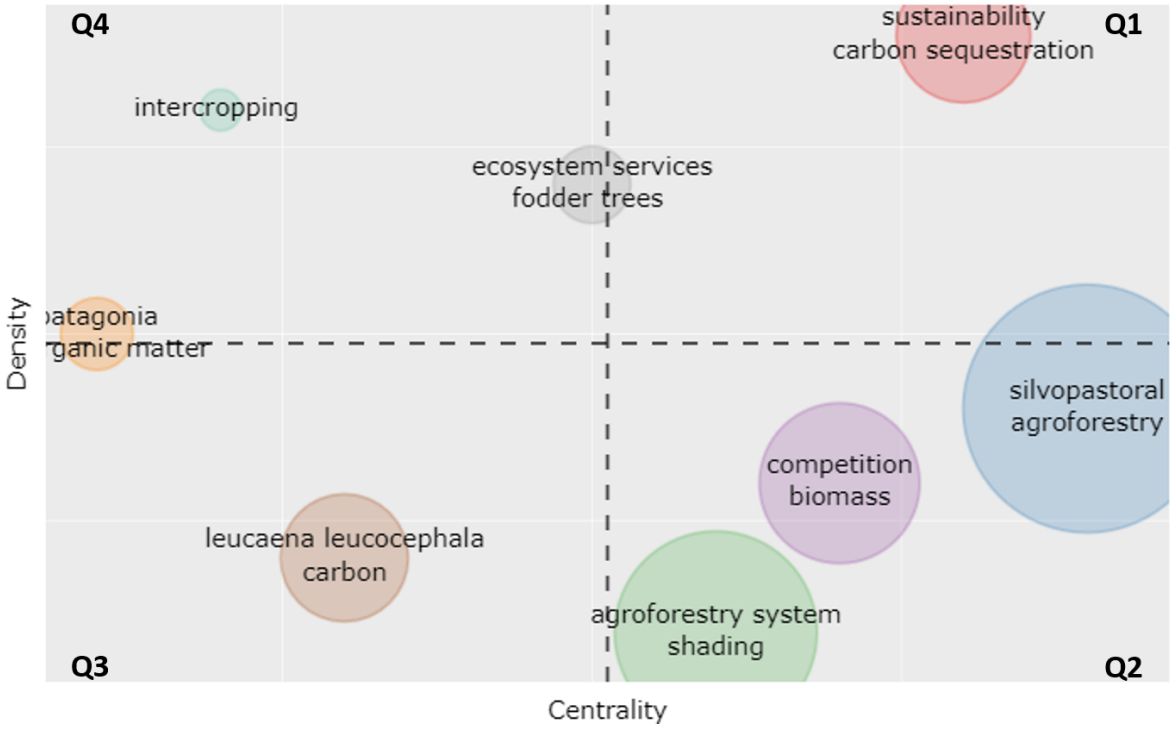

Figure 4 - Thematic map of the publications analyzed on the theme of crop-livestock-forestry integration system in the Web of Science and Scopus databases. Q1 = quadrant 1, Q2 = quadrant 2, Q3 = quadrant 3, Q4 = quadrant 4.
Figura 4 - Mapa temática para publicações analisadas no tema integração de cultivos e florestais no banco de dados do *Web of Science* e *Scopus*. Q1 = quadrante 1, Q2 = quadrante 2, Q3 = quadrante 3, Q4 = quadrante 4.

Discussion

A timid growth in research on the subject was obtained over 25 years with 374 published works, an average of 14.96 publications per year. The results of this scientometric research corroborate its relevance, as many works in this knowledge area have been developed over the years. There is a growing production of scientific knowledge on the Crop-Livestock-Forest integration system theme from 2008 onwards.

