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Grass-livestock interaction: a critical review of current research progress

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Introduction: Grass-livestock interaction is of great value in maintaining ecological balance, regional economic development, and the sustainability of grassland husbandry, which has gained attention in recent years in both academia and practice, however, study on grass-livestock interaction possesses cognitive bias and gaps.

Methods: This study clarified the latest research progress and development trend in the grass-livestock interaction field by illuminating publication trend, cooperative network, keyword co-occurrence relationship, keyword clustering during 2000 to 2022 based on the Web of Science core database.

Results: The results indicated that the annual number of publications in the grass-livestock interaction field showed a globally increasing with interdisciplinary and international collaboration, and the United States of America ranked firstly, followed by Brazil, England, Australia, China. Agricultural Research Service, the U.S. Department of Agricultures was the organization with the highest number of publications, and *Rangeland Ecology & Management*, *Agriculture, Ecosystems & Environment*, *Grass and Forage Science* were the top three journals. Furthermore, in terms of the temporal evolution, the research targeting the grass-livestock interaction mainly went through three stages: initial exploration period (2000–2011), to the period of rapid development (2012–2016) to transitional development period (2017–2022), and the notable existing keywords was Management, Livestock, Cattle, Vegetation, Growth, Soil. In terms of the structural composition, four broad divisions including mechanism of human activities, grassland resource monitoring and management, grassland livestock competition/adaptability, grassland land/soil research were identified. The results provide positive and objective insights into that grassland sustainability and grazing control through strengthening cross-disciplinary and cross-regional cooperation, and applying of standard methods based on evaluation system in the grass-livestock interaction field.

Discussion: The overall contribution of the work is provision of novel insight into the intellectual structure and temporal progression of grass-livestock interaction research at a macroscopic scale and the directions in which the field is headed currently.

KEYWORDS

grass, livestock, sustainability, grazing, bibliometrics

1 Introduction

Grass-livestock interaction is generally defined as the interaction between the production layers of plants and the production layers of animals (livestock) in grassland agroecosystems (Campbell et al., 2021). Grass-livestock interaction not only affects the production and stability of grassland ecosystem, but also provides the driving force for the service function of grassland ecosystem (Chang et al., 2015; Guo et al., 2022). Maintaining the balance between livestock and grass reflects in the grazing intensity of livestock and plant productivity (Chu et al., 2022; Dang et al., 2023), and indicates the diversity of species and the energy flow and material circulation of ecosystems (van Hal et al., 2019; Zhang et al., 2019; Cheruiyot et al., 2020; Xue et al., 2021). Therefore, how to improve degraded grassland, maintain sustainable development of grassland ecosystem and protect grassland resources through grassland management measures including grass-livestock interaction while developing economy is an urgent issue. However, there are still some challenges in the practical application of grass-livestock interaction. For example, grass-livestock interaction involves multi-stakeholder collaboration, including farmers, governments, scientific research institutions, enterprises, and so on, which requires the establishment of effective cooperation mechanisms and management systems (Krizsan et al., 2021), as well as farmers' knowledge and skills related to fine livestock management and healthy breeding (Genevieve and Libby, 2023; "The grass is greener on the other side: The impact of innovation on environmental sustainability," 2023). Furthermore, the application of grass-livestock interaction also needs to fully consider the local natural, economic, social, and cultural characteristics, and adapts to local conditions to ensure sustainability and adaptability (Singh et al., 2011; Elgersma et al., 2021).

Grass-livestock interaction is synthetic effected by natural factors including grassland resources, terrain, climate, and social issues involving land policy, agricultural technology, capital (Watson et al., 2021). The monitoring of grass-livestock interaction is mostly derived from mesoscale and macro data, which lacks a systematic analysis framework of grass and livestock balance (Spagnuolo et al., 2020; Zhao et al., 2023). The measurement systems constructed by different scholars vary greatly lead to wide differences in corresponding measurement results and different explanations for grassland overload. In terms of sustainability evaluation, the economic, social, and environmental benefits were comprehensively evaluated through life cycle evaluation, comprehensive evaluation, and other methods, so as to explore its performance and optimization strategies in long-term and comprehensive grassland sustainability (Lanzoni et al., 2023). According to research findings, the grass-livestock interaction can increase the income of farmers, reduce the production cost, and improve the efficiency of resource utilization (Knudsen et al., 2019; Jackson, 2020; Jan et al., 2020). In terms of social benefits, grass-livestock interaction can promote rural employment, improve rural residents' living standards, and promote rural tourism and cultural inheritance (Vold et al., 2019; Wells et al., 2021; Tscharntke et al., 2022). In aspects of environmental benefits, it can improve soil quality, reduce the use of fertilizers and pesticides, and protect biodiversity (Tscharntke et al., 2021; Shen et al., 2022; Thomas et al., 2023). These assessment results provide a scientific basis for the sustainability and long-term development of grass-livestock interaction (Grass et al., 2020). In general, there have been a large number of studies on grass-livestock interaction at home and abroad from the aspects of vegetation-bio-environment (Yan et al., 2021), structure and function (Bedoić et al., 2019) due to standardized methods and empirical emphasis (Pausas et al., 2020; Lu et al., 2023), and a series of positive results have been achieved in the research status (Van Buren et al., 2015; Castrosanto et al., 2021; Jaramillo et al., 2021). However, it is difficult to effectively summarize and quantitatively analyze the development status and trend in the field of grass-livestock interaction based on systematic perspective and bibliometrics. Moreover, it is also unclear which divisions remained alive, which ones disappeared or shrank, and which areas of grass-livestock interaction research and practice are emerging.

This study investigates the patterns of grass-livestock interaction research across various geographical regions as well as the variation of this geographical distribution through the 5,505 literatures collected in the core database of Web of Science from 2000 to 2022. The main research objectives are to: (1) Raise awareness in the field of grass-livestock interactions by analyzing the basic characteristics and changes, critical research topics and major divisions in the grass-livestock interaction field. (2) Propose further insights and recommendations for future research in grass-livestock interactions, discussing ways to strengthen the application of remote sensing technology in this area and foster comprehensive interdisciplinary development.

2 Materials and methods

2.1 Data and materials

Full bibliometric data of this set of documents were exported in the form of text files for analysis, which included their title, date of publication, author names and affiliations, citation count, list of keywords, abstract text and list of references. The source of literature data is Web of Science database core collection (accessed on 9th to 22nd September 2023),[1] which the retrieval period was from 2000 to 2022. To analyze the grass-livestock interaction research in its broadest scope, collective publications in grass-livestock interaction were considered and their full bibliometric information was exported and analyzed. The specific research steps: (1) Web of Science core database searching subject is grass and livestock with a total of 18,342 valid data; (2) control time range is from 2000 to 2022, with a total of 11,636 data; (3) the type of control literature is articles and reviews, with a total of 8,258 data; (4) 5505 valid literature records are obtained after refining, cleaning, and summarizing the initial search results to ensure the quality and applicability of literature data.

2.2 Visualization and statistical methods

The research methods of this paper include bibliometric method, content analysis method and clustering analysis method. In this study, the methodology of Visualization of Similarities (VOS) and the Document Co-Citation Analysis (DCA) are proposed to process the retrieved literature data, and data mining, mapping, and clustering are

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[1] https://www.webofscience.com/

carried out graphically to extract key information from countries, academic institutions, journals, and keywords. They can be constructed based on citations, bibliographic coupling, co-citations, or co-author relationships. Compared with other document metrology software, VOSviewer has the advantages of strong graphical display ability, which is suitable for large-scale data, and strong versatility, which is suitable for various formats of source data. The clustering algorithm employed in VOSviewer is the stepwise clustering approach, which involves R-type clustering analysis of a large samples (keywords) and their categorical variables (such as citation frequency, publication year, etc.) after filtering, and primarily relies on the algorithm of association strength, selecting high-frequency keywords from the study for cluster analysis (van Eck and Waltman, 2017). The analysis results include cluster divisions, keyword linkage coefficients (co-occurrence strength), total node linkage strength (reflecting the strength of relationships between multivariate nodes), and the strength assignment of various variables related to keywords.

3 Results

3.1 General situation of grass-livestock interaction research

3.1.1 Trend and number of publications

The annual number of publications and the interannual change are important indicators to measure the trend of research on the topic of grass-livestock interaction. The number of published papers in the grass and livestock interaction field showed an overall upward trend from 2000 to 2022, increasing from 84 papers in 2000 to 453 papers in 2022, with a growth rate of 81.46% (Figure 1). Among them, the peak number of published papers was 510 papers in 2021. In 2007, 2009 and 2014, the number of published papers increased rapidly, which were 24.58, 33.76 and 28.75%, respectively, indicating that the research scale in the grassland and livestock interaction field emerged phased expansion.

