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Review

Structure and Stability of Agroforestry Ecosystems: Insights into the Improvement of Service Supply Capacity of Agroforestry Ecosystems under the Karst Rocky Desertification Control

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Abstract: Agroforestry provides essential ecosystem services; its structure and stability directly determine ecosystem function and service provision. Sustaining agroforestry ecosystem functions and services in the long term is necessary to meet the needs of people. This study conducted a literature search and statistical analysis based on WOS and CNKI literature databases. We reviewed 136 literature reports on studies of agroforestry ecosystem structure and stability. The landmark results are summarized in five aspects of agroforestry ecosystems: structure characteristics, structure optimization, structure design, stability research, and influence factors. On this basis, the key scientific issues that need to be solved are summarized, and their insights for improving the supply capacity of agroforestry ecosystem services under the rocky desertification control are discussed.

Keywords: agroforestry; ecosystem; structure; stability; progress; insights; rocky desertification control

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1. Introduction

As the process of intensifying agricultural production activities develops, it causes continuous land degradation and the gradual loss of essential ecosystem services, which calls for the adoption of sustainable farming systems that balance production activities and improve ecology [1,2]. Agroforestry practice combines perennial woody plants with crops or livestock, arranged in chronological and spatial order [3–5]. Recently, agroforestry ecosystem services have gradually become a research hotspot [6]. Some studies point to trade-offs and synergies between the ecosystem services they provide, which often depend on the structure of the agroforestry ecosystem and its multifunctional role [7]. It has been shown that a rational agroforestry ecosystem structure provides material products such as food, herbs, and timber and a variety of ecological services such as soil and water retention, pest and disease control, and seed dispersal pollination and biodiversity conservation [8–11]. Thus, for agroforestry, the ecosystem structure plays a non-negligible role in maintaining and supplying ecosystem services.

An agroforestry ecosystem structure is composed of the elements of the system (such as woody plants, crops, livestock breeding, etc.) in space and time according to the properties of each species, using a certain distance and hierarchical arrangement, which contains the species structure, space and time structure, and nutrient structure (food chain structure) [4,5,12]. A reasonable agroforestry ecosystem structure is one of the main ways to improve the ecosystem environment and enhance its sustainability and resilience, as crop rotation in the temporal structure can reduce pest infestation, mitigate competition, reduce disease, and improve soil fertility and crop productivity [7]. In essence, the structure of the agroforestry ecosystem can play an important role, which largely depends on the selection of species, planting time, planting density, and spatial location [13]. The benefits provided by the agroforestry ecosystem have been shown to depend on the structural characteristics [14]. Additionally, optimizing the structure of the agroforestry ecosystem to maintain and improve the provision of ecosystem services will enable land users to choose the best species allocation and appropriate time gain distribution, whether it is to help smallholder farmer groups improve and upgrade farming techniques or improve land productivity restoration in ecologically fragile areas [15,16]. These all-highlight agroforestry characteristics that combine production activities and ecological protection. Therefore, deepening the understanding of the structure of the agroforestry ecosystem will be beneficial in improving the benefit of the agroforestry ecosystem for the maximum optimal design [17,18].

Karst landscapes are widely distributed worldwide and account for 15% of the overall land area in the world [19]. Under unreasonable human development activities, its typical fragile ecological background makes rocky desertification a significant ecological degradation problem in global karst areas [20–23]. The primary manifestation is unreasonable human interference, which destroys surface vegetation and causes severe soil erosion, extensive bedrock exposure, and gradual degradation of the land to form a desert landscape [24–26]. This area is weak disaster resistance and low environmental capacity greatly restricts land use and economic development and threatens ecological security [27,28]. To reduce the rate of land degradation and promote environmental and economic development, the Chinese government launched a national comprehensive rocky desertification control and reforestation program at the end of the 20th century [29]; some scholars then proposed involving agroforestry as one of the ecological restoration solutions in rocky desertification control [30,31]. This idea has attracted much attention and has been adopted by researchers [32,33]. After years of control, the development of agroforestry under rocky desertification areas can maximize its soil and water conservation benefits [16,34] and has a positive role in improving the productivity of rocky decertified land and maintaining soil faunal diversity [35,36]. This highlights the broad prospects for agroforestry development in rocky desertification areas. It also promotes the study of single ecosystem services of agroforestry under the rocky desertification control areas, for example, the effect of rose (Rosa rugosa) agroforestry systems on soil fauna community structure [37], the characteristics and influencing factors of soil water infiltration in several agroforestry systems [38], and the energy value of different agroforestry systems [39]. However, little is known from current research about the ability to supply agroforestry ecosystem services in the later stages of rock desertification control. The study on the structure and stability of agroforestry ecosystem is related to the improvement of the service supply capacity of agroforestry ecosystem under the control of rocky desertification, but there are few relevant studies at present. Therefore, it is necessary to review agroforestry structure and stability research progress. It is crucial to explore how to improve the supply capacity of agroforestry ecosystem services under rock desertification control.

Recently, studies have been conducted on the quantitative analysis of structural characteristics [40–43], structural optimization design [1,2,44], stability studies [45,46], and analysis of influencing factors [47]. Groundbreaking work has been carried out to explore the functions and services of agroforestry ecosystem maintenance. The vulnerability risk of agroforestry ecosystems is caused by the two-way drive of frequent extreme climate events and unreasonable human activities [48,49]. This, in turn, causes changes in biodiversity that directly affect ecosystem function [50]. In this context, the ability of agroforestry ecosystems to maintain operations and services in the long term, their structure, and their stability are the most significant fundamental factors; a review and commentary on the urgent need to strengthen research in these areas are needed. Therefore, based on bibliometric statistics, this paper systematically reviews the search progress and landmark results on the structure and stability of global agroforestry ecosystems and discusses the key scientific issues that need to be addressed, aiming to provide insight into the structure and stability of agroforestry ecosystems under rocky desertification control and to promote the improvement of the supply capacity of agroforestry ecological services in this region.

2. Methods

The systematic review of scientific information provided by databases has been applied to various research areas [51], such as environmental protection and management [52]. This approach has the advantage of transparency, robustness, independence, and comprehensiveness, mainly through the analysis of previous rigorous studies. This helps develop new research perspectives [53]. The focus is on scientific information provided through existing works that apply to the study of the structure and stability of agroforestry ecosystems; our approach comprised four main steps: identification, screening, qualification, and inclusion [54]. The details are illustrated in (Figure 1) below.

