STATUS AND DEVELOPMENT OF ECOLOGICAL AGRICULTURE IN CHINA: BIBLIOMETRIC AND SPATIAL STATISTICAL RESEARCH

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Abstract. China has to perform high-intensity and high-chemical input agricultural production to improve its food security, which has caused uncertainty in the development of ecological agriculture. This study utilizes bibliometrics and spatial statistical methods to examine the representative literature on ecological agriculture published in the CNKI database from 2012 to 2023. The findings reveal that keywords such as rural revitalization, modern agriculture, and ecological tourism are frequently mentioned while emerging interests include carbon neutrality, eco-circular agriculture, and industrial integration. The main clusters of keywords can be classified into specific practical research, general studies, and countermeasures orderly. The themes of ecological tourism, developing mode, and rural revitalization have attracted long-lasting concerns in research over the past decade. Spatial statistical analysis indicates that, aside from the Eastern coastal areas, most provinces in China exhibit insufficient collaboration and limited spill-over effects in research of ecological agriculture, highlighting the necessity for enhanced integration. This study also provides recommendations to address the prevailing challenges to food security through the promotion of ecological agriculture in China.
Keywords: *food security, ecological challenge, timeline analysis, countercultures, spatial auto-correlation*

Abbreviations: IAED, CAAS: Institute of Agricultural Economics and Development, Chinese Academy of Agricultural Sciences; UCAS: University of China Academy of Science; IGSNRR, CAS: Institute of Geographic Sciences and Natural Resources Research, China Academy of Science

Introduction

Ecological agriculture, also known as eco-agriculture, is a farming approach that aligns with ecological principles and emphasizes environmental sustainability. While sharing similarities with sustainable agriculture, ecological agriculture places a stronger emphasis on specific technologies and practices (Xu, 2004). Chinese researchers used 'ecological agriculture' more frequently in the literature compared to 'sustainable agriculture'. Ecological agriculture integrates ecological processes into agricultural systems to reduce negative environmental impacts and promote sustainable productivity. In contrast to conventional practices that are reliant on synthetic fertilizers and insecticides, ecological agriculture emphasizes working in harmony with nature and utilizing natural inputs and techniques, such as organic fertilizers, crop rotation, agroforestry, biological pest control, and alternative cultivation. Moreover, ecological agriculture acknowledges the significance of social equity and well-being (Akamani, 2021). Its objectives encompass establishing sustainable livelihoods for farmers,

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ensuring food security, and fostering robust connections between farmers and consumers through local food systems.

China has a large population and deep-rooted farming tradition; agriculture and food security have always been major themes of social development. From the 1980s to the 2000s, China encountered serious ecological challenges arising from rapid industrialization and intensive agricultural production (Chen, 2007), including soil erosion, water pollution, loss of biodiversity, and crop reduction. In response to these issues, the Chinese government recognized the urgency of transitioning towards ecological agriculture. Since the 1990s, China progressively implemented several policies aiming to encourage the development of ecological agriculture (*Table 1*).

Table 1. *The policies related to ecological agriculture in China from the 1990s*

Period	Administration/policy	Meanings and key points
1991	Former Ministry of Agriculture/Opinions on Accelerating the Development of Ecological Agriculture	Official recognition of ecological agriculture; conservation of water resources and biodiversity
2001	Former Bureau of Environment Protection/Organic Products Certification Regulation	Set standards/regulations for organic production and certification
2005	Ministry of Environment Protection/Program of National Ecological Demonstration County (NEDC)	NEDCs emphasize resource efficiency, environmental protection, and the improvement of farmers' livelihoods
2015	Ministry of Agriculture and Rural Affairs/Zero-Growth Action Plan for Pesticide Use	Gradually reduce chemical pesticide usage and promote integrated pest management practices; realize zero increase of pesticide in 2020
2016	Ministry of Agriculture and Rural Affairs/13th Five-Year Plan (2016-2020)	Increase the share of organic farming, promote efficient water use and soil conservation
2021	Ministry of Agriculture and Rural Affairs/14th Five-Year Plan (2021-2025)	Green Development of agriculture; Low carbon and circular agriculture
2022	Ministry of Agriculture and Rural Affairs/Ecological Farm	Build 1000 national ecological farms and 1000 local ecological farms before 2025

As a result, ecological agriculture in China has shown significant progress. The area dedicated to ecological agriculture increased to 10 million ha in 2020 (XYZ Research, 2023); there were approximately 2,500 national-level ecological demonstration counties across China. The huge demand from the market encourages organic-certified farmland to expand from 0.13 million ha in 2009 to 2.2 million ha in 2019 (AAAC, 2020).