3.1.2 Distribution and cooperation of key countries and institutions

Figures 2A,B as showed the distribution of countries and their cooperation in the grassland and livestock interaction field. In the past 23 years, a total of 127 countries and regions have published articles in the grass and livestock interaction field. Among them, the top 10 countries are United States of America, Brazil, England, Australia, China, France, Germany, Argentina, South Africa, and Spain. The total number of published papers in these countries was 4,596, accounting for 58.21% of the total amount. The number of articles published in the United States, with 1,498 articles, ranked first, accounting for 18.97% of the total number of articles. Brazil, with 587 papers is close behind in second place, but the total number is only 39.19% of the United States. China (399 articles) ranked fifth, with a certain gap with England (497 articles) and Australia (465 articles; Figure 2C).

In the recent 23 years, there have been 3,375 global research institutions on grass-livestock interaction, widely distributed around the world. The top 20 institutions (Table 1) in the number of publications showed that the Agricultural Research Service, the U.S. Department of Agriculture, had published 372 papers, ranked first, which the number of papers was much higher than other institutions. The Institut National de la Recherche Agronomique of France, with 131 publications, was in second place. Chinese Academy of Sciences ranked third with 128 articles. From the perspective of institution type (Table 1), there were 15 universities, which were the main issuing institutions, two scientific research institutes including Institution National de la Recherche Agronomique of France, and Chinese Academy of Sciences, three government agencies, mainly involving Agricultural Research Service, the U.S. Department of Agriculture, Agriculture and Food Development Authority of Ireland, and Agriculture and Agri-Food Canada.

3.1.3 Main published journals of grass-livestock interaction

In the retrieved articles, a total of 1,060 journals have published articles targeting grass-livestock interaction, and the top three journals have published more than 100 articles, most of which mainly included related contents on ecology, agronomy and crop science, animal science (Table 2). According to the statistics of the top 20 journals, *Agriculture, Ecosystems & Environment, Agricultural Systems, Animal Feed Science and Technology, Animals, Animal, Journal of Animal Science, Agronomy-Basel*, showed higher citation scores and impact factors, and were in the first partition. And these seven journals published a total of 462 papers, accounting for 31.9%.

3.2 Temporal evolution of grass-livestock interaction

3.2.1 Initial research period (2000–2011) of grass-livestock interaction

Shown as Figure 3, the number of core subject words appeared was 2,128 from 2000 to 2011, the standardized average citation rate

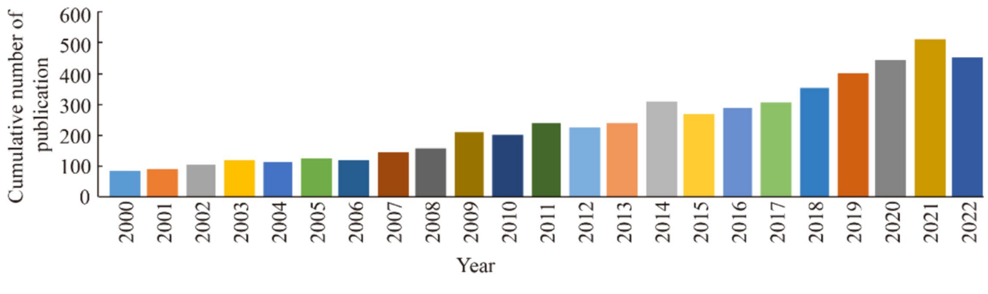

FIGURE 1
Annual trends and cumulative number of publications in the grassland ecosystem field from the Web of Science core database (2000–2022).

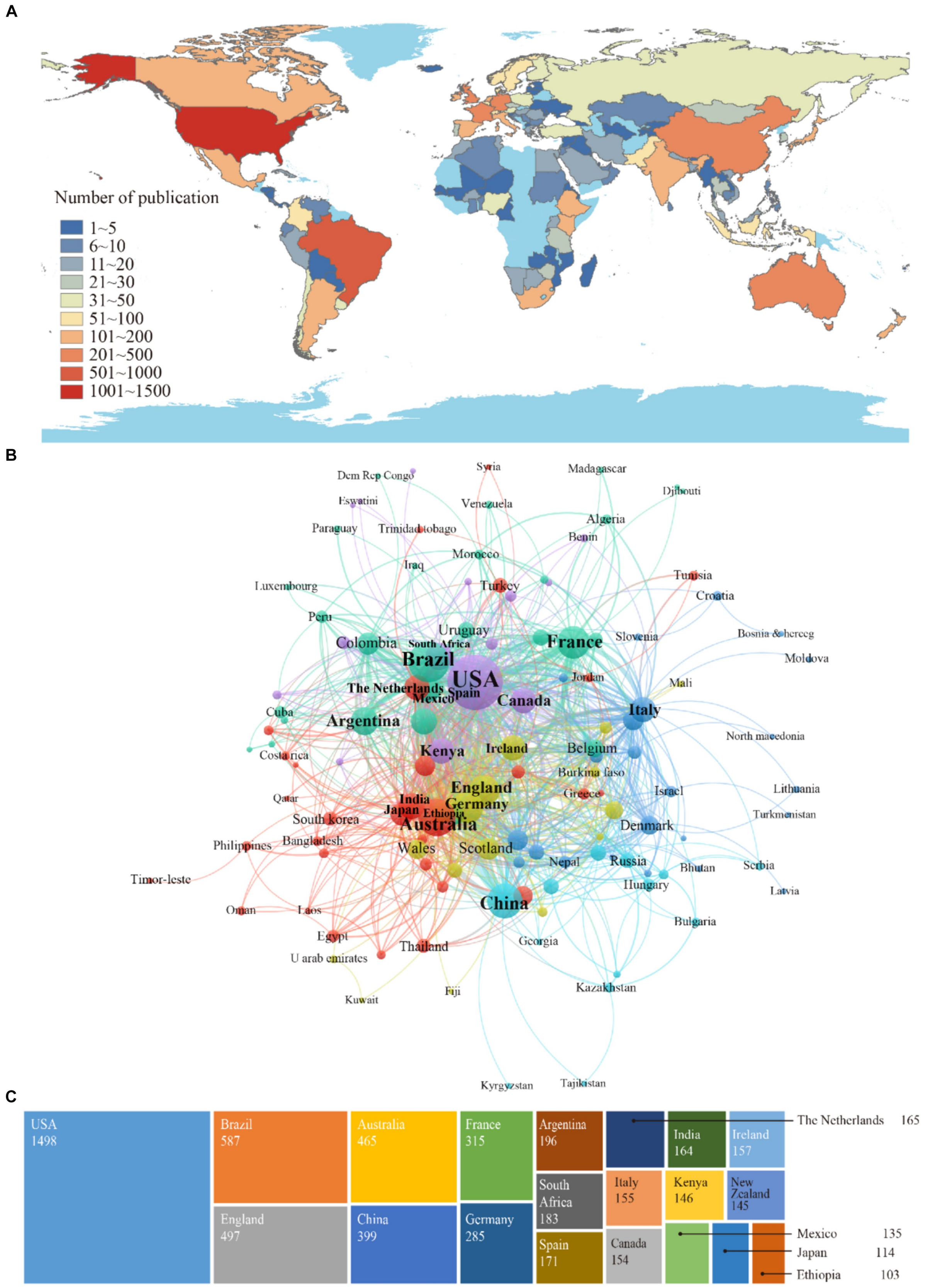

FIGURE 2
Mapping knowledge domain of countries in grass-livestock interaction research from 2000 to 2022. **(A)** Distribution and cooperation of countries based on number of publications; **(B)** Cooperation network of countries researching on grass-livestock interaction from 2000 to 2022; **(C)** Key countries that published papers in grass-livestock interaction research from 2000 to 2022. Light blue is the base color of the map, no data included.

TABLE 1 Top 20 institutions determined by the number of published papers in grass-livestock interaction research from 2000 to 2022.