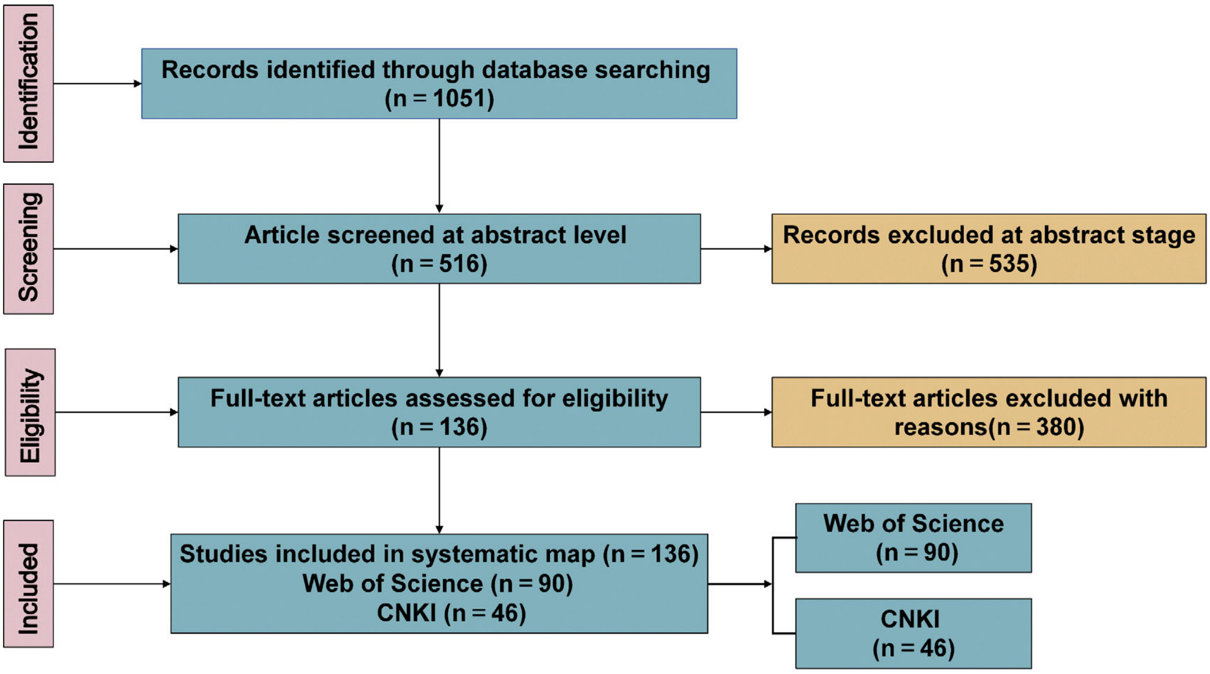

Figure 1. The study's systematic mapping process illustrates articles from the initial search to screening for synthesis (identification, screening, eligibility, and inclusion). Papers were found through a database search at the identification stage. Then, the articles captured were screened based on the categories of agroforestry structure, agroforestry ecosystem structure concept, characteristics, design principles, optimization strategies, influencing factors, and agroforestry stability (through titles, keywords, abstracts, and full-text articles) at the screening and eligibility stages. Finally, the articles satisfying the eligibility criteria were included in the study.

2.1. Literature Acquisition Sources

To comprehensively explore the status of research on the structure and stability of agroforestry ecosystems at home and abroad, this study consulted two core databases, the Web of Science and CNKI (China National Knowledge Internet). The international literature was primarily from the WOS core database, and the Chinese literature was mainly from the CNKI core database (Table 1). This search process was as follows.

The first search was conducted by entering "ecosystem structure" and "ecosystem stability" in the WOS database, and the second search was conducted by entering "agroforestry", resulting in 964 documents in English.

Secondly, we searched the CNKI database by entering "agroforestry structure", "agroforestry complex management structure", "agroforestry complex system structure" "agroforestry stability", and "agroforestry complex management stability" and "agroforestry complex system stability" and retrieved a total of 87 Chinese papers.

Table 1. Literature search strings.

Database	Retrieval String	Number	Search Date
WOS	First search string: "Ecosystem structure"; second search string: "agroforestry"	825	30 December 2021
	First search string: "Ecosystem stability"; second search string: "agroforestry"	139	30 December 2021
CNKI	"agroforestry structure"	10	30 December 2021
	"agroforestry complex management structure"	18	30 December 2021
	"agroforestry complex system structure"	18	30 December 2021
	"agroforestry stability"	7	30 December 2021
	"agroforestry complex management stability"	31	30 December 2021
	"agroforestry complex system stability"	3	30 December 2021
Total		1051	30 December 2021

Note that the data here include comments and original articles in all languages.

The total number of documents obtained from the initial search after excluding duplicate items for both was 1051. The search timeframe for both databases was the maximum time frame of the databases, and the search deadline was 30 December 2021.

Finally, based on the related research topics of agroforestry ecosystem structure and stability, the titles, abstracts, and keywords of the articles were initially reviewed, and on this basis, the research contents on agroforestry ecosystem structure, such as structural characteristics, structural optimization, and structural design, were explicitly reviewed; in addition, the literature on stability research was also reviewed for stability concepts, research methods, stability evaluation indexes, and enhancement strategies. Finally, the alternative literature was browsed in full text, and a total of 136 (see Supplementary Materials Table S1) papers were obtained for the textual review after eliminating duplicate items.

2.2. Literature Selection Criteria

Strictly following the procedures of the systematic review of the literature, 1051 documents from the initial search were manually screened through two stages. Both are based on the time of publication in the database, with different screening criteria for each step. The first screening mainly reviewed the studies' titles, abstracts, and keywords, retaining those related to the research topic for full-text review. Re-screening, reading through the entire text, and screening for research covering at least one description of agroforestry ecosystem structures was carried out. Most of the selected articles were excluded due to irrelevance, and the final number of pieces was reduced to 136.

3. Results

To explore the research progress and landmark results concerning agroforestry ecosystem structure and stability, to better enlighten the supply capacity of agroforestry ecosystem services under rocky desertification control, we conducted a statistical analysis of the 136 acquired papers by year, research content division, and research countries and institutions, and discussed the research progress and landmark results.

3.1. Annual Distribution of Literature

As shown in Figure 2, the analysis of the 136 obtained papers was divided into the annual distribution of agroforestry ecosystem structure and stability. Firstly, the number of articles published, and the growth trend of agroforestry ecosystem structure research were higher than those for agroforestry ecosystem stability; secondly, based on the total number of articles published, there were more papers related to agroforestry ecosystem structure, while the research reports on stability were relatively scarce; finally, from the overall development, the research on agroforestry ecosystem stability appeared later than that of the system structure.