Although the statistics highlight the manifest progress of ecological agriculture, it is crucial to acknowledge the prevailing problems. Urbanization and ecological deterioration resulted in the loss of approximately 113 million ha of farmland in China from 2009 to 2019, as reported by the Ministry of Natural Resources of China (2021). Furthermore, in 2022, China imported a staggering 146.872 million tons of grain, with a self-sufficiency rate of only about 65% (Wang, 2023). Given that food security is of utmost importance to the country, China has been compelled to increase the frequency of cultivated land use and rely heavily on chemical fertilizers and pesticides to ensure grain production (Cui and Shoemaker, 2018). Consequently, this has led to severe land degradation issues, including soil desertification, acidification, and salinization,

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impacting an arable land area of more than 0.44 million ha in 2020, which accounts for one-third of the country's arable land, as reported by Chinese News Weekly (2022). The urgency of addressing food security concerns has unfortunately relegated ecological agriculture to a subordinate position, thus creating limitations to its implementation. However, challenges associated with food production, such as land degradation and water scarcity, need to be addressed by adopting ecological agriculture practices. These factors introduce significant uncertainties to the development of ecological agriculture in China. Furthermore, given China's status as the country with the largest population and substantial agricultural output globally, it plays a critical role in global food security and ecological agriculture. Therefore, a comprehensive review of existing research to understand the current status, trends, and challenges of ecological agriculture in China is vital for addressing and resolving pertinent issues. Most of the previous studies are qualitative, furthermore, the existing bibliometric studies are simplified and lack of more quantitative interpretation of the results.

This study aims to conduct a bibliometric analysis combined with spatial statistical analysis of representative literature related to ecological agriculture in China. We tried to discuss the research status, emerging trends, and challenges encountered in China's ecological agriculture and propose strategies for the development of ecological agriculture and food security. Furthermore, it is essential to acknowledge that the implementation of ecological agriculture in China exhibits pronounced regional disparities influenced by geographical, climatic, and economic factors. The quantity of literature published by researchers reflects local priorities regarding ecological agriculture, while the presence of advanced academic studies contributes to the development of regional ecological agriculture. Therefore, as a valuable supplement and novel attempt, we incorporated spatial statistical analysis on the number of regional literatures to further interpret the bibliometric findings and tried to provide insightful recommendations for regional collaborations to improve the nationwide research of ecological agriculture.

Review of literature

Bibliometric study on agriculture

Bibliometrics is a facilitative tool for performing statistical analysis of literature related to a specific topic. This methodology has been widely applied in studies related to agriculture and ecological agriculture. Yang et al. (2022) conducted a bibliometric analysis for a total of 18,628 published English and 3460 published Chinese research articles and dissertations on circular agriculture. The authors explored the research hotpots, methods, trends, and mainstream technical models of crop–livestock systems and provided suggestions for the development of circular agriculture by reducing the pollution risks of agricultural waste and improving both the ecological and economic benefits of the system. The challenges of ecological agriculture were also analyzed by bibliometric method, Xie (2020) concluded the hotspots, main themes, high-frequency keywords, and timeline analysis of papers related to land degradation published from 1990 to 2019 in the WOS database. The research indicated the research directions on land degradation in the future include new monitoring methods for land degradation, methods and models of ecological restoration, and reconstruction of degraded land. Muhl (2022) used a bibliometric

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method to analyze the data collected by the PRISMA protocol related to Agriculture 4.0 (social-ecological agriculture, Rose et al., 2021). Two main research fronts, positive or negative effects of agriculture 4.0 were found by the research. Yang et al. (2023) reviewed nearly 3000 literature related to plant phylogenetic zones. The study identified the key characteristics, hot spots, and evolution trends within this field. The findings indicate that biological phenomena were the main theme, demonstrating a clear interdisciplinary and fusion advancement. Moreover, it was observed that model prediction would be the research trend in the future. The bibliometric method can analyze numerous literatures and conclude the trends, main themes, hotspots, and further suggestions for a research topic. The number of Chinese papers on ecological agriculture is quite large and involves various fields, which is very suitable for the use of the bibliometrics method for research.

Review of China's ecological agriculture

Early studies mainly focused on historical reviews and general introductions. Ye (2002) introduced the origination, connotation, underlying principles, and emerging problems of ecological agriculture in China. Shi (2002) suggested the potential of ecological agriculture to address the problem of sustainable human-environmental interactions and overcome the limitations of traditional agriculture in meeting the needs of China's growing population. Wang et al. (2007) reviewed the research status of ecological agriculture in China and discussed the key characteristics, similarities, and differences between Chinese ecological agriculture, alternative agriculture, ecological agriculture, and international sustainable agriculture in the West. Li et al. (2011) indicated that the main problems from the 1990s to the 2000s were the lack of research and accounting across a variety of agroecosystem service functions and market-oriented information. The author suggested the reconsideration of circular economy, multifunctional agriculture, high-quality agriculture, and the integration of traditional essence and modern technology. In a study published in Chinese, Wang (2019a) analyzed the literature related to green technology in agriculture from 2004 to 2019. The study concluded the researching hotspots on the safety of inputs, friendly production processes, and economical and efficient use of resources. Liu et al. (2023) reviewed the literature from 1998 to 2019 using the bibliometric method and indicated that rural revitalization, targeted poverty reduction, and the evaluation system of agriculture were the main research trends. Song et al. (2022) analyzes the development process of China's ecological agriculture, and the practice and construction process of modern ecological agriculture were comprehensively researched. The study found that the methodology and theoretical basis, optimization design of agricultural ecosystems, and integrated application of eco-agricultural technology were the basic contents of China's ecological agriculture from the 1990s to the 2020s.