Rank	Institution	Number of papers	Country	Type
1	Agricultural Research Service, the U.S. Department of Agriculture	372	United States of America	Government agency
2	Institut National de la Recherche Agronomique	131	France	Research institute
3	Chinese Academy of Sciences	128	China	Research institute
4	Agriculture and Food Development Authority	104	Ireland	Government agency
5	University of Florida	83	United States of America	University
6	Oregon State University	73	United States of America	University
7	Colorado State University	71	United States of America	University
8	University of São Paulo	70	United States of America	University
9	New Mexico State University	69	United States of America	University
10	Utah State University	65	United States of America	University
11	Texas A&M University	63	United States of America	University
12	University College Dublin	62	Ireland	University
13	Wageningen University & Research	59	The Netherlands	University
14	Lanzhou University	57	China	University
15	University of California, Davis	57	United States of America	University
16	Universidade Federal do Rio Grande Do Sul	57	Brazil	University
17	Universidad de Buenos Aires	54	Argentina	University
18	Agriculture and Agri-Food Canada	51	Canada	Government agency
19	University of KwaZulu-Natal	50	South Africa	University
20	University of Queensland	50	Australia	University

score was 1.25 (high), the average association strength was 50.22 (high), and the keywords with the top 10 frequency were Management, Cattle, Vegetation, Livestock, Grazing, Sheep, Nitrogen, Grass, Grassland, Growth. The research content of this period focuses on understanding and improving the related content of grass-livestock interaction including forage, pasture, livestock, and management, and emphasizes on the influence of grassland forage feed on the development of animal husbandry and the impact of grassland on the carrying capacity of livestock.

3.2.2 Rapid development period (2012–2016) of grass-livestock interaction

Shown as Figure 4, the number of core subject words was 1919 from 2012 to 2016, the standardized average citation rate score was 1.18 (high), the average association intensity was 50.90 (high), and the keywords with the top 10 frequency were Management, Livestock, Vegetation, Cattle, Grassland, Growth, Diversity, Nitrogen, Grass, Soil. During this period, the main contents of the research on grass-livestock interaction were forage, pasture, livestock, soil and management, and the focus of the research was shifted from the single grass-livestock relationship to pasture management, biodiversity, and soil research.

3.2.3 Transitional development period (2017–2022) of grass-livestock interaction

Shown as Figure 5, the number of core topics reached 3,140 during 2017 to 2022, the standardized average citation rate score was 1.11 (high), the average association strength was 67.92 (high), and the top 10 keywords with the frequency of occurrence were “Management, Livestock, Cattle, Vegetation, Growth, Nitrogen, Diversity, Performance, Grass, Grassland,” in which research focused more on refining and optimizing management method to improve productivity, yield and economic efficiency of livestock, as well as on the health and diversity of soil and grassland ecosystems.

3.2.4 Comparative changes of grass-livestock interaction in different periods

By comparing the top 30 groups of keywords related to grass-livestock interaction in the three periods (Figure 6), it can be found that “Management, Livestock, Cattle, Vegetation, Growth, Soil” have always existed, indicating that it is the core key issue of grass-livestock interaction, which may have greater research value or difficulty.

The most frequent keywords are “Management, Cattle, Vegetation, Livestock, Grazing, Sheep, Nitrogen” from 2000 to 2011 (Figure 6), which mainly related to the grazing behavior of cattle and sheep. Keyword Nitrogen may discuss topics related to forage growth and yield, such as nitrogen fertilizer, indicating that grassland and livestock yield are the main direction of discussion in this period. Compared with the top 35 keywords in the three stages, the occurrence frequency of “Disturbance, Communities, Grasslands, Phosphorus, Ecology and Rangelands” has decreased significantly in the latter two stages. In addition, the top 30 keywords group added keywords “Systems, Land use, Biomass” during 2012 to 2016 (Figure 6), which indicated that ecosystems, biodiversity, and land use become the key research direction, and the “Disturbance, Communities, Grasslands” keywords related to grasslands have declined. Furthermore, the standardized

TABLE 2 Ranking of top 20 journal sources by the number of publications on grass-livestock interaction from 2000 to 2022.

Rank	Journal	Country	Number of papers	Covered field	Cite Score	Impact factor	JCR partition
1	*Rangeland Ecology & Management*	United States of America	168	Ecology, Management, Socioeconomic and Policy-Pertaining	4.6	2.3	Q3
2	*Agriculture, Ecosystems & Environment*	The Netherlands	119	Agriculture, Ecosystems and Environment	10.2	6.6	Q1
3	*Grass and Forage Science*	England	116	Grass and Forage Science, Agriculture, Botany, Cattle, Crops, Dairy Industry, Forage Silage Production, Grasses	5.7	2.4	Q2
4	*Fourrages*	France	88	Agriculture, Dairy and Animal Science	0.6	0.2	Q4
5	*Journal of Arid Environments*	United States of America	88	Ecology, Earth-Surface Processes, Ecology, Evolution, Behavior and Systematics	5.0	2.7	Q2
6	*Animal Production Science*	Australia	83	Agricultural and Biological Sciences-Food Science	3.2	1.4	Q3
7	*Agronomy Journal*	United States of America	70	Agriculture, Natural Resource Sciences, Soil Science, Crop Science, Agroclimatology, Agronomic Modeling, Production Agriculture, and Instrumentation	4.3	2.1	Q2
8	*Crop Science*	United States of America	64	Fields of Crop Breeding and Genetics, Crop Physiology, and Crop Production	4.8	2.3	Q2
9	*Agricultural Systems*	The Netherlands	61	Agricultural and Biological Sciences (General), Agronomy and Crop Science	11.9	6.6	Q1
10	*Animal Feed Science and Technology*	The Netherlands	59	Food Science, Animal Science and Zoology, Veterinary Science	5.6	3.2	Q1
11	*Animals*	Switzerland	59	Zoology, Ethnozoology, Animal Science, Animal Ethics and Animal Welfare	4.2	3.3	Q1
12	*Animal*	England	57	Innovative and Cutting-Edge Science That Relates to (Farmed or Managed) Animals	6.6	3.6	Q1
13	*Journal of Animal Science*	United States of America	57	Agriculture, Dairy & Animal Science	5.2	3.3	Q1
14	*PLoS One*	United States of America	57	Two Hundred Subject Areas Across Science, Engineering, Medicine, and the Related Social Sciences	6.0	3.7	Q2
15	*Rangeland Journal*	Australia	56	Biophysical, Social, Cultural, Economic, and Policy Influences Affecting Rangeland	3.4	1.2	Q4
16	*Agroforestry Systems*	The Netherlands	52	Agroforestry and Other Integrated Systems Involving Trees and Crops	5.5	2.2	Q2
17	*Agronomy-Basel*	Switzerland	50	Agronomy and Agroecology	5.2	3.7	Q1
18	*African Journal of Range & Forage Science*	South Africa	49	Rangeland Ecology and Pasture Management	3.1	1.4	Q4
19	*Livestock Science*	The Netherlands	48	Animal Genetics, Breeding, Growth, Reproduction, Nutrition, Physiology, and Behavior	3.6	1.8	Q2
20	*Tropical Animal Health and Production*	The Netherlands	48	Animal Health, Production, and Management in Tropical Regions	2.9	1.7	Q2

Journal Citation Reports (JCR) partition divides each subject classification into 4 regions on average according to the impact factor of the journal. The top 25% of the impact factor is Q1 partition, the top 26% ~ 50% of the impact factor is Q2 partition, the top 51% ~ 75% of the impact factor is Q3 partition, and the impact factor 76% and thereafter is Q4 partition.