There was a considerable increase in the annual scientific production in 2017. It is necessary to understand the world scenario involving environmental issues to understand this significant increase. The United Nations Summit on Sustainable Development recognized the imperative of creating a sustainable global economy in order to protect and restore the global environment in September 2015. In this context, the United Nations adopted the "2030 Agenda for Sustainable Development" as a new framework for the global economy and development. This agenda promotes a global strategy to create non-sectoral obligations and environmental protection goals that are relevant to each country and to all actors in society, thus contributing to this leverage in the knowledge production in the study area.

Political, economic and social concerns reflected the modern global ecological concept of nature and the environment in the mid-20th century. In light of this, the United Nations, under the prelude of its Educational, Scientific and Cultural Organization (UNESCO) and the Environmental Program (UNEP) established the International Environmental Education Program (IEEP) in 1975, which was the first environmental education program articulated at the global level. From this, there were chronological markers in the outline of the historical development of environmental education around the world. There has been an evolution in the philosophy of providing instructions on protecting nature and conserving natural resources throughout this journey in order to promote an environmental ethic. This change led to the adoption of the sustainable development concept (DORN, 2020).

This transition (to some extent) reflected that global conservation strategies would not succeed without the development and cooperation of all nations in uniting economic development and environmental preservation. The launch of the final report of the UN World Commission on Environment and Development established sustainable development as a UN goal. The report, entitled "Our Common Future", defined the concept as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Thus, these events contributed to boosting research on sustainable agricultural management and practices from the 1980s onwards, which can be confirmed in the results of this research in which the first work can be found published in 1983.

It is possible to identify the growing interest in the study area related to Crop-Livestock-Forest integration systems, as the conservation or restoration of such systems is being promoted to increase biodiversity. At a landscape level, integrated production systems provide more ecosystem services than monoculture and open pastures (BUTTLER et al., 2009). They create complex habitats that support diverse plants and animals (MORENO and PULIDO, 2009), harbor richer soil biota and increase connectivity between forest fragments (IBRAHIM et al., 2006).

The largest publication vehicle on the subject according to the obtained results was in Agroforestry Systems, a journal with its knowledge field is focused on agroforestry and particularly encourages contributions that demonstrate the role of agroforestry systems in providing advantages and benefits of these systems to the ecosystem as a whole. This fact confirms that this is a journal with greater relevance, as it comprises the largest number of publications due to its specificity in the subject.

It is noted that among the 10 most relevant sources, 2 of them are Brazilian journals. The Brazilian Agricultural Research journal is in fifth place (5th) and the Brazilian Archive of Veterinary Medicine and Animal Science journal is in tenth place (10th). The systems adopted in tropical livestock are mostly considered simplified and homogeneous ecosystems, meaning biodiversity and its complex ecological functions give rise to deforestation and monoculture of herbaceous plants that sustain agriculture (LATAWIEC et al., 2014). The reality in Brazil was no different, as the intensive use of land by agriculture and its growing extension aggravated the effects of soil degradation and climate change (SONE et al., 2019).

Brazil has doubled its agricultural area in recent decades (Empresa Brasileira de Pesquisa Agropecuária, 2018) and has become one of the world's largest producers of beef and soy (United States Department of Agriculture, 2017). This extensive practice has been responsible for environmental impacts, mainly in the Amazon (BARONA et al., 2010) and Cerrado (SCARAMUZZA et al., 2017) biomes. According to Aidar and Kluthcouski (2003), the following are among the most aggravating problems in Brazilian livestock farming: the degradation of pastures and soils; the inadequate handling of animals; low nutrient cycling in the soil; physical impediments of soils; and low technological investments. Such restrictions have negative consequences for livestock sustainability.

The soil degradation scenario has driven the scientific community to seek sustainable production systems in order to combine the increase in plant and animal productivity with the preservation and conservation of natural resources (BALBINO et al., 2011). Motivated to address the issue of pasture deterioration, research-oriented organizations such as the Brazilian Agricultural Research Corporation (EMBRAPA) initially began to develop solutions and transfer of technologies to reformulate pastures using the Crop-Livestock Integration (CLI) systems and later developed the Barreirão Systems in 1980 and the Santa Fé System in 1990; years later the forestry element was inserted (KLUTHCOUSKI et al., 1991).