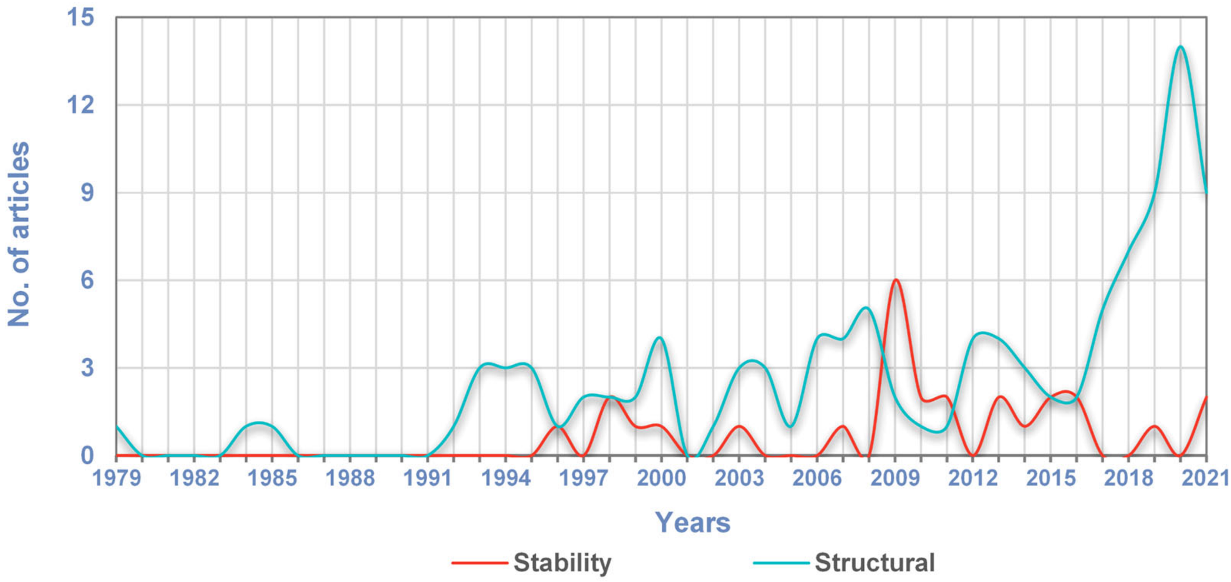

Figure 2. Trend in the annual distribution of literature related to the structure and stability of agroforestry ecosystems.

3.2. Classification of Literature Research Content

As shown in Figure 3, after studying the 136 different research papers, we divided the literature into five sections around the main research content, as follows: the characteristics of agroforestry ecosystem structure, optimization of agroforestry ecosystem structures, design of agroforestry ecosystem structures, the study of agroforestry ecosystem stability, and influencing factors. Firstly, we summarized the species composition and their quantitative relationships, vertical stratification, and horizontal mosaic as the structural characteristics of agroforestry ecosystems based on the research results of Nair [4] and Li et al. [5]. Secondly, studies that combine biology or engineering, biological or chemical control, forestry or agriculture, and conventional or modern measures to adjust and enhance the tools according to the changes in the structure of agroforestry ecosystems and coordinate the relationship between the various product categories are classified as structural optimal regulation [55,56]. Again, the research literature that combines ecological theory with the need to match plantings in time and space in a certain ratio according to the properties of the selected species is summarized as structural design. Following this, the research literature on the stability of agroforestry ecosystem associations, structural stability, and functional stability is grouped into stability studies. Finally, the literature exploring the factors influencing the structure and stability of agroforestry ecosystems is collectively categorized as influencing factors. Therefore, the 136 papers were divided into five sections according to the main research area. The research progress and landmark results are discussed in Sections 3.3.1–3.3.5.

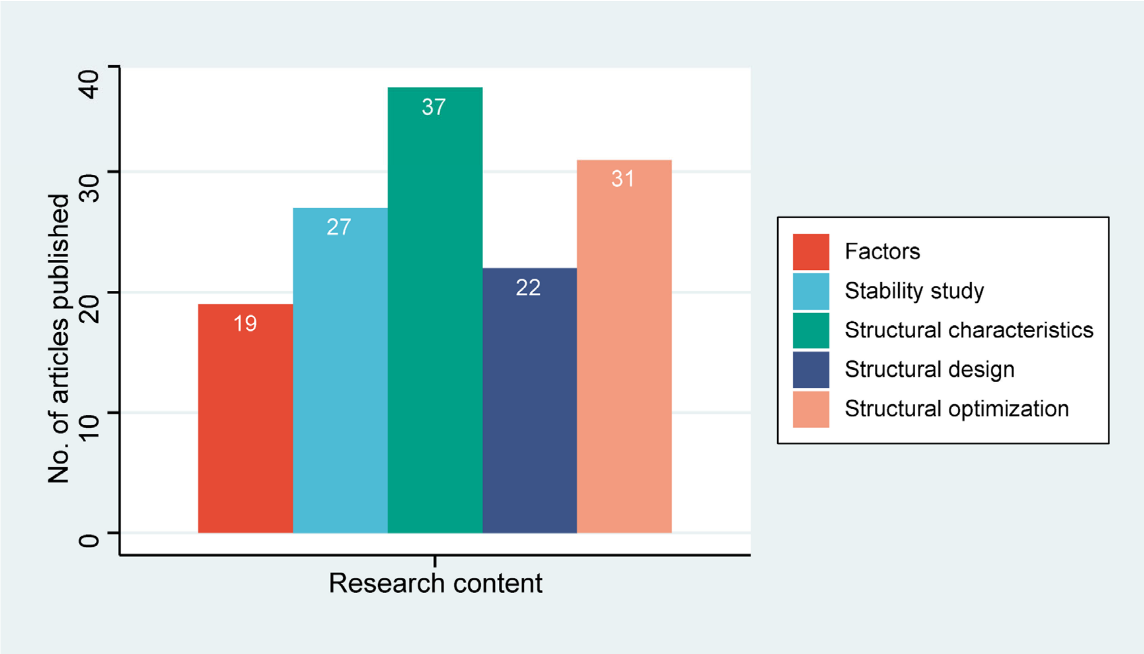

Figure 3. Research content division.

3.3. Research Progress and Landmark Results

Identifying and quantifying the structural characteristics of agroecosystems is a prerequisite for achieving improved ecosystem service provisioning capacity. The optimal and innovative design of the agroforestry system structure is necessary to improve its service supply capacity. Stability is an essential guarantee for the long-term maintenance of agroforestry ecosystem services. Therefore, based on the above delineation of the research content, we conducted a systematic review of relevant research progress and landmark results on the structure and stability of agroforestry ecosystems to improve the research systems in these areas.