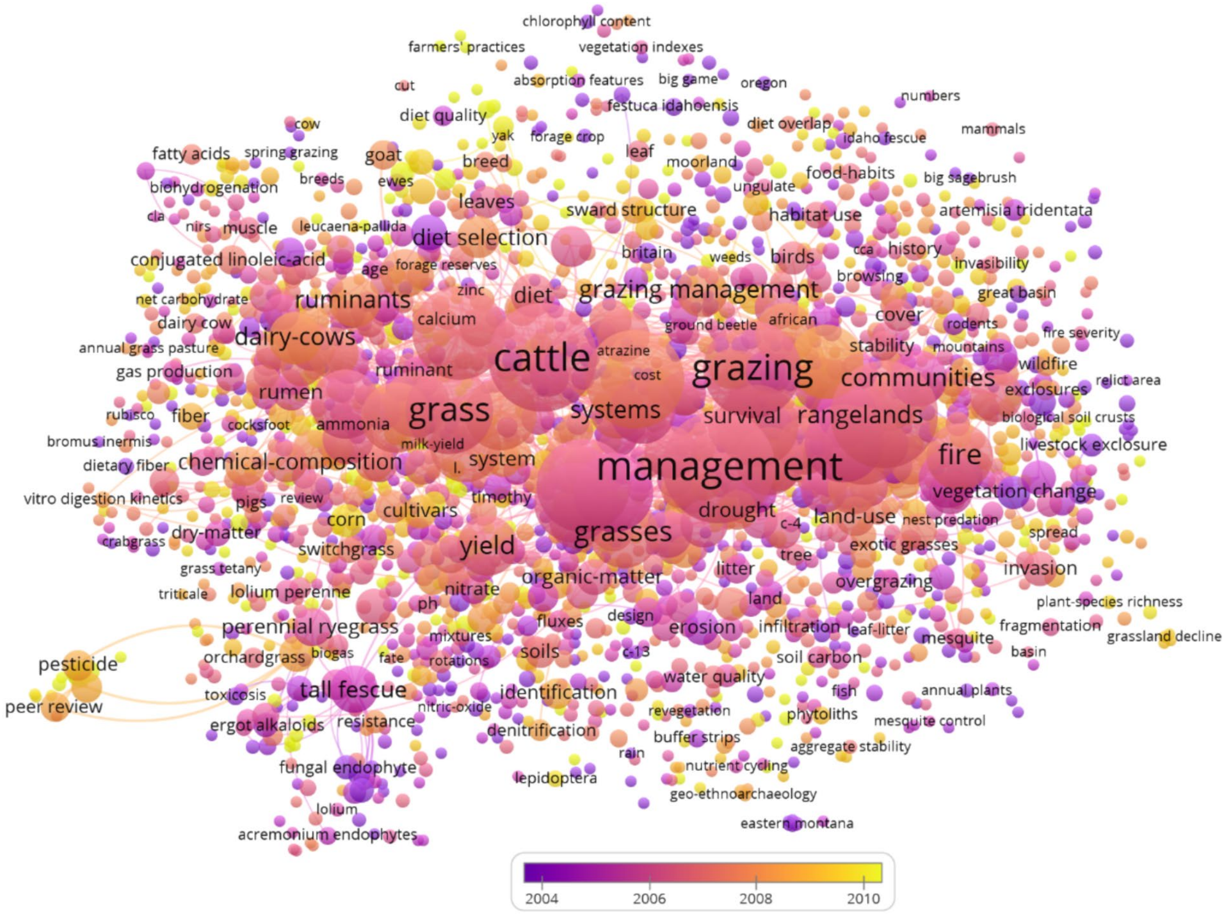

FIGURE 3
Keyword occurrences of grass-livestock interaction research from 2000 to 2011. The node size represents the frequency of keyword occurrence, the font size marked with node keywords represents the intensity of node centrality, and the thickness of the line represents the correlation strength between the keyword and other keywords. The thicker the line, the higher the correlation strength. The same below.

average citation rate score of keywords decreased slightly and the correlation intensity increased significantly during 2017 to 2022 compared with the terms from 2000 to 2016. Keywords such as "Management," "Cattle," "Vegetation," "Livestock," "Growth," "Diversity" and "Grassland" are recurring and dominate the list (Figure 6), reflecting the continuous attention paid to the main components including management, livestock husbandry and vegetation, that affect the interaction of grass and livestock. Furthermore, the increase of the repetition rate of "Performance" shows the increasing importance to the efficiency and performance of livestock husbandry.

Compared with the top 30 sets of keywords, it is found that two new keywords "Climate-change, Impacts" have been added in 2019, including which indicated involving in climate impacts and environmental factors break through the previous evaluation system that determined livestock by grass and coordinated livestock. and not only taking economic and social development or environmental protection as the main goal, but also starting to analyze the interaction between grass and livestock in a diversified way. We have diversified our research into grass-livestock interaction, rather than focusing on economic and social development or environmental protection.

3.3 Keyword co-occurrence network and theme mining of grass-livestock interaction research

The keyword clustering (Table 3) and visual knowledge map formed by the selected relevant literature data are shown in Figure 7. Keywords related to the grass-livestock interaction can be divided into four clusters. The cluster one is the cluster related to "Livestock and grassland forage" composed of the red area, which mainly involves the contents related to animal husbandry such as cattle, sheep, grass, grazing, grassland, pasture, feed quality, feed yield, feed nutritional value and so on. It contains 2,389 keywords. Among them, Cattle, Nitrogen, Growth, Grass, Sheep, Grazing, Grassland, Performance, Pasture, Quality, Soil, Forage, Digestibility, are high-frequency keywords that are widely cross-linked with keywords in other clusters. The cluster two is target "Vegetation and grassland management" for the green area, which includes management strategies, biomass change, species richness, and sustainability. It is composed of the keywords "Management, Vegetation, Dynamics, Systems, Biomass" and so on. The cluster contains 1,336 keywords. The keyword "management" has the highest frequency (633 times) and the highest total link strength

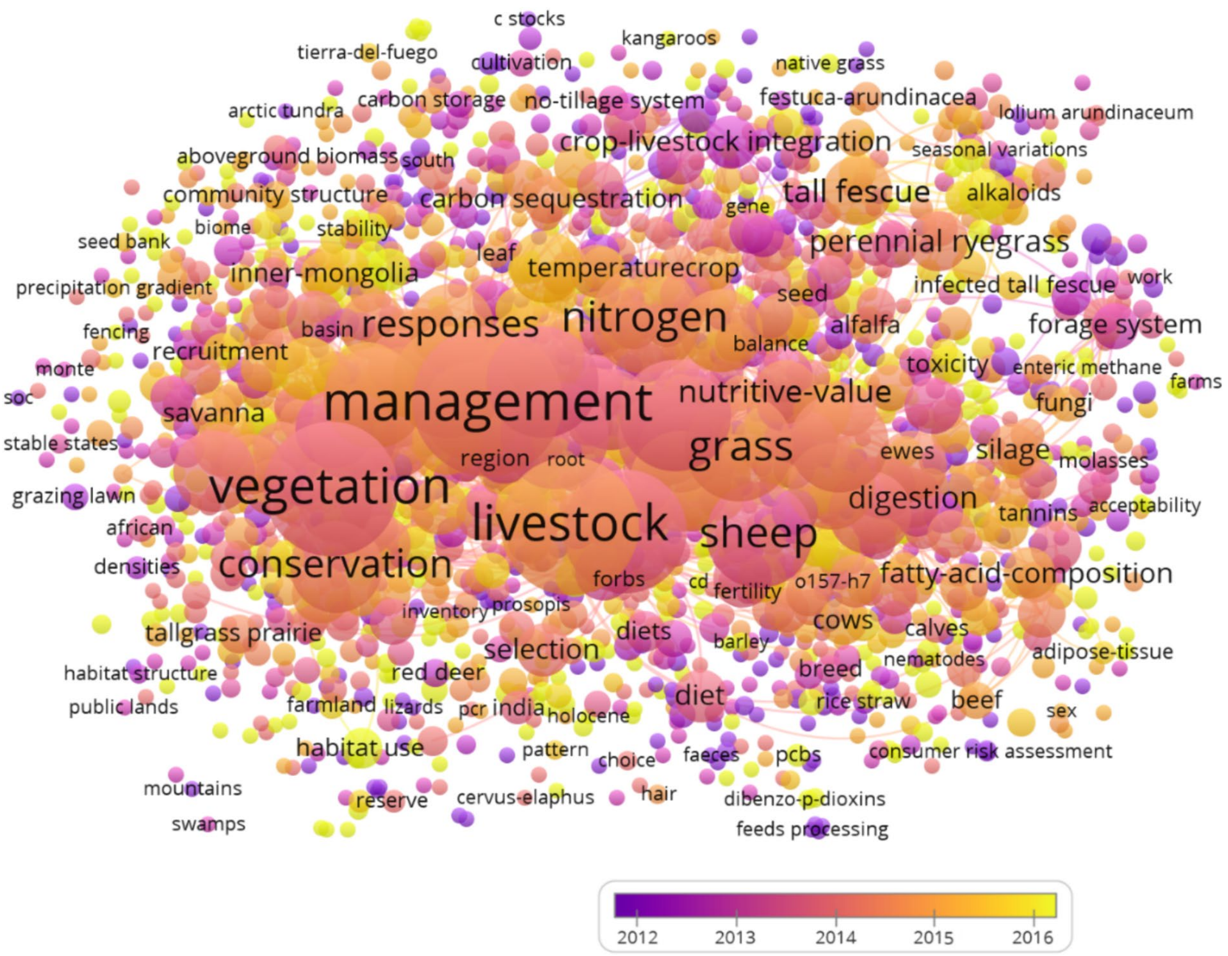

FIGURE 4
Keyword occurrences of grass-livestock interaction research from 2012 to 2016.