The CLFI Development Network, the result of a public-private partnership between Embrapa, Bradesco, Ceptis, Cocamar, John Deere, Soesp, and Syngenta was started in 2012 with the main purpose of accelerating and expanding adoption of CLFI systems by producers in rural areas, aiming at the sustainable intensification of Brazilian agriculture. The project supports 97 Technological Reference Units (TRUs) spread across all Brazilian biomes and involves the monitoring of 23 Embrapa Research Units (REDE ILPF, 2020).

Thus, we can infer that relevant works are being developed in the national territory that contribute to the scientific production on this topic in the world, which can be seen by placing national journals among the 10 most relevant sources. Parallel to this, research has boosted adopting these systems in the national territory, as they cover the edaphoclimatic differences in Brazil.

Furthermore, public policies in Brazil related to developing management and practices that provide for mitigating greenhouse gases (GHG) and expanding production areas that use more sustainable technologies gained momentum. With the 15th Conference of the Parties of the United Nations Framework Convention on Climate Change (COP-15), the Brazilian government voluntarily presented proposals and actions to mitigate climate change that the country intended to take, with the PLANO ABC being adopted in the agricultural sector (REIS et al., 2016).

Crop-Livestock-Forest and agroforestry integration systems were identified as one of the technologies to be adopted among the measures proposed in the PLANO ABC (BRASIL, 2012), as they provide combined benefits such as water regulation (SONE et al., 2019), favorable microclimate (DENIZ et al., 2020; CASTILLO et al., 2020), biodiversity (FIALHO et al., 2021) and carbon stock (MORALES et al., 2020; NATH et al., 2021),

contributing to providing environmental services and greater resilience to climate change (MURGUEITIO et al., 2011; LANDHOLM et al., 2019). Studies aimed at this research area were intensified and boosted by these public policies that invest in innovative technologies of a sustainable nature.

Regarding the number of citations, when an author cites a work, it demonstrates the relevance of this work in the research area and the higher frequency of citations indicates how useful it is for the scientific advancement of the area in question (AKSNES et al., 2019).

Among the most cited works, Belsky et al. (1993) determined how important tree species affect their understory environments under different rainfall regimes in order to understand that silvopastoral practices can be more successful in low rainfall regions than in high rainfall regions. The aforementioned authors discuss how these species can contribute to the productivity of the herbaceous layer in two different environments, evaluating the microclimate and soil properties. This study has proven to be important for evaluating environments which are more favorable to implementing silvopastoral practices.

Bergmeier et al. (2010) dealt with a review on the types of European silvopastoral systems highlighting their historical and ecological importance in the region. The authors discuss the role of silvopastoral systems in preserving regional biodiversity, and maintaining and enhancing pastures. The other most cited works which address issues on the same theme of using silvopastoral systems as a way of preserving the natural environment, reducing deforestation caused by the opening of new areas, reducing soil degradation and promoting its restoration, increasing animal productivity per hectare and the possibility of mitigating greenhouse gases through carbon fixation in the system as a whole are discussed by Murgueitio et al. (2011); Pagiola et al. (2007) and Harvey and Haber (1998). The importance of evaluating both productive and environmental benefits generated by silvopastoral systems demonstrates how they can help in the environmental preservation process while generating productivity and income for producers. The concern with natural resources has been evident since the last century and practices which envision sustainability in world agriculture are the focus of research.