3.3.1. Structural Characteristics

The structural characteristics of agroforestry ecosystems consisting of the composition of species and their quantitative relationships in species structure, stratification in vertical format, and mosaic in the horizontal form are the focus of the current exploration of structural characteristics. Firstly, as far as species structure is concerned, the structural differences in agroforestry ecosystems due to changes in species composition and planting density directly determine the supply of ecosystem services, thus affecting the range of benefits available to farmers [57,58]. Secondly, in terms of the vertical structure of stratification, the three-dimensional hierarchy of components on the ground, underground, and water can better use natural resources such as light, heat, water, and soil, leading to ecological and economic benefits [59]. Horizontal structural mosaics such as strips and clusters have an excellent planting density and planting environment that can better contribute to the supply of ecosystem services. Proper structural characteristics of agroforestry ecosystems have better service provisioning capacity, such as improving pollination, stabilizing yields, extending land use duration, controlling pests and diseases, increasing biodiversity, mitigating climate change, and maintaining soil and water, among others [60,61]. However, with the gradual renewal and succession of species in the development process, the lack of human scientific management, for example, pruning and other dwarfing as well as dense planting techniques, leads to unreasonable planting density and hierarchical structure, which affects plant growth space and nutrient acquisition, thus affecting the ecosystem service capacity [62,63]. Therefore, a better understanding of the structural characteristics of agroforestry ecosystems is vital for the supply of system services.

As research grows and expands, a large body of literature has reported discussions around species structure in agroforestry ecosystems [64,65]. Especially in the tropics, cocoa and coffee agroforestry ecosystems' species composition and diversity have received more attention [66–68]. Researchers investigated the tree species compositions and their uses and quantified the importance values of the constituent species. The use of species diversity and farmers' willingness to cultivate illustrates the value of timely and appropriate adjustments in the species composition of agroforestry ecosystems to conserve local biodiversity, sustain farmers' livelihoods, and provide multi-species habitats [40,69,70]. This includes essential information on vegetation structure, diversity, composition, and management practices of agroforestry ecosystems [71]. However, fundamentally, the differences in the scope and subjects chosen by the researchers quickly lead to variability in the findings; most studies are in the qualitative description stage [72], and similar results can be extended to other types of agroforestry ecosystem studies remain to be verified.

The study of agroforestry ecosystem structure requires a focus on both its horizontal and vertical development, including assessing the stand structure in terms of horizontal and vertical structure [73]. Stand attributes and their complexity define stand structure. Researchers have used spatial distribution patterns to explore stand structure and divide it into stand non-spatial and spatial structures [74,75]. The spatial structure factors of the frame are refined into species composition, diameter at breast height, tree height, stand age, and distribution. In particular, species design determines the type of agroforestry structure and biodiversity. This is an adequate basis for management and coordinated management, and research on this factor has focused on both species' description and biodiversity [57,73]. The age of a stand is a reflection of the renewal process and the rate of renewal and is also closely related to the distribution, height, diameter at breast height, growth, and seedling renewal of the stand. When evaluating the quality of stand conditions, tree height is generally used as an essential reference index, and the method is to analyze and evaluate the quality of the stand using the relationship between the average height of the dominant trees in the stand and the age of the stand. Therefore, as an essential part of the ecosystem, tree height and diameter at breast height are critical characteristic factors. It is crucial to study the distribution of tree height and diameter at breast height to establish the diameter order of tree growth in agroforestry and the storage volume and timber volume of forest trees and to provide a theoretical basis for the management of agroforestry in the cultivation interval [76–78]. The spatial structure of forest stands is mainly described by parameters such as the spatial distribution pattern of trees, competition index, mixing degree, angular scale, and stand index [72]. The patterns exhibited by these stand structure factors determine the function of agroforestry ecosystems to help quantify the complexity of the relationships between the biotic and abiotic components of their systems and the mechanisms of their interactions [73] and ensure rational decision making in selecting and optimizing agroforestry ecosystem structures and their service capacity enhancement.

3.3.2. Structural Optimization

Optimized structural means with a combination of biology and engineering, physical and chemical control, forestry and agriculture, and conventional and modern measures are adjusted and enhanced with changes in the structure of agriculture and forestry, coordinating the relationship between production and the overall benefits of agroforestry [55,56]. This is essential for the livelihood of farmers and the sustainable development of the regional economy and is also reflected in the crucial role of structural optimization participation in the production of natural resources and management of environmental services. In recent years, agroforestry ecosystem structures have been simplified, as farmers believe that cutting down trees will help increase yields and reduce disease incidence. However, according to available studies, logging does not necessarily increase production and limits the ability to provide goods, cultural services, biodiversity conservation, and ecosystem functioning [76,79]. The reduction in tree density and diversity does not significantly affect yield and does not affect disease incidence, as confirmed in [80]. Therefore, implementing appropriate techniques for the scientific management of agroforestry ecosystem structures is crucial in improving the services and overall quality.

In the 1980s, many experts and scholars at home and abroad summarized the general structural patterns of agroforestry. They pointed out that structural optimization is a vital issue in developing agroforestry ecosystems [4,5]. In recent years, advanced mathematical and technical tools have been applied by more and more researchers to the study of the structural optimization of agroforestry ecosystems. The systematicity, scientificity, and feasibility of structural optimization have been verified [56,81]. For example, adjusting the planting ratio of crops, forestry, and fodder crops; determining the appropriate planting and breeding scale; improving farm animal species and optimizing production links; integrating agroforestry ecosystem management strategies to incorporate agricultural resources; achieving a suitable configuration of the industrial structure of agriculture, forestry, and animal husbandry as well as the cycle of the breeding and processing industrial chain; and maximizing economic benefits [82–84]. In general, the optimization of agroforestry ecosystem structures is mainly divided into species allocation and agronomic management aspects.

In terms of species configuration, the combination of slow- and fast-growing, deep- and shallow-rooted, light- and shade-loving, rhizomatous and non-rhizomatous trees and crops [85] is mainly used to make full use of the adaptability of species' attribute characteristics to the environment. In agronomic management, the most common practices are tree pruning, dwarfing, and dense planting, but these practices may impact seed production [86]. Therefore, researchers have reverted to another strategy to exploit the shaded part of the tree, such as planting shade-tolerant crops under the tree. In contrast, light-demanding crops are grown outside the shaded area and are used in many agroforestry plantations. This strategy enables farmers to make the most of their space, benefiting from the trees planted and eliminating the need to provide shade to the plants by other means [87,88]. In addition to this, it has also been noted that understocking may also have a positive impact on stand growth, i.e., by reducing the allocation of soil water using trees; thinning of the stand can lead to increased tree growth, which can provide better growing conditions for understory vegetation [89]. This is a method of improving the quality of remaining stands on a sustainable basis by removing slow-growing, damaged, or unhealthy trees. Consequently, scientific thinning is considered an important and effective way to manage the growth and yield of agroforestry [90].