(6,434 times). Meanwhile, the top five terms (Cultural Landscape, Semi-Natural Grasslands, Sustainable Grazing, Pika Ochotona-Curzoniae, Temperature Sensitivity) with the highest standardized average citation rate are all from this cluster. The cluster three is related to “Environmental impact and resource conservation” for the blue region containing 1,176 keywords, which mainly deals with the role of animal husbandry in the restoration and protection of grassland ecosystem, and the relationship between animal behavior and ecology. It is composed of the key words “Livestock, Diversity, Biodiversity, Productivity, Conservation” with high repetition frequency. The average number of citations is the highest, which indirectly indicates that the keywords related to “Livestock” have received early attention and continue to affect livestock balance. The cluster four is composed of “Forage characteristics and soil texture” clusters in the yellow regions containing 1,065 keywords, which deals with different kinds of grass herbs and their relationship to soil phosphorus, nutrients, bacteria. Top keywords are Grass, Plant, Phosphorus, Tall fescue, Forage quality, Ryegrass, White clover, Cultivars, Environment. As the basis of forage feed, the keywords related to soil ecological environment play important roles in the study of grass-livestock interaction.

4 Discussion

4.1 Research progress evolution of grass-livestock interaction

The initial exploration period (2000–2011) is the initial stage of the Millennium Development Goals (MDGs) put forward by the United Nations. Animal husbandry is the pillar industry in many developing countries, and researches in the field of grass-livestock interaction have attracted wide attention. However, researches on grass-livestock interaction in countries around the world tend to adopt a single-factor and crude analysis model at this period. In addition, the direct factors that threaten animal husbandry and anti-risk strategies have been explored worldwide to cope with climate change and food crisis (Li, 2009). The research on grass-livestock interaction in China is in the initial stage of development, and the research content is mainly to establish a regional water-grass-animal mathematical model according to the planned area (Jun Li et al., 2007; Zhou et al., 2017), propose the theoretical threshold of grassland ecosystem management (Li et al., 2005).

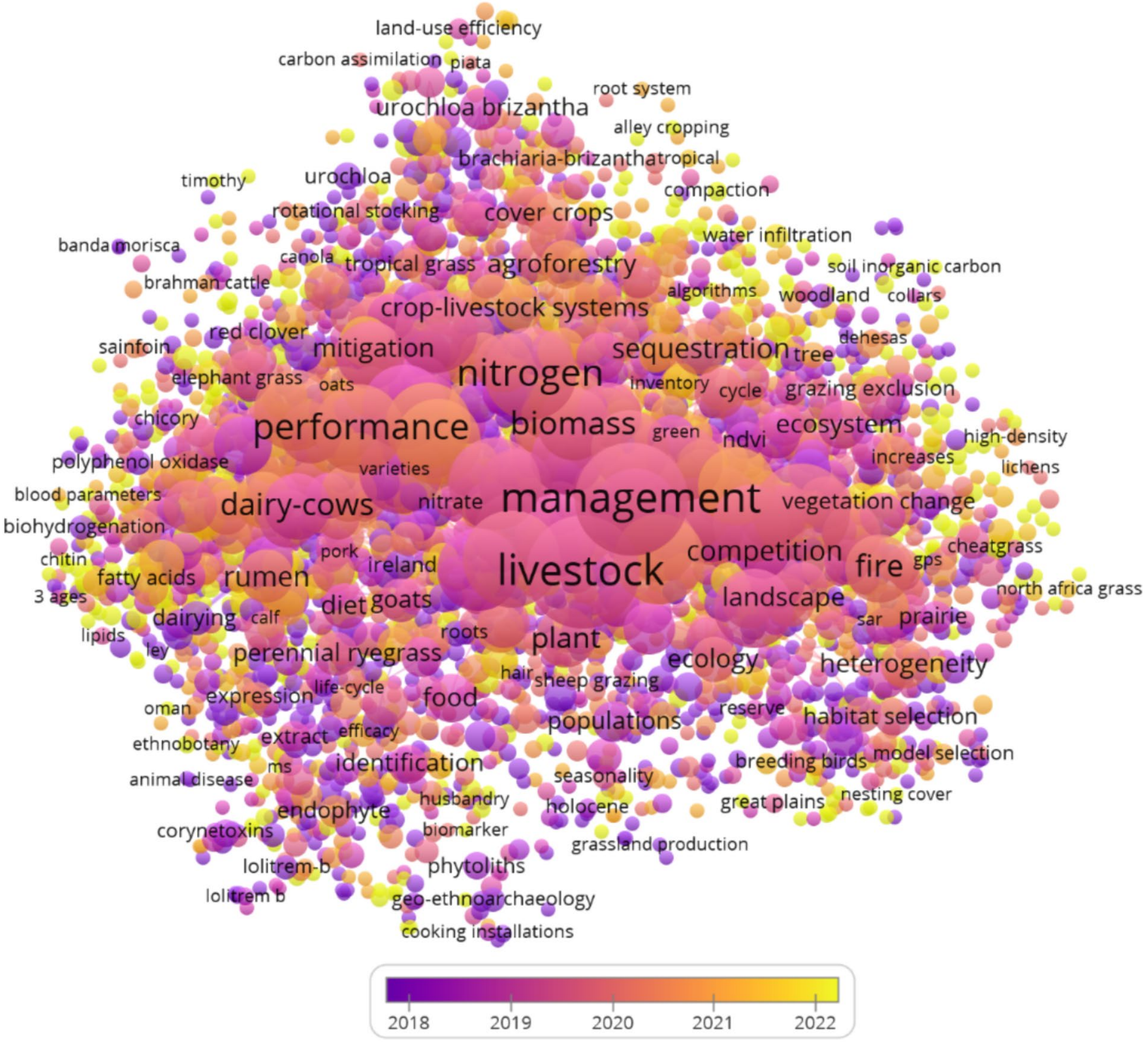

FIGURE 5
Keyword occurrences of grass-livestock interaction research from 2017 to 2022.

During the period of rapid development (2012–2016), developing countries, which have long been plagued by problems such as pasture shortage, poverty (Briske et al., 2015), and food security, intend to achieve increased production and income through research related to grass-livestock interaction in order to accelerate the realization of the United Nations Millennium Development Goals (Yang et al., 2019). At this stage, the research goal of grass-livestock interaction was inclined to promote economic growth and social equity (Wang et al., 2017; Zhang and Wang, 2023). By referring to the keywords, it is found that the research of Chinese scholars is consistent with the policy direction. During this period, China introduced a series of protection policies, including grassland protection and construction, economic development of pastoral areas, and grassland supervision system (Li et al., 2018, 2021). At the same time, developed countries pay attention to the balance of ecological protection and biomass, focusing on the role of human activities in the grass-livestock interaction (He et al., 2015; Li et al., 2017; Wang et al., 2017; Wang S, et al., 2023), or the study of global grassland degradation or grassland ecosystems under extreme conditions (Yao et al., 2016; Dong et al., 2020; Bardgett et al., 2021).

In the transitional development period (2017–2022), policies and research in countries around the world begin to adapt to new challenges, and the grass-livestock interaction field integrates climatology, ecology, sociology, etc., to deal with more complex problems (Sun et al., 2020). Furthermore, all-round and full-detailed research on professional fields emerged (Rosolem et al., 2017). The research on grass-livestock interaction shows the trend of comprehensive and sustainable development emphasizing the economic, social, and ecological protection.

4.2 Strengthening cross-disciplinary and cross-regional research cooperation

In the grass-livestock interaction field, the number of publications has shown a significant increasing trend in the recent 23 years. The