Nair (1985) is the fourth most cited work, as it is a work aimed at classifying agroforestry systems and building the concepts related to this theme, delimiting the terms and what they mean in this broad, complex and multidisciplinary spectrum that are agroforestry systems. The works developed by Soto-Pinto et al. (2010) and Dixon (1995) address the role of Crop-Livestock-Forest integration systems as a potential for mitigating greenhouse gases, acting as a great carbon store in trees and soil, in addition to its potential for offsetting immediate greenhouse gas (GHG) emissions associated with deforestation and intensive agriculture. It is noted that these are highly cited works and the 10-year difference in their publications demonstrates how this theme has gained strength and visibility by researchers, mainly due to issues related to global warming, showing that Crop-Livestock-Forest integration systems are needed in the race to reduce GHG emissions.

The works carried out by Plieninger et al. (2003) and Torralba et al. (2016) address issues related to biodiversity which integration systems can provide for in the environment and ecosystem services inherent to this increase in biodiversity. Torralba et al. (2016) concluded that agroforestry can improve biodiversity and the provision of ecosystem services compared to conventional agriculture and forestry.

According to the thematic evolution map of the analyzed publications (Figure 4), sustainability and carbon sequestration are highly developed themes. These themes are being explored in research due to the proposed reorganization of the world economic system proposed by the UN, which aims to guarantee food production for the entire population without this being synonymous with the degradation of environmental liabilities, providing a social balance. Partnerships

between countries around the world seeking to reduce GHG emissions are driving forces for research on this topic.

The "agriforestry and silvopastoral", "competition and biomass", "agroforestry system shading" themes were considered relevant basic themes. As discussed above, agroforestry and silvopastoral themes are addressed in many studies and within these systems understanding of competition between species, biomass production from agricultural and forestry components, and the interspecific and intraspecific influence are important for adopting these practices on a large scale, providing a change of land use. "Leucaena leucaphala" carbon is a theme found in the quadrant which indicates emerging or declining fields in scientific research. This fact occurs because publications in journals with an impact on this topic may be in decline, which indicates that this topic has been poorly focused on by researchers. Leucaena leucaphala is a leguminous tree species widely used in Mexico; however, it is not a highly valued species for silvopastoral production in other countries as compared with Eucalyptus spp., which is the most planted species in the world, and which is planted in 6.97 million ha in Brazil alone (Indústria Brasileira de Árvores, 2021). Species of the Eucalyptus genus are also the most used in CLFI systems in Brazil (Empresa Brasileira de Pesquisa Agropecuária, 2015).

The "integration", "organic matter" and "ecosystem services" themes are specialized themes in this research niche, as the crop-livestock-forest integration systems are complex and provide conditions within their practices which elevate the biodiversity of the site, increase wildlife survival, and improve nutrient cycling, and all of these benefits are inherent to adopting their practices (LINDELL et al., 2004).

The construction of this new paradigm for organizing the agricultural production structure, public policies which encourage adopting sustainable systems and the demand for reversing pasture degradation processes drive research around the world. This is the key element for maintaining Brazil as a protagonist in the world scenario in scientific knowledge production on Crop-Livestock-Forest integration systems.

Conclusions

There has been growth in the number of studies and research focused on Crop-Livestock-Forest integration systems in the last 37 years. These systems are identified as potential production systems that meet the current demands for sustainable development, especially in tropical developing countries such as Brazil.

Brazil stands out worldwide in scientific knowledge production on Crop-Livestock-Forest integration systems, where there is a trend towards greater adoption of these practices due to public policies practiced nationally.

Two of the 10 journals that published the most on the analyzed topic are Brazilian, namely the Brazilian Agricultural Research and the Brazilian Archive of Veterinary Medicine and Animal Science journals. However, the sum of articles published by these two journals was only 44, indicating that studies carried out in Brazil are mostly published in international journals, as it was the country that most published studies on the subject.

The number of articles published with the participation of Brazilian authors is the result of actions and projects implemented over time by public and private institutions (for example EMBRAPA and REDE ILPF), such as the PLANO ABC and public policies aimed at the development of practices, sustainable management systems and technologies aimed at mitigating greenhouse gases and reducing the impacts of agricultural activities.

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