Materials and methods

Literature collection

The most representative Chinese academic database, Chinese National Knowledge Infrastructure (CNKI), was selected as the source of literature. CNKI is a comprehensive repository that includes journal articles, theses, conference papers, news,

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and other scholarly works. The retrieval term 'Title/Abstract/Keyword = Ecological agriculture' was set to cover the period from January 2012 to June 2023. Only journal articles, theses, and conference papers were included in the search result, while news articles published in newspapers were excluded. The retrieved literature was exported in the form of "refer text", and literatures on any disciplines unrelated to ecological agriculture were manually removed. To ensure the academic impact of the retrieved literature, only journals cited by Core Journals of China were selected. Core Journals of China enlisted approximately the top 15% of the whole journals of CNKI, while the Q1 journals account for 25% of Journal Citation Reports (JCR). In total, 1986 papers were obtained, including 1524 journal articles, 338 theses, and 124 conference papers. These papers are all published in Chinese journals and written in Chinese, and almost all have English abstracts.

To compare the Chinese publication activity with that of other countries, a search was conducted using the WoS (Web of Science) database, employing the aforementioned retrieval methods. The literature cited by SCIE (Science Citation Index-Expand) and SSCI (Social Science Citation Index) was selected and the proportion of papers published by Chinese and global researchers, as well as the output of different institutions, were included for subsequent analysis.

Bibliometric methods

The data exported from the CNKI database was processed using Citespace (6.1R4, Chen, 2006). The visualization of keyword co-occurrence was based on their frequency of occurrence (greater than 12 times), and the centrality of each node was calculated to display the importance of the keywords. Terms such as "ecological agriculture," "ecology," and "agriculture" were excluded due to their lack of specificity. The cluster analysis of keywords was visualized using the log-likelihood ratio (LLR), and the eight clusters with the highest k-values were listed and studied in the timeline analysis. In the timeline analysis, a maximum of two node labels were set for each year. The network of institutions provided a number of relevant literatures for individual provinces. To better visualize the clusters, specific software settings were listed in the supplementary documents.

Spatial statistical analysis

The bibliometric approach provided the number of literatures published by various institutions, and this number was summed by province. The number for each province was normalized to perform spatial statistical analysis at the provincial level. Geode 1.20 (Version 1.20, Anselin et al., 2006) was used as the spatial analysis software, and the Queen's contiguity model (adjacent at edges and corners) was employed to capture the relationships between neighboring regions in the spatial weight matrix. Cluster analysis (by K-means) was conducted to characterize the regional variations of research on ecological agriculture. The Global Moran's I index (clustered or dispersed tendency), Local Moran's I index (high or low-value clustering), and Geary's C index (similarity differences) were calculated and visualized to discuss the spatial characteristics of academic research on ecological agriculture in China. The principles and details of spatial statistical analysis can be referred to in previous studies (Anselin, 1995; Fan and Xue, 2020). The details of regions and provinces related to this study are listed in *Table 2*.

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Table 2. *Geographic division and code of provincial-level regions in China mentioned in this study*

Geographic division	Province and code	Geographic division	Province and code
Northern (HuaBei)	11 Beijing 12 Tianjing 13 Heibei 14 Shanxi 15 Neimenggu	Central (HuaZhong)	41 Henan 42 Hubei 43 Hunan
		Southern (HuaNan)	44 Guangdong 45 Guangxi 46 Hainan
Northeastern (DongBei)	21 Liaoning 22 Jilin 23 Heilongjiang	Southwestern (XiNan)	50 Chongqing 51 Sichuan 52 Guizhou 53 Yunnan 54 Xizang
Eastern (HuaDong)	31 Shanghai 32 Jiangsu 33 Zhejiang 34 Anhui 35 Fujian 36 Jiangxi 37 Shandong	Northwestern (XiBei)	61 Shaanxi 62 Gansu 63 Qinghai 64 Ningxia 65 Xinjiang
	71 Taiwan 81 Hongkong 82 Macao		