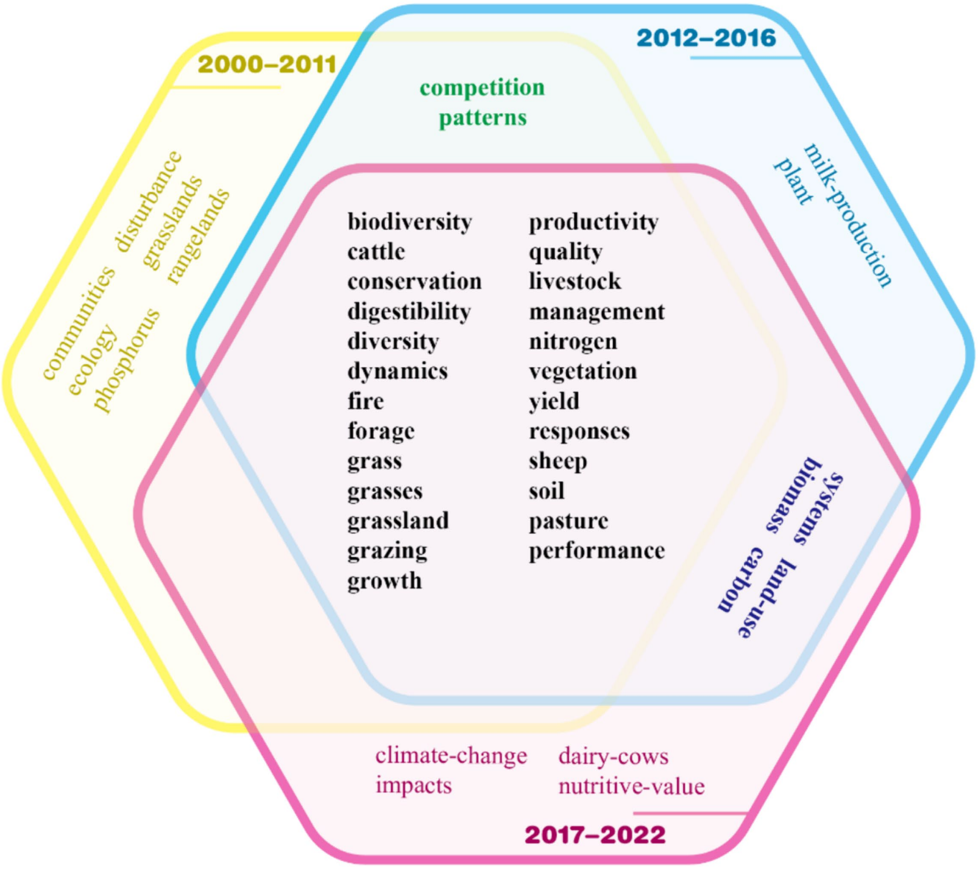

FIGURE 6
Keyword occurrences change of grass-livestock interaction research in different period (2000–2011, 2012–2016, 2017–2022).

number of keywords related to "Management, Livestock, Vegetation" has increased (Figures 4–6), covering multiple disciplines such as botany, soil science (Pulido et al., 2018), animal management (Reinermann et al., 2020), climate change (Uwizeye et al., 2020), social economy (Sharma et al., 2021), and policy science (Wei et al., 2021), which influence social stability, economic growth, and environmental protection (Herrero et al., 2013). Therefore, cross-disciplinary and cross-field cooperation is urgently needed to integrate expertise and research methods in different fields in order to solve scientific problems in the grass-livestock interaction field.

Through summarizing the past research (Figure 2C), it was found that in the initial exploration period (2000–2011), China implemented the subsidy and incentive policy for grassland ecological protection, and the grassland policy was changed from "taking grain as the key link and comprehensive development" to "attaching equal importance to ecological production and giving priority to ecology" (Li et al., 2022), so as to further improve the policy system related to grassland ecological restoration such as returning grazing to grassland, banning grazing and ending grazing. Compared with other countries (Figure 2C), French animal husbandry is faced with short-term or long-term drought at this stage, and how to enhance the natural resilience of grassland ecosystem to cope with various problems caused by climate change is their primary issue (Rigolot et al., 2014). In developing countries with more natural grassland resources, such as Kazakhstan and Mongolia, there are relatively few reports on the research and practice of restoration of degraded grasslands, while in South America, Australia, Africa and other savanna areas, have been partially transformed into pasture, farmland and forestland due to local natural and economic conditions, which the degradation of grassland ecological resources has not attracted enough attention (Gao and Ding, 2022).

During the period of rapid development (2012–2016), the research priorities of developed and developing countries differ greatly (Figure 2C; Distel, 2016; Fynn et al., 2017; Rosolem et al., 2017). Fensham et al. (2015) suggests that land clearing exacerbates the spread of buffel grass and the control of this practice is an important contribution to the conservation of savannas. Scasta et al. (2016) proved that overgrazing, fire, and species invasion greatly damaged local ecosystems in different regions in the United States. In developing countries, faced with problems such as poverty and food shortage, the research direction is mostly to solve social practical problems (Rudel et al., 2015). Distel (2016) evaluated the ecosystem and economic situation under different management modes of pastures in the semi-arid region of central Argentina. Forrest et al. (2016) large-scale removal of landscape-bearing woody plants was urgently needed to promote livestock productivity.

In the transitional development period (2017–2022), the research on grassland productivity (Petrie et al., 2018; Su et al., 2022), ecological protection (Hu et al., 2021), forage management (Guuroh et al., 2018; Arimitsu et al., 2021; Domiciano et al., 2021), anti-risk countermeasures (Fernández-Rodríguez et al., 2018; Davies et al., 2022), and economic benefits (Bilancia et al., 2020; Euclides et al., 2022) related to grassland

TABLE 3 Clustering results of grass-livestock interaction research topics.

Rank	Research topics	Number of the keywords	Average citations score	Average association strength	Top 20 keywords	Keyword clustering
1	Livestock and grassland forage	2,389	21.95	95.77	Cattle, Nitrogen, Growth, Grass, Sheep, Grazing, Grassland, Performance, Pasture, Quality, Soil, Forage, Digestibility, Yield, Nutritive-Value, Dairy-Cows, Carbon, Milk-Production, Chemical-Composition, Pastures	Pasture quality: Growth, Grass, Digestibility, Yield, Nutritive-Value, Nutrients: Nitrogen, Nutritive-Value, Carbon, Chemical-Composition Ranch Management:Cattle, Sheep, Grazing, Performance
2	Vegetation and grassland management	1,336	28.22	84.55	Management, Vegetation, Dynamics, Systems, Biomass, Impacts, Climate-Change, Grasslands, Degradation, Impact, Climate Change, Agriculture, Species Richness, Sustainability, Savanna, Ecosystem, Strategies, Ecosystem Services, Legumes, Variability	Influencing Factors:Vegetation, Biomass, Climate Change, Agriculture, Environmental Assessment:Dynamics, Degradation, Species Richness, Ecosystem Management Protection:Management, Sustainability, Strategies, Ecosystem Services
3	Environmental impact and resource conservation	1,176	25.96	95.76	Livestock, Diversity, Biodiversity, Productivity, Conservation, Responses, Fire, Land-Use, Competition, Rangelands, Patterns, Restoration, Communities, Rangeland, Climate, Selection, Livestock Grazing, Disturbance, Ecology, Behavior	Grazing Behavior:Livestock, Land-Use, Competition, Livestock Grazing, Grazing Patterns:Productivity, Conservation, Responses, Restoration, Ecological Impact:Biodiversity, Fire, Climate, Disturbance
4	Forage characteristics and soil texture	1,065	22.78	55.00	Grasses, Plant, Phosphorus, Tall Fescue, Forage Quality, Perennial Ryegrass, Ryegrass, White Clover, Cultivars, Environment, Persistence, Botanical Composition, Identification, Brachiaria, Ergot Alkaloids, Ergovaline, Nutrient, Crops, Bacteria, Evolution	Plant Species:Grasses, Tall Fescue, Perennial Ryegrass, White Clover, Soil Composition:Phosphorus, Ergot Alkaloids, Ergovaline, Nutrient, Soil Identification:Forage Quality, Environment, Persistence, Identification