3.3.3. Structural Design

To gather the essential information for the innovative structural design of agroforestry systems that meet farmers' livelihood and ecological needs, we focus on the adaptation and use-value of species in agroforestry ecosystems to optimize the structural design. This initiative will help to maximize agroforestry ecosystem functions and enhance service capacity [91].

In terms of species adaptability and their use values, some scholars have approached the issue of the relationship between the reasonable spatial allocation of trees and their understory crop growth from the perspective of individual or group shading effects [92,93]. This type of research is highly accepted and adopted by many researchers. Empirical studies have proven that this structural design can better enable the selected species to use natural resources such as light, heat, and water according to their properties, which better contributes to the realization of the ecosystem service value [59,94,95]. In particular, it is widely used in the structural design of cocoa agroforestry ecosystems. For example, cocoa trees are planted under shade trees in many countries worldwide to reduce pests and diseases and increase cocoa production [96,97]. However, the diversity of crop species produces a variety of phonological, morphological, and physiological characteristics, and the combination of these characteristics affects the ecological functions created by agroforestry through facilitative or competitive effects [98]. Thus, a good structural design is needed to maintain agroforestry ecosystem service capacity [17].

In terms of technology application, Xiong et al. [99] used mathematical tools and technical tools to quantify the design of agroforestry ecosystem structures, taking the design of agroforestry structures as a critical issue. Such general mathematical methods and specialized tools may produce different results when targeting other research subjects, making it challenging to ensure the operability of the study and the accuracy of the results; in addition, there is the added difficulty of conducting experimental work that is too expensive and time-consuming to carry out on a large scale in the long term [100,101]. Furthermore, farmers' wealth characteristics, household size, tree species selection preferences, and management strategies influence the design of agroforestry ecosystem structures [102,103], e.g., poor households prefer to grow more economically efficient crops and care more about stable yields and economic returns to meet livelihood needs while ignoring ecological and social benefits [44]. Because of this, a participatory approach provides an idea to resolve the above contradictions by combining the overall performance of agroforestry ecosystems with farmers' living conditions for holistic improvement to promote species diversity and rational spatial allocation.

3.3.4. Stability Study

The production model of agroforestry had a long history before becoming a separate discipline. International research on agroforestry ecosystems has gradually increased [104]. In the current international situation, sustainable development occupies an important place in the international arena and has become a topic of global concern. Agroforestry ecosystems have natural advantages over other systems in stability and sustainability. On the one hand, intensive agroecosystems are one of the leading causes of global biodiversity loss [105]. On the other hand, a growing body of ecological research proves that biodiversity confers ecosystem stability and enhances system productivity by buffering natural and anthropogenic disturbances [106,107]. Agroforestry ecosystems increase biodiversity [108]; this compensates for the problems that agricultural production create for the ecosystem. Conway in 1987 proposed several fundamental properties of agroforestry ecosystems: productivity stability, sustainability, and equilibrium. Of these, productivity reflects the efficiency of the material cycle of the whole ecosystem. In contrast, strength, persistence, and balance can reflect the entire system's regulatory capacity and reflect the information flow aspect of the whole system [45]. However, according to the literature search results, the research on agroforestry ecosystem stability is less reported, mainly in the following aspects.

Firstly, the fundamental theories of agroforestry ecosystem concept definition and connotation expression are not specific. Only Hu et al. [12] mentions that the stability of such an ecosystem has both commonality and individuality when classifying the agroforestry ecosystem as an artificial ecosystem. No specific concept or connotation expression has been offered to date. Secondly, the establishment of the index system, due to the complexity and geographical characteristics of agroforestry ecosystems themselves, brings challenges to establishing a unified evaluation index system. Among them, Yuan et al. [109] and Yu [45], using correlation stability theory, combined differential equation models to establish an evaluation index system of agroforestry ecosystem stability composed of agroforestry pastoralism, resulting in the stability status and sustainable development level of agroforestry ecosystems. However, the evaluation index system based on such mathematical methods may not necessarily apply on a large scale due to the variability and spatial heterogeneity of the study area and the study scale range. In addition, in terms of stability enhancement strategies, the adoption of cultivation management measures to improve ground strength is mainly a mechanism for maintaining stability through human regulation, for example, considering forest density in conjunction with a horizontal structure and thus creating pioneer species to increase species diversity; clearing insect-infested trees, uprooting, screening, and breeding highly insect-resistant forest strains; pruning, nurturing, truncating, and sanitary-felling [110–112]. Although studies have confirmed that human regulation of stability maintenance mechanisms has been effective, it is worth noting that species competition, access to market information, and how to master the inputs of artificially assisted energy at this stage are crucial in maintaining the agroforestry ecosystem stability.

3.3.5. Influencing Factors

In terms of factors influencing the structure of agroforestry ecosystems, numerous studies have confirmed that the structural configuration and development of agroforestry ecosystems are more limited by abiotic factors, such as climate, geographical distance, altitude and slope, and different stand conditions changes, leading to a decrease in species composition and diversity and stand density. Species richness reduces the overall agroforestry ecosystem service provisioning capacity [41,113,114]. In addition, some scholars have emphasized human activities, such as the habits and management practices of farmers, i.e., a preference for tree species and crops with high yields, higher economic returns, and continuous cultivation for long periods [115]. Farmers are more concerned about the economic benefits than the ecological and social benefits, so the incentive to adopt agroforestry practices can be somewhat limited. Most of the above studies are on abiotic factors and human activities, while biotic factors are more sparsely explored.

In terms of factors affecting the stability of agroforestry ecosystems, the relationship between biotic and abiotic interactions is one of the key influencing factors. In general, the more complex the structure of a natural ecosystem, the more stable the ecosystem. Still, a more complex structure in agroforestry ecosystems does not necessarily mean that the system is more stable. It is worth noting that competition is often a key factor affecting stability [116–118]. It has been demonstrated that plant species with similar ecological niches in agroforestry ecosystems share the same resources. Interspecific competition for resources occurs when resources are insufficient, such as competition between forest trees and crops for living space, light, nutrients, and water [47]. However, the current understanding of interspecific relationships in agroforestry ecosystems is based on conclusions drawn from studies of specific systems. Further in-depth studies are needed to determine whether these conclusions apply to other agroforestry ecosystems under different stand conditions. Therefore, it is crucial to study the influencing factors of the agroforestry ecosystem, establish a perfect structure of the agroforestry ecosystem, and maintain the system's stability [119,120].