Results

International and domestic publication

Based on the retrieval method in this study, a total of approximately 7,000 papers about ecological agriculture were identified within the WoS database. Notably, Chinese institutions accounted for around 1,700 of these papers, representing the highest proportion (24%) among all countries, highlighting the role of Chinese institutions in the development of knowledge in the studied topic. Moreover, approximately 1,000 of the aforementioned papers explicitly incorporate 'China' in their titles, indicating a country-specific study is valuable. However, over 60% of the 1700 papers above mentioned were published by institutions based in Beijing, despite the city not being recognized as a major agricultural region. It indicated that these papers may not effectively reflect the diverse agricultural regions within China. In the retrieval result from the CNKI database, only 15% of the research institutions were located in Beijing, indicating that the majority of researchers from provincial or prefecture-level research institutions tend to publish literatures in Chinese, particularly those addressing regional practices and case studies of ecological agriculture. Therefore, conducting literature research within the CNKI database can provide a more comprehensive understanding of the status of ecological agriculture within China as a whole and present more practical suggestions.

Annual published literature

Ecological agriculture research in China exhibits a strong connection to the policy orientation of local governments at different administrative levels. Moreover, the number of publications is also influenced by the preference of funding and the prevailing trends in economic development. From 2012 to 2022, the annually published output of literature on ecological agriculture in China exhibited fluctuations ranging

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from approximately 160 and 230 (*Fig. 1*). Before 2020, there was a general upward trend in the quantity of papers published in academic journals. However, notable changes have occurred in the output of conference papers, which may be related to the time interval of academic conferences. The introduction of the significant policy of 'Rural Revitalization' by the central government in early 2018 may shift the concerns of researchers and lead to a decrease in published output in 2019. A slight decrease in the number of publications can be observed after 2020, which may be attributed to the impact of COVID-19. The travel restrictions and university closures during this period hindered the academic activities as well as the publication of thesis and conference papers.

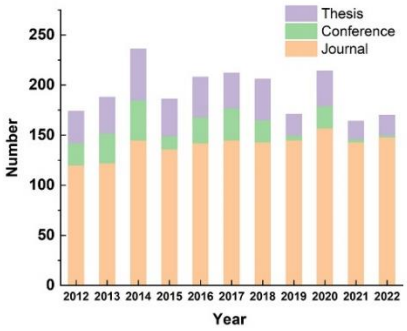

Figure 1. *Annually published literatures related to ecological agriculture on the CNKI database of China from 2012-2022*

Network of institutions and authors

The institutional network analysis revealed only one major cluster (*Fig. 2a*). This cluster consisted of institutions such as the Chinese Academy of Sciences (CAS) and the Chinese Academy of Agricultural Sciences (CAAS), both located in Beijing. Their research covered agricultural culture (Li et al., 2012), and strategic planning (Liu et al., 2022). Besides Beijing, institutions in other provinces did not exhibit effective collaboration, even in regions with similar agricultural conditions. This indicates the need for more regional cooperation among institutions and universities. The Northwest Agriculture and Forestry University, Central South University of Forestry and Technology, and Hunan Agricultural University are the top three institutions in terms of the number of published literatures, situated in the Northwest, Southwest, and Central regions respectively. In contrast, the top three institutions with the most published papers in the WoS database are all affiliated with the Chinese Academy of Sciences (CAS) in Beijing. This also indicates that the literatures from the CNKI database can more comprehensively reflect the status of research in different regions of China.

The author network displayed more cooperative clusters than that of institutions (*Fig. 2b*), the largest cluster was connected through influential nodes such as Kang Chuanzhi (China Academy of Chinese Medical Sciences, CACMS), Wang Jijun (CAS), Zhang Wenjin (CACMS), Gu Wen (CAS), and Lv Chaogeng (CAS). These authors' research focused on the planting of traditional Chinese medicinal herbs and other economically viable crops (Kang et al., 2020). Furthermore, there was a cluster centered around Cui Shaofang (Northwest Agriculture and Forestry University), primarily investigating soil and water conservation in ecologically vulnerable areas (Cui et al.,

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2013). Additionally, a highly collaborative cluster consisting of Feng Zhongchao (HuaZhong Agriculture University), Wu Wenbin (CAAS), and Yang Xingjie (HuaZhong Agriculture University) conducted extensive research on rice-based ecological farming systems (Yang et al., 2021).