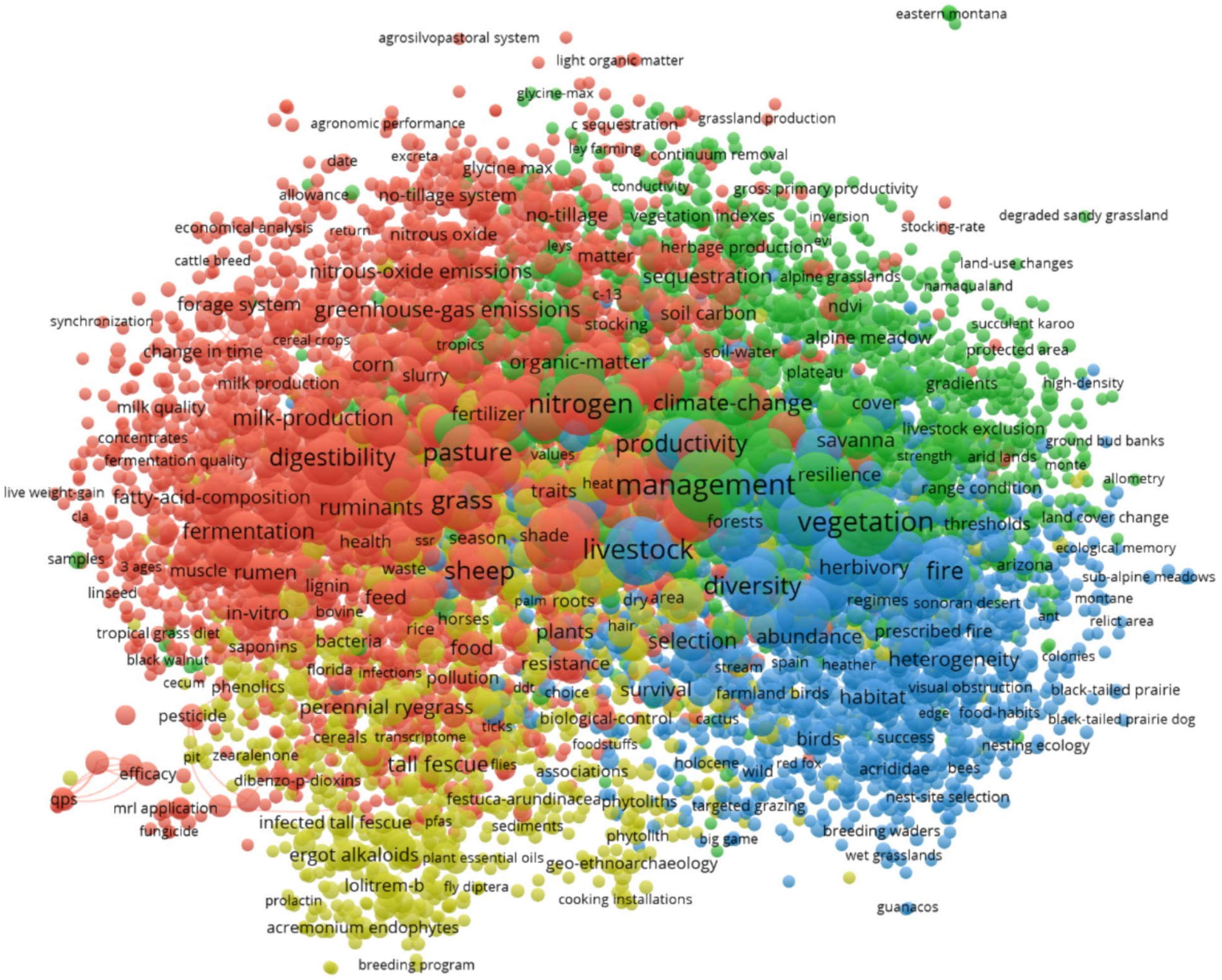

FIGURE 7
Thematic clustering of grass-livestock interaction research from 2000 to 2022.

and livestock interaction has a certain basis (Figures 4–6), and the research method based on interdisciplinary optimization has provided new perspective and brought innovative development to the field of grassland and livestock interaction. In the previous study, Sun et al. (2020) considered grass-livestock-human system as a coupled social ecosystem, and used the theories and methods related to population, resources and environmental economics to explore strategies on the development of the grass-based livestock husbandry (GLiH; Wezel et al., 2020). An et al. (2021) pointed out that forages played a key role in catalyzing transformation to livestock production, and close nutrient loops. Pereira et al. (2022) measured and monitored the conversion and loss of nitrogen in grazing pastures, and proposed a more accurate nitrogen fertilizer scheme that could be developed in pasture livestock systems supplied by tropical perennial grasses.

From the improvement of the basic elements of grass-livestock interaction in the first period (2000–2011), to the improvement of production capacity and ecological protection in the second period (2012–2016), to the deepening and refining of management strategies in the third stage (2017–2022), research priorities of grass-livestock interaction are discrepant in different periods and different countries, therefore it is necessary to stand in a global perspective, integrate resources and superior scientific research forces to work together so as to solve the global common problems in grass-livestock interaction. New ideas and methods are generated in multiple disciplines (Stock and Burton, 2011), and the joint thinking and cooperation of experts in different fields is conducive to the solution of complex problems concerning grass-livestock interaction (Zhang et al., 2023).

In addition, the global ecological environment is complex and diverse, and the key research points on grass-livestock interaction in different countries and regions may change due to different geographical conditions and needs. For example, Brazil has the most biodiverse tropical savanna in the world, and clarifying invasive alien species and protecting the original grassland structure are the key directions on grass-livestock interaction research (Hilario et al., 2017; Guerra et al., 2020) As one of the most fire-prone ecosystems in the world, the destructive effects of fire management on grassland ecosystems in the Australian inland has received extensive attention (Beringer et al., 2015; Andersen, 2021; Santos et al., 2022). The grass-livestock interaction research of a single country lacks a global perspective and cannot form a joint force since different countries/regions emphasize different research directions. In the future, the research on the grass-livestock interaction should strengthen the cooperation and exchange between different regions and different subject areas, maximize the integration and utilization of resources, so that the research results can be disseminated in a wider range and get more comprehensive and objective practical feedback.

4.3 Exploring the standardized method based on remote sensing technology and evaluation index system

In the face of higher precision data analysis and multi-type and multi-scale monitoring needs (Bhattacharjee et al., 2018; Daly and Fenelon, 2018; Kupková et al., 2023), more detailed and analytically robust indicators and evaluation systems are needed for the grass-livestock interaction study. Remote sensing plays an irreplaceable role as an efficient and efficient analysis tool (O'Connell et al., 2016; César de Sá et al., 2022). According to previous studies, the existing evaluation system of grass-livestock interaction mainly focuses on grassland production, livestock composition, management mode, soil environment and economic benefits, supplemented by drought prediction model and environmental factor analysis (Rao et al., 2015; Pereira et al., 2022; Subhashree et al., 2023). In recent years, the development of multispectral, hyperspectral, infrared, radar, cubesats and other sensing technologies has promoted the use of remote sensing technology in the field of grass and livestock interaction (Zhang T, et al., 2022), and achieved good results (Weiss et al., 2020; Tzanidakis et al., 2023). Future research should develop machine learning and deep learning algorithms (Jiang et al., 2022; Munyati and Mashego, 2023), accompanying with UAV remote sensing (UAV-RS; Diaz-Gonzalez et al., 2022), realize automatic processing and classification based on large-scale data sets (Elkind et al., 2019; Pfitzner et al., 2021; Sun Y, et al., 2022), and establish a remote sensing monitoring system integrating space, earth and space to improve the efficiency and accuracy of data analysis.

Remote sensing technology can cover a large area and obtain more comprehensive image information (Shafique et al., 2022; Wang et al., 2022), including the monitoring of important indicators affecting grass and livestock interaction such as vegetation cover (Hijmans et al., 2005), water content (Hansen et al., 2013) and soil quality (Hersbach et al., 2020), which can capture changes in a short period of time, conduct temporal monitoring of different times and seasons, and track their change trends (Lu and Weng, 2007). It provides an efficient tool for monitoring and managing grazing (Wolf et al., 2021), studying grassland degradation (Tasumi et al., 2014; Hunter et al., 2020), estimating biomass (Ali et al., 2014), and estimating climate change (Cao et al., 2022). In the research of grass-livestock interaction, Dusseux et al. (2015) introduced PaturMata model to evaluate consequences of current environmental changes on grasslands. Zhang et al. (Zhang et al.) established grass production random forest estimation model using the CACART decision tree to evaluate total yield result and the grassland load pressure. However, the existing remote sensing observation technology is still not perfect, mainly spectral images, overlap and occlusion between leaves, different lighting conditions and different growth stages, easy to cause inaccurate monitoring data, coupled with environmental, atmospheric conditions, phenological period and other factors caused by spectral variability, so that the application scenario is limited (Huang et al., 2023). The selection indexes of remote sensing monitoring for grassland, such as coverage, height, biomass and soil organic matter, are not uniform (Zhu et al., 2021) due to different monitoring indicators, reference basis, and selection of research areas and there is a lack of systematic combing of remote sensing monitoring analysis indicators and analysis methods (Sun X, et al., 2022; Zhu et al., 2022).

4.4 Grassland sustainability and grazing control are the key research directions of grass-livestock interaction

Grassland sustainability is of great significance in addressing climate crisis (Lei et al., 2016; Abhilash, 2021), enhancing food security (Meli et al., 2023), protecting biodiversity (Fick and Evett, 2018; Yang et al., 2021), maintaining water cycle and carbon sequestration (Overbeck et al., 2015; Török et al., 2021). In response to climate change, with the rise of temperature and the change of precipitation pattern, grassland may face the threat of drought and water shortage (Öztürk and Sen, 2022). Studies such as Wang M, et al. (2023) show that nitrogen deposition, warming and precipitation can change regional vegetation composition, improve grassland productivity, and increase grassland carbon sequestration capacity. To evaluate the productivity of livestock production, a comprehensive consideration should be given to market demand, feeding methods, processing technology and other factors. Lopez et al. (2024) believed that the human feeding system was helpful to avoid overgrazing and promote the regeneration of natural plants, and the adoption of grass feeding can help improve the quality of mutton. Human activities have a huge impact on grassland ecology (Chu et al., 2022; Evans et al., 2023). For example, animal husbandry is the most important economic activity in tropical Mexico, however, grassland has been seriously degraded, and at least 24 states have exceeded grassland carrying capacity due to poor management and continuous expansion of factory agriculture (Quiroz et al., 2021). At the policy and management level, the optimization of management strategies has a positive effect on restoring grassland degradation (Hu et al., 2019; Laitinen et al., 2022; Tao et al., 2022; Dang et al., 2023). Hou et al. (2023) discussed the impact of land tenure reform on grassland quality in China's pastoral areas based on remote sensing survey data of nearly 40 years, and found that grassland quality increased by about 3% after the privatization of land use rights, but it was still necessary to provide policy support related to environmental safety and environmental protection to expand its positive impact. Furthermore, many countries in the world still need to establish reasonable land management policies and land ownership systems (Achieng et al., 2023), and the allocation of grassland use rights is crucial to protect grassland ecology and maintain grassland sustainability (Barcus, 2018), which is a key issue to ensure the long-term health of grassland ecosystem (Liu et al., 2020; Mangialardo and Micelli, 2021).