4. Discussion

This paper systematically reviews the progress of research on agroforestry ecosystem structure. Through an overview of the volume and temporal distribution of relevant literature and the global distribution of research regions and institutions, the results highlight the gaps and limitations of previous work on the structure and stability of agroforestry ecosystems, focusing on the classification description of structural features, structural optimization, structural design, and influencing factors. In addition, stability studies are fewer in number, and few studies have reported the link between structure and stability. In the following sections, we will explore these gaps and limitations.

4.1. Structure and Stability of the Variability of the Annual Volume of Articles Issued

First of all, the increasing trend shows that more publications focus on structure than on stability. Therefore, strengthening the study of agroforestry ecosystem stability and discussing the intrinsic link between structure and stability in agroforestry research would be a valuable research topic, as it is crucial for maintaining the ecosystem services of agroforestry ecosystems. Secondly, the study of agroforestry ecosystem structures started earlier than stability-related research. Agroforestry-related research has been involved in and accounts for 66.18% of the total number of articles issued; however, a systematic theory has not yet been formed, showing that the development of theory and practice is not synchronized, and theory often lags behind practice. In terms of stability, there are relatively few studies on the stability of agroforestry ecosystems, accounting for only 19.85%.

The main focus in the studies on agroforestry ecosystem stability is on partial ecosystem stability, such as structural stability, temporal stability, functional stability, and association stability [45,46,119]. This may make it challenging to develop a universal, generalized, and systematic knowledge base due to the complexity of agroforestry ecosystem structure types. In addition, the complexity and conceptual ambiguity of ecosystem stability [121] have not attracted much academic discussion. On the other hand, in the literature related to agroforestry ecosystems, the main focus has been the structure, function, and services of agroforestry ecosystems. While stability has been a popular topic of ecological discussion, it has not been used for separate discussion in agroforestry ecosystems, presumably because its concept and connotation are not clearly defined, making it challenging to discuss separately in agroforestry ecosystems.

4.2. Differences in the Distribution of Study Areas

Due to the differences in regions' natural economic and social conditions, the development of agroforestry is uneven and has prominent regional characteristics (Figure 4). Firstly, in terms of the number of publications, Asia accounts for 46.32%, which is related to the national policy support and the attention of research institutions [122] and may also be related to the use of the CNKI database. In the Asian region, papers are published primarily in countries such as China and India due to the emergence of global issues such as dramatic population growth, food shortage, resource crises, and environmental degradation, which have prompted a deep awareness that forests and sustainable development in the 21st century are vital issues [123–125]. As a result, there has been a gradual increase in publications focusing on the combined benefits derived from the agroforestry model. Secondly, Europe accounts for 22.06%, where agroforestry started earlier. Still, the number of publications related to agroforestry ecosystem structures is low due to insufficient attention from early policy and research institutions. Towards the end of the 20th century, agroforestry areas in the region gradually decreased. The remaining agroforestry was also vulnerable, which attracted the attention of the government [126]. In addition, with the requirement of a global biodiversity conservation policy [127], the European Union has provided financial support to national and regional governments to establish new agroforestry ecosystems [128]. Therefore, the benefits of agroforestry have been gradually receiving attention from many European countries and research institutions, and the number of publications is increasing progressively. Again, Africa and North America accounted for 12.5% and 11.03%, respectively; Oceania and South America had the fewest publications. In short, agroforestry development and extension vary by location. On the one hand, natural factors such as climate, topography, water, and soil are the primary considerations. On the other hand, it should also be integrated with the political status and recognition of agroforestry development in the region, the regulatory authority and economic strength, and the acquisition and application of relevant knowledge [129].

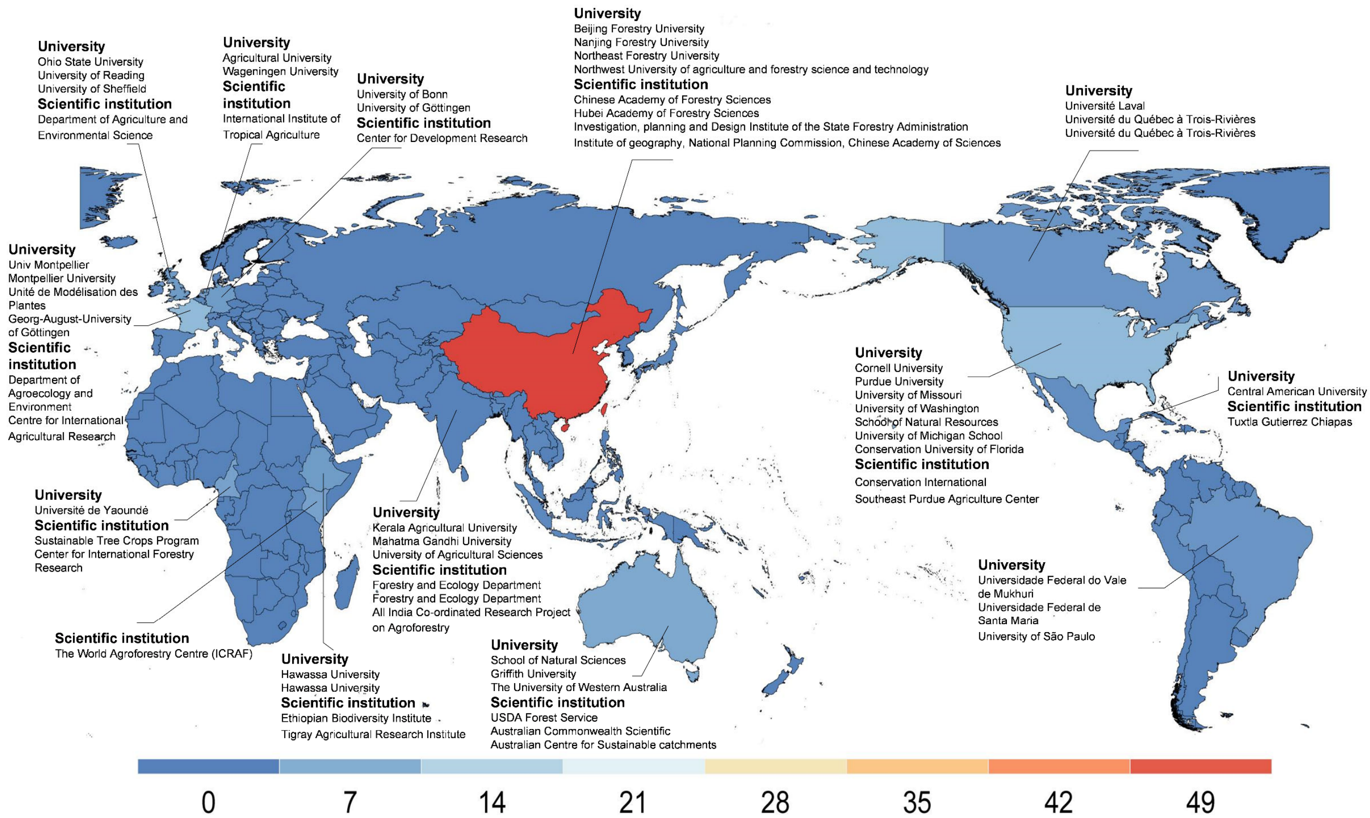

Figure 4. Distribution of countries and institutions studied in the literature. The different color bands and numbers at the bottom indicate the number of publications; the redder the color the higher the number of publications.