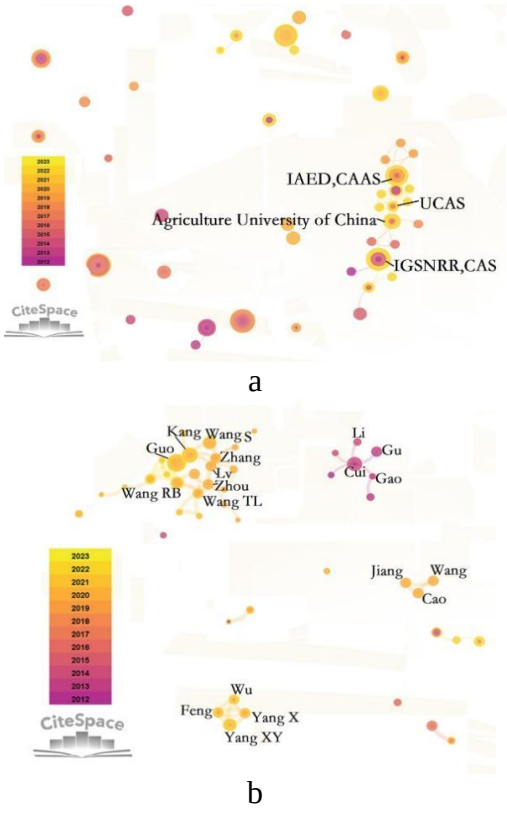

Figure 2. *The visualized network of institutions (a) and authors (b). Nodes indicate the institutes or authors; the size of the nodes indicates the number of published literatures*

Co-occurrence and cluster of keywords

The co-occurrence analysis of keywords (*Fig. 3*) reveals the most frequently used terms in the field of ecological agriculture research over the past decade. These keywords encompass various aspects such as ‘rural revitalization’, ‘modern agriculture’, ‘leisure agriculture’, ‘circular economy’, ‘planning’, ‘green planting’, and ‘ecological civilization’. Additionally, keywords including ‘Genuine herb’, ‘low-carbon economy’, ‘free-picking’, ‘Northeastern’, and ‘San Xia’ reflect diverse disciplinary perspectives. Notably, ‘green development’, ‘rural revitalization’, and ‘modern agriculture’ are higher centrality and serve as pivotal nodes that connect different literature sources. It underscores the significance of modern agriculture and rural revitalization as a focus for interdisciplinary research. Researchers considered ecological agriculture as a primary form of modern agriculture in China, while the realization of green development is an important approach to implementing rural revitalization (Wang and Shi, 2019). Moreover, a considerable number of keywords are associated with tourism, indicating a strong correlation with ecological agriculture. In rural areas, tourism serves as a practical approach to implementing ecological agriculture (Sun, 2019), as it can quickly generate economic returns without requiring specialized techniques or advanced management.

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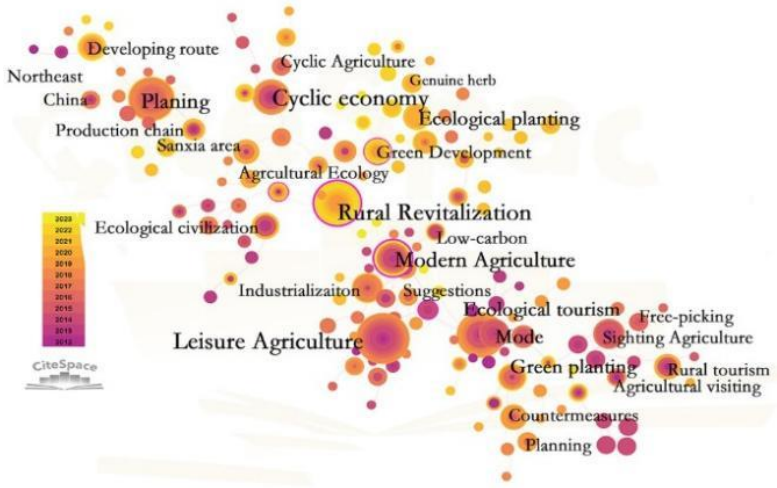

Figure 3. *Visualization of co-occurrence keywords with high-frequency. One node indicates one keyword, the larger front/node sizes of the node indicate the more frequent occurrence*

Figure 4 illustrates the results of the keyword cluster analysis, with a Modularity value of 0.608 (threshold 0.3) and a Silhouette value of 0.748 (threshold 0.5). These values indicate a highly effective cluster structure with significant differentiation. The identified clusters can be classified into three overarching themes: macro-level studies, specific practical research, and countermeasures for addressing challenges.

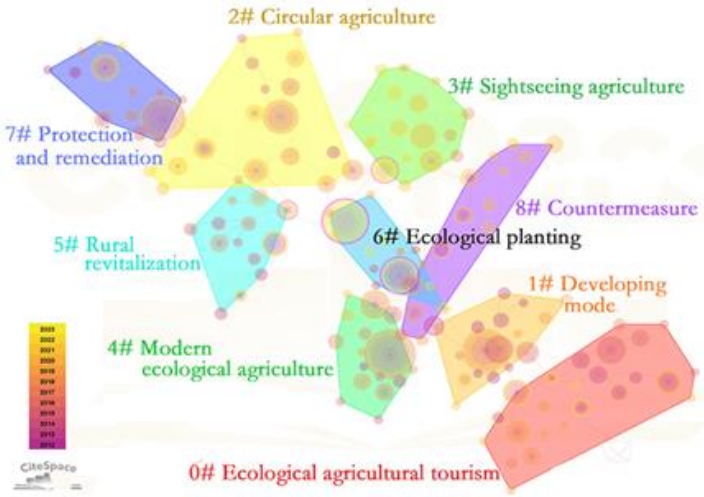

Figure 4. *Cluster analysis of co-occurrence keywords in research of ecological agriculture. The nodes enclosed by the colorful polygon represent a cluster*