Grazing is the most important usage of grassland, and it is the crucial issue to future research on ecological grassland husbandry to clarify the interaction process of grass and livestock under grazing interference and the cooperative regulation mechanism of above and below ground (Tittonell, 2021). How to determine the appropriate grazing density, grazing cycle and grazing area is the main problem in formulating a rational grazing strategy (Hempson et al., 2015). Song et al. (2020) address that free-range grazing is more beneficial to the diversity of intestinal microbiota, and this index can be used as an important marker to improve the evaluation of different grazing management methods. Luo et al. (2023) discover that grassland health assessment is a bridge for grassland ecosystem research, and monitoring and assessment are key components of grazing control (Wang et al., 2022). The health status of grassland can

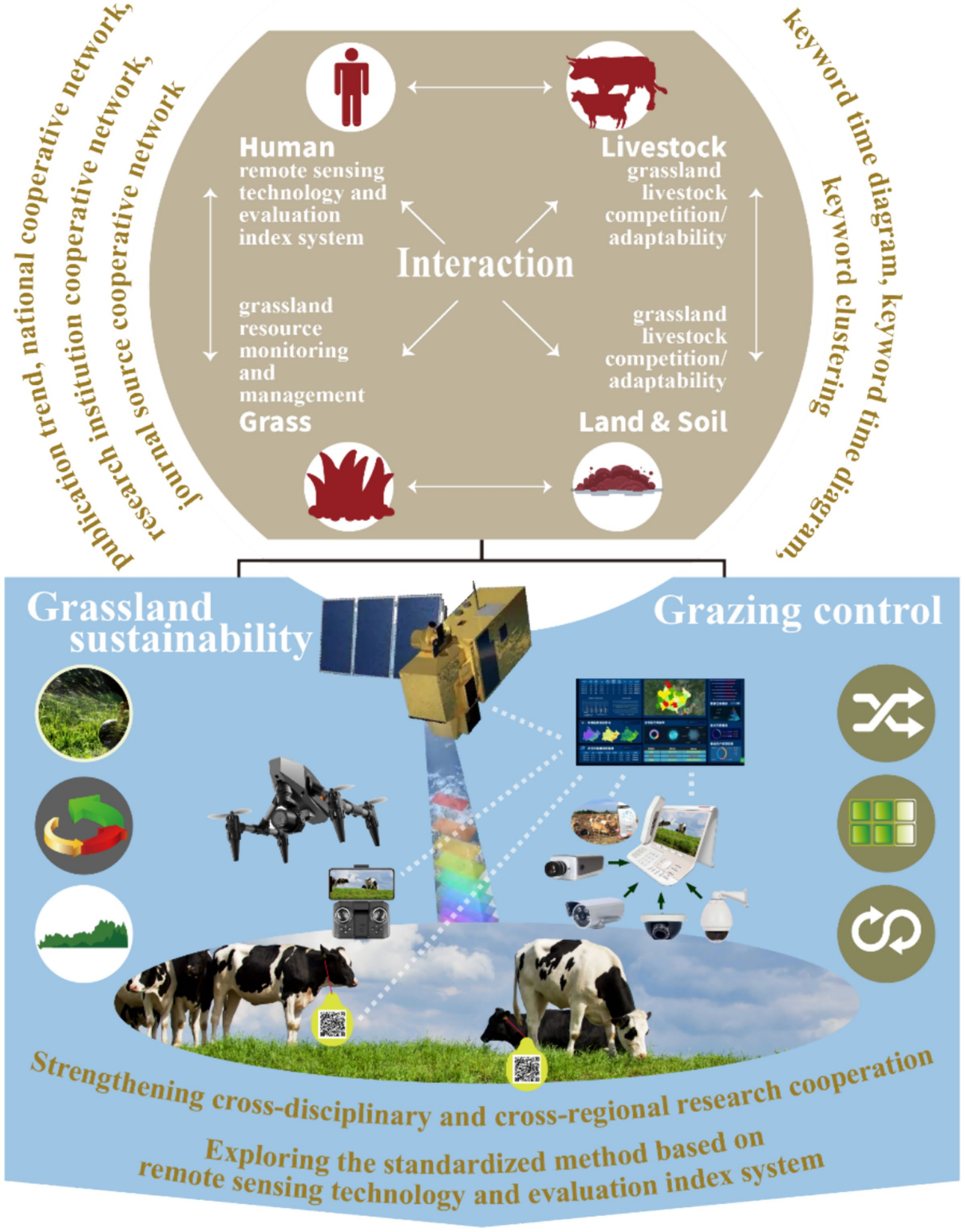

FIGURE 8
Future research themes and directions of grass-livestock interaction based on four broad divisions including (1) mechanism of human activities, (2) grassland resource monitoring and management, (3) grassland livestock competition/adaptability, (4) grassland land/soil research.

be monitored in real time through remote sensing and geographic information system, which helps to timely adjust grazing strategies in response to different meteorological conditions and ecological changes (de Faccio Carvalho et al., 2021; Machado et al., 2021). A comprehensive review of several studies found that long-term exclusion of grazing could not effectively alleviate grassland degradation, but would lead to a decline in grassland productivity and biodiversity (Zhao and Rokpelnis, 2016). Reasonable grazing system, grazing intensity and timing, and sustainable grazing management can promote the health of grassland ecosystem and maintain grassland ecosystem services (Ding et al., 2020; Kim et al., 2023).

Grass-livestock interaction is a crucial component of grassland ecosystem (Li et al., 2013; Shen et al., 2022), grassland sustainability and grazing control will be the key research directions of grass-livestock interaction in the near future (Figure 8). Ecological, economic, and social factors should be comprehensively considered to ensure the long-term health of grassland ecosystem and the coordinated and sustainable development of animal husbandry (Chu et al., 2022). Future research should integrate advanced science and technology, especially remote sensing technology and machine learning, to improve the efficiency and accuracy of data acquisition (Lutta et al., 2020; Casenave et al., 2022; Hu et al., 2022). Global information on grassland and rangeland resources, establish a more comprehensive indicator system (Toscan et al., 2017; Qiu et al., 2020; Gray et al., 2022), should be conformity and cooperate with the optimization of management policies to provide effective ecosystem assessment and meet the socio-economic needs of sustainable development.

5 Conclusion

This study examined research progress of grass-livestock interaction and identified major actors and contributors to grass-livestock interaction research using bibliometrics based on 5,505 literatures during 2000 to 2022, and the application of remote sensing technology in grass-livestock interaction research was put forward for future studies. The main findings of this article are as follows:

The annual number of publications in the grass-livestock interaction field showed a worldwide increasing and interdisciplinary integration trend with the research scale gradually expanded. The research targeting the grass-livestock interaction mainly went through three stages: initial exploration period (2000–2011) treated Management, Cattle, Vegetation, Livestock, Grazing as the primary keywords, to the period of rapid development (2012–2016) mainly by Management, Livestock, Vegetation, Cattle, Grassland, to transitional development period (2017–2022) treated Management, Livestock, Cattle, Vegetation, Growth as the primary keywords. In terms of the temporal evolution, it can be found that Management, Livestock, Cattle, Vegetation, Growth, Soil have always existed by comparing the top 30 groups of keywords related to grass-livestock interaction in the three periods. In terms of the structural composition, the research mainly identified four broad divisions including the mechanism of human activities, grassland resource monitoring and management, grassland livestock competition/adaptability, grassland land/soil research. Furthermore, grassland sustainability and grazing control have been the focus of attention in the near future, and a more comprehensive standardized evaluation system for grassland and livestock interaction should be established through strengthening cooperative research and promoting the application of remote sensing technology, which provide more scientific, precise and sustainable solutions for global grassland management and livestock production.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

XZ: Writing – original draft, Writing – review & editing. DT: Writing – original draft, Writing – review & editing. YL: Writing – review & editing. CS: Writing – review & editing. RY: Writing – review & editing. WZ: Writing – review & editing. XX: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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