4.3. Key Scientific Questions That Need to Be Addressed Urgently

Because the theoretical research on the structure of agroforestry ecosystem lags in practice, we can improve the academic research system by analyzing the system composition, construction, and dynamics and clarify its structural elements and characteristics. The identification and quantification of structural traits are the basis for exploring the pathways of service formation. Since the ecosystem itself is composed of producers, consumers, and decomposers, the trophic hierarchy and network relationships among the three are formed through feeding and being fed to drive the material cycle and energy flow of the ecosystem, thus determining the ecosystem services [14,130]. However, most existing studies have focused on exploring the agroforestry ecosystem structure from the aspect of the spatial structure of forest stands; there is little focus on the analysis of the temporal structure and food chain structure and the exploration of the relationship between each structure type. This affects the research results on its functions and services. Therefore, to improve the research system of the agroforestry ecosystem structure, we should further strengthen and deepen the research of its temporal structure and food chain structure and deepen the theoretical investigation of its network to better guide agroforestry practice.

Given that the application of structural optimization in agroforestry ecosystems is relatively homogeneous and mainly focuses on the allocation of components among woody plants in the same land unit, it can be improved through optimization models, such as conceptual models, mathematical models, and spatial modelling computer technology and 3S technology, to create a set of systematic and scientific structural optimization techniques. Applying the theory of structural optimization to optimize the design of agroforestry ecosystem structures has a crucial role in fundamentally solving the contradiction between population growth and resources, soil erosion and vegetation growth, as well as providing scientific and technological support for ecological construction projects, such as returning farmland to forest and natural forest protection. Thus, the evaluation criteria for the structural optimization of agroforestry ecosystems are continuously improved through disciplinary synthesis, multi-perspective analysis, and multi-implementation tools.

Given the problem of unclear intrinsic linkages between the structure and function of agroforestry ecosystems, the relationship between form and function can be scientifically and accurately elucidated by qualitatively and quantitatively analyzing structural characteristics, clarifying the mechanism of ecosystem interactions from structure to function to services and their feedback and regulation mechanisms, and exploring the pathways to achieve system function. The importance of agroforestry ecosystems is increasing, to meet farmers' livelihood objectives and ecosystem service needs [131]. It has been demonstrated that the agroforestry ecosystem structure determines its function [14,132]. However, the study of this theory has not allowed us to fully understand the benefits of agroforestry ecosystems in terms of their ecological, economic, and social service functions. An in-depth clarification of ecosystem structure–function relationships is key to understanding the response of ecosystem dynamics to global change [130].

Given that the intrinsic linkage between agroforestry ecosystem structure and stability is unclear, qualitative and quantitative analysis of agroforestry ecosystem structural characteristics was conducted to elucidate the relationship between them and system stability, using biodiversity as a transmission medium. Existing studies have demonstrated that the more complex the structure, the higher the resilience [133,134]. However, little research has been reported in recent years in this field on the intrinsic link between structure and stability. Many studies have shown that increased biodiversity can maintain ecosystem stability [11,135], and agroforestry ecosystems have the function of growing biodiversity [136]. Therefore, we believe there is an inevitable link between system structure and stability. This calls for a strong need to discuss the two together in future studies, seeking to improve further the research systems related to agroforestry ecosystems.

Given the unclear mechanisms for maintaining agroforestry ecosystem stability, a set of indicators can be established through field monitoring to evaluate ecosystem stability in the area, and the dynamic changes in the agroforestry ecosystem can be monitored in real time. Since the "production-flow-use" of ecosystem services is a complex dynamic process based on time and space, changes in the drivers of any of these processes will cause ecosystem service functions to affect human well-being [137,138]. Additionally, as one the artificial ecosystems, agroforestry ecosystems are more open, have higher rates of material and energy input and output, and are constantly disturbed by the external environment [12]. Therefore, the establishment of a complete monitoring system helps us to make timely scientific decisions to adjust and strengthen the stability of agroforestry ecosystems as they change, to coordinate the relationship between various methods of production using technical means, to maintain the stability of agroforestry ecosystems and achieve the overall functional optimization and service gain of agroforestry ecosystems.

Given the lack of systematic and scientific evaluation methods for evaluating agroforestry ecosystem stability, theories such as dissipative structure theory and information entropy change can characterize the strength of ecosystem stability with objectivity and feasibility [139,140]. There are two basic types of methods for determining and evaluating ecosystem stability: one is the empirical method or expert method; the other is the use of mathematical techniques to construct mathematical models to characterize ecosystem stability conditions, such as differential equation models, food web models, etc. [141–143]. The empirical method or expert method is used to obtain the evaluation indexes and their weights by practical judgment or expert scoring and then evaluate the study area after a field survey, which requires a high level of experience. The statistical results of different experts often vary greatly. In addition, most mathematical modelling methods quantify a specific impact factor. Their findings may be inapplicable on a large scale because of the variability and spatial heterogeneity of the study area and the study scale range. Therefore, to comprehensively understand the stability of agroforestry ecosystems and formulate suitable forestry measures, an objective evaluation of agroforestry ecosystem stability is needed. Information entropy theory uses the entropy value size to determine the discrete degree of a factor: the higher the entropy value of an element, the greater the discrete degree; the higher the uncertainty and the lower the information utility, the smaller the weight of the factor. Therefore, using information entropy to determine the significance of evaluation indexes belongs to the objective assignment method, which can avoid the interference brought by human factors.

4.4. Implications for the Improvement of Supply Capacity of Agroforestry Ecosystem Services under the Rocky Desertification Control

Although economic and ecological benefits have been achieved during the participation of agroforestry ecosystems in rock desertification control [39], the typical characteristics of ecological fragility of karst rocky desertification [22,144] make the overall ecosystem of the region weak in resistance to external disturbances and unstable [145]. Unreasonable human agricultural activities will exacerbate the vulnerability of rocky desertification habitats, which will affect the species composition and structural configuration of agroforestry ecosystems [146], thus affecting the supply of agroforestry ecosystem services. Therefore, synthesizing the summary and review work on the above agroforestry ecosystem structure and stability in this paper, we mainly focus on the natural ecological environment conditions and sustainable development to highlight areas of the improvement of agroforestry ecosystem service supply capacity under the karst rock desertification control.