The clusters associated with #1 Developing mode and #5 Rural revitalization align with the broader objective at a macro-level, highlighting the strategic direction of ecological agriculture in China. Notable studies within these clusters include the collaborative innovation of rural revitalization (Wang, 2019b) and ecological circular agriculture within the framework of rural revitalization (Song, 2022). Specific practical research is represented by clusters #0 Ecological agricultural tourism, #2 Circular agriculture, #3 Sightseeing agriculture, #4 Modern ecological agriculture, and #6

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Ecological planting. These clusters encompass the primary approaches employed in the implementation of ecological agriculture. Representative studies included the ecological planting of traditional Chinese medicine herbs (Kang, 2020), the integration of the 'Beautiful China' with ecological tourism (Zhao, 2014), and strategies for regional development (Zhang, 2016); Given the diverse agricultural and rural landscapes across the country, tourism and sightseeing have emerged as feasible modes of integrating ecological agricultural practices into rural areas nationwide (Zhang and Yaun, 2023). Furthermore, research has been conducted to address existing challenges faced by current agricultural production, particularly in the Southern and Northeastern regions of China (Sun et al., 2018).

Timeline analysis and bursting keywords

In timeline analysis (*Fig. 5*), there is significant variation in the research period among the different clusters. Clusters #1 Ecological agricultural tourism, #2 Development mode, and #7 Protection and remediation have consistently been subjects of study over the past decade, indicating their significant academic value. Conversely, research on #2 Circular agriculture, #3 Sightseeing agriculture, #4 Modern ecological agriculture, and #8 Countermeasure has gradually declined since 2016. These topics have been superseded or updated by emerging areas, such as #6 Ecological planting and #4 Rural revitalization.

Clusters #0, #2, #3, #4, and #6 are all associated with the implemented routes of ecological agriculture. Early research on #0 Ecological agricultural tourism and #3 Sightseeing tourism focused on rural sightseeing, tourism farms, and Henan Province. However, since 2022, the latest hot spots have shifted towards value development and carbon neutrality (He et al., 2023). Research on tourism agriculture in #3 Sightseeing tourism has significantly decreased after 2016, potentially being replaced by ecological agricultural tourism. The introduction of policies such as the Zero-Growth Action Plan for Pesticide Use and the 13th Five-Year Plan in 2016 elevated the attention given to organic farming and the concept of zero pesticides (Editorial, 2016). Consequently, #6 Ecological planting has received increasing academic interest. #4 Modern ecological agriculture summarizes research on design and planning, mid-term evaluation studies, and the latest trends. The early research on #2 Circular agriculture mainly focused on Marx's theory and related concepts. Studies conducted since 2016 have examined emerging practical routes associated with circular economy, such as bio-energy and the 3R principle. From a macro-level perspective, initially, studies of #1 Developing mode were fundamental issues such as pathways, influencing factors, and efficiency. Subsequently, the research shifted towards specific modes such as industrialization, rural eco-agriculture, and circular agriculture in 2016; The latest research hotspots in #5 Rural revitalization include ecological civilization (Zhao, 2023), green agriculture, and industrial integration (Zhang and Zhao, 2021). This indicates that to accomplish the goals of rural revitalization, ecological agriculture should not only focus on practical implementation but also fulfill its educational function for farmers. Clusters #7 and #8 concentrate on countermeasures and ecological restoration. Due to issues concerning food security, China has engaged in high-intensity agricultural production, leading to ecological problems like salinization and soil erosion. In response, the Chinese government proposed the 'Beautiful Waters and Green Mountains' initiative in 2016, prompting academic research to explore alternative planting methods, basic farmland protection, and soil remediation (Zhang and Bai, 2021).