In terms of natural ecological conditions, karst mountains have shallow soil layers, discontinuous soil cover, bare surface bedrocks, calcium-rich and alkaline soils, and fertile but low total soil [147,148], which exhibits unique characteristics such as high heterogeneity in horizontal space, multilevel vertical profile, high spatial and temporal heterogeneity, and inadequate soil moisture [24,32,149,150]; this becomes a critical limiting factor for the structure and stability of agroforestry ecosystems, especially in terms of the differences in water and heat conditions and their matching degree of soil thickness. Different topographic features and slope orientations directly affect plants' diversity and spatial distribution patterns [151], which affects the ecosystem services provided by agroforestry. So, as described above in this paper, the species structure characteristics of agroforestry ecosystems are combined with the selection of lithophytic, arid, calcium-loving, and other characteristics of plants. The utilization of structural optimization measures can be implemented in three ways: firstly, shallow-rooted and deep-rooted plants are optimally configured for soil and water nutrient competition to mitigate their uneven distribution of subsurface nutrients and water [152]; secondly, for the rocky desertification areas with a shallow soil layer, discontinuous soil cover, and a high bare rock rate, lithophytic woody plants can be selected for planting to solve the problem of accelerated evaporation of surface moisture due to the reflection of solar radiation by rock outcrops [38]. Once again, in response to the differences in topography and landscape, we suggest targeted configurations according to the growth habits of each species and transformation of the structure of the agroforestry industry portfolio [153,154] to regulate the three-dimensional hierarchy of each component of the system above and below ground and to improve the alternate use of time and space by each component. Therefore, the abovementioned ideas will effectively maintain and optimize the material cycles and energy flows formed by living or non-living organisms, producers or consumers, and consumers or decomposers during long-term evolution [61]. This has a crucial role in improving the diversity and stability of agroforestry systems, consolidating the effectiveness of rocky desertification control, and improving the formation pathways of agroforestry ecosystem services [155].

In terms of sustainable development, the inherent vulnerability of karst itself, irrational agricultural production activities, and the lack of alternative farming livelihood patterns exacerbate the degradation of rocky desert environments [156,157]. To address these problems, the successful combination of ecological restoration and poverty alleviation cases in southern China, Indonesia, and other regions has been actively tackled, and agroforestry as an effective practice has also been repeatedly mentioned [158,159]. Additionally, it has been proven that agroforestry has become a vital development objective to protect the karst ecosystem and maintain farmers' livelihoods [160]. Considering long-term sustainable development, attention should be paid to the ecosystem services brought by agroforestry participation in rock desertification control and restoration. Internalizing the externalities of environmental governance benefits and introducing market transaction mechanisms to activate the consumption of agroforestry ecosystem services should be proposed [107] as should the promotion of the active role of agroforestry in reconciling environmental management and farmers' livelihoods. To meet the above long-term sustainability goals, we need to optimize and regulate the structure of agroforestry ecosystems to promote the protection of ecosystem functions and service supply, which is a prerequisite for achieving the ability to enhance the supply of agroforestry ecosystem services.

4.5. Comparison with Other Reviews and Limitations of the Study

After the above literature search and analysis, it was found that the relevant research reviews on agroforestry ecosystem structure and stability all revolve around a single research object. For example, Sonwa et al. [131] took the structure of the cocoa agroforestry ecosystem in Central and West Africa as the research object and mainly explored the current status of the research on structural characteristics such as species composition and hierarchical structure, planting density, the density of associated plants, basal diameter, and growth cycle. However, due to the limitation of the research object and scope, this study cannot be directly used to describe the characteristics of agroforestry ecosystem structures in other regions. In addition, few reviews on agroforestry ecosystem stability studies have been reported, and scholars have focused more on investigating the relationship between ecosystem stability and diversity [121]. This study conducted a systematic review of the research on agroforestry ecosystem structure and resilience, focusing on structural characteristics, structural design, structural optimization, stability, and influencing factors of agroforestry ecosystems, summarizing the landmark results achieved and condensing the critical scientific issues to be addressed. It can provide a theoretical basis for future research on the structure and stability of global agroforestry ecosystems and improve the capacity of ecosystem service.

Although different search methods and screening strategies were utilized, multiple uncontrollable influences may lead to omissions within the literature, making the scope of the literature selection limited. First, only two core databases, Web of Science and CNKI, were selected as search databases, which excludes the literature published in databases such as Scopus. Secondly, the literature reviewed in this paper used Web of Science and CNKI databases in Chinese, so it is difficult to guarantee that the results will not be biased. Finally, the search string used in this paper does not guarantee that it is sufficient to cover all relevant literature on the topic of this study.

5. Conclusions

This paper conducted a literature search for agroforestry ecosystem structure and stability through two databases, Web of Science and CNKI, and analyzed and reviewed the 136 selected papers. The following conclusions were drawn: (i) The number of annual publications on agroforestry ecosystem structure and stability showed a significant upward trend. However, the literature on agroforestry ecosystem structure studies is more widely reported. Studies related to stability are scarce, and research that separately explores the intrinsic link between agroforestry system structure and stability was not found. Researchers should continue to explore the relationship between structure and stability in depth to improve the agroforestry research system in the future. (ii) Research on the structure of agroforestry ecosystems is mainly focused on its characteristics, optimal regulation, and design and is gradually deepening from qualitative to quantitative research. The study of stability is mainly focused on local stability. The complexity of the definition of stability makes it difficult to define the concept of stability of agroforestry ecosystems. Exploration of agroforestry ecosystem stability is still needed in the future. (iii) The development of agroforestry ecosystem structure and stability is influenced by natural factors such as climate, topography, soil, and water; social factors such as national policies, research, and development efforts of research institutions and universities; and activities such as farmers' willingness to accept, economic income. and management intensity. (iv) The optimization of agroforestry ecosystem structures and the improvement of stability play a vital role in the long-term maintenance of agroforestry ecosystem service supply capacity.

In conclusion, this paper summarizes the current research progress and landmark results in five aspects of structural characteristics, optimal regulation and design, stability research, and influencing factors of agroforestry ecosystems. The key scientific questions that need to be answered within the scope of this research theme are explored to indicate future research directions for structural optimization and stability enhancement of agroforestry ecosystems. It provides significant insights into improving the supply capacity of agroforestry ecosystem services for rocky desertification control.

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