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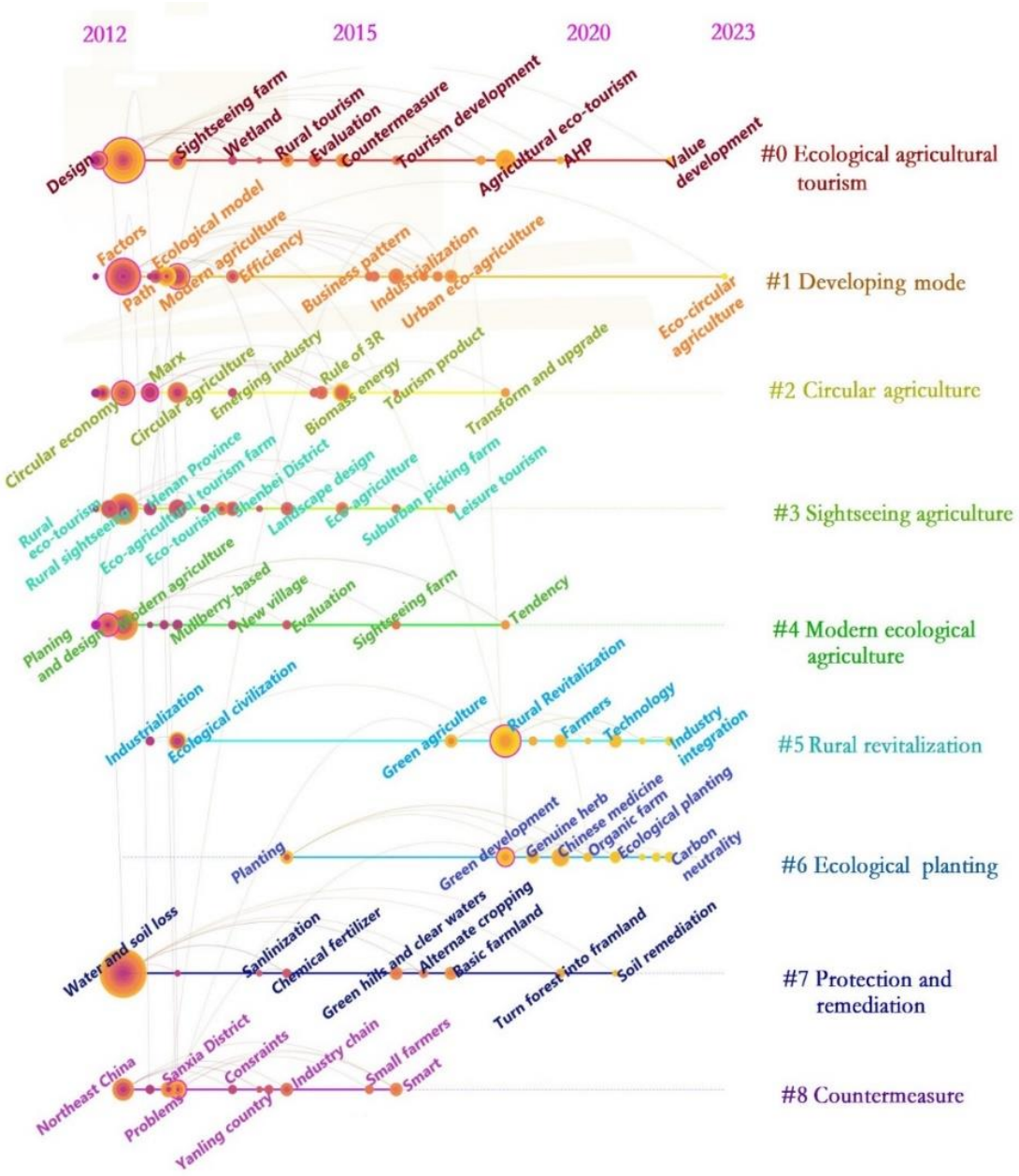

Figure 5. *Timeline analysis of the clusters of keywords. Colorful line displays the occurring sequence of keywords (nodes) in each cluster*

The emergence of keywords with strongest citation bursting (*Fig. 6*) coincides well with the policy orientations and industrial hotspots. In the initial stages, the bursting keywords included broader aspects, such as modern agriculture, development pathways, and sustainable development. As the practice of ecological agriculture advanced, the focus shifted towards enhancing efficiency and promoting industrialization (2016-2018). Following the introduction of the 'Rural Revitalization' policy in 2018, the related keyword gained significant prominence from 2019 to the present. Since 2020, the emphasis has shifted towards ecological aspects, as indicated by the popularity of keywords such as green development, ecological planting, and agricultural ecology, which have persisted until 2023.

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Figure 6. *Keywords with strongest citation bursting in the published literature related to ecological agriculture from 2012-2023*

Spatial statistical analysis

The quartile map (*Fig. 7a*) of the provincial published literature reveals that the provinces with a higher number of published literatures are primarily situated in the eastern coastal region (Shandong (37), Jiangsu (32), Shanghai (31), Zhejiang (33)), Shanxi (14), and Guangdong (44) from 2012 to 2017. Conversely, most provinces in the Northwestern and Southwestern regions are in the lowest quartile, indicating a significant regional imbalance in terms of literature output. This disparity reflects the heterogeneity in academic research and generally corresponds to the level of educational development in each province. It is worth noting that Shaanxi (61) province, with its numerous agricultural universities, presents as a high quartile in Northwestern China. However, starting in 2018 (*Fig. 7b*), there has been a noticeable increase in the number of published literatures in coastal provinces such as Fujian (35) and Hebei (13). Similarly, provinces in the Northeastern and Central regions have also experienced growth compared to the preceding five years. The developed economy of Eastern, coupled with robust consumer demand for organic food, plays a crucial role in driving research on related ecological agricultural topics in these provinces. Additionally, Heilongjiang (23) in the Northeastern region, has garnered more research attention on ecological planting due to its favorable geographical conditions. Provinces in the Southwestern and Northwestern regions have not exhibited significant growth in terms of published literature over the past decade. This can be attributed to the relatively underdeveloped economies, as well as weaker academic research infrastructure.

The Global Moran's I index of the provincial number of literatures was calculated to be 0.398 ($z = 1.58$, $p = 0.07$), indicating a tendency towards spatial clustering. Further analysis using the Local Moran's I index (*Fig. 8a*) identified significant clusters with high-high or low-low values. The provinces of Ningxia (64), Gansu (62), Qinghai (63), and Xinjiang (65) exhibited low research output, which can be attributed to their economic underdevelopment, forming a cluster with low-low values. In contrast, Shandong (37), Jiangsu (32), and Shanghai (31), located in one of China's most developed regions and renowned for their well-established agricultural sectors, displayed relatively high levels of research output, forming a cluster with high-high values. Additionally, Shaanxi (61) province, characterized by a high level of higher education and its proximity to the Northwestern region with low-low values, stood as a high-low outlier.

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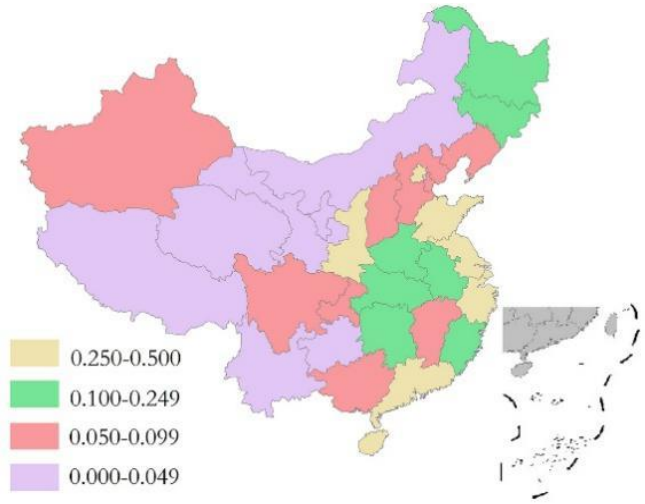
Similarly, Guizhou (52) and Guangxi (45) provinces, neighboring Guangdong (44), and Hunan (44) 's well-developed agricultural and economic regions formed a low-high outlier. These findings suggest that regional cooperation in research is mainly limited to several coastal provinces, with scarce collaboration among other provinces across China. To assess the differences among neighboring provinces, Geary's C index was calculated. As shown in *Figure 8b*, research output in Shandong (37), Jiangsu (32), and Shanghai (31) demonstrated positive correlations with their neighboring provinces. This indicates that the increased literature in the surrounding provinces was influenced by the research output of these three provinces, demonstrating a certain spill-over effect on academic research. Conversely, Shaanxi province exhibited a negative correlation, suggesting that research output in neighboring provinces did not experience a corresponding increase in benefiting from Shaanxi (61). The low-low values observed in Qinghai (63) and Guizhou (52) provinces further highlight the overall underdevelopment of academic research in the Southwestern and Northwestern regions.



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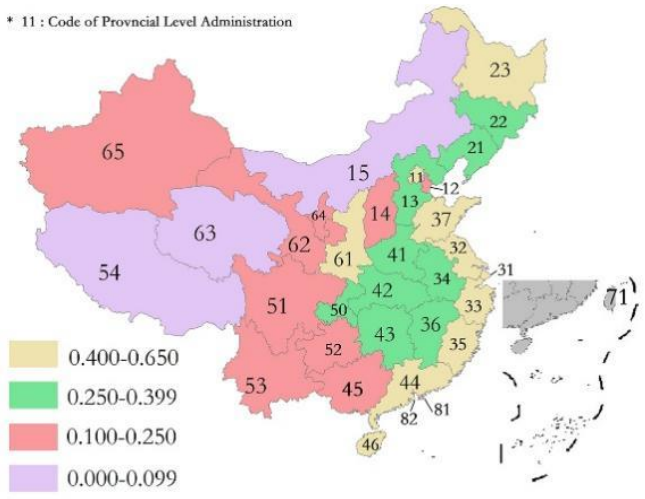

b

Figure 7. *Quarterlies map of the number of literatures related to ecological agriculture of different provinces in 2012-2017 (a), and 2018-2023 (b). Codes and geographic divisions: '1x': Northern, '2x': Northeastern, '3x': Eastern, '4x': Central and Southern, '5x': Southwestern, '6x': Northwestern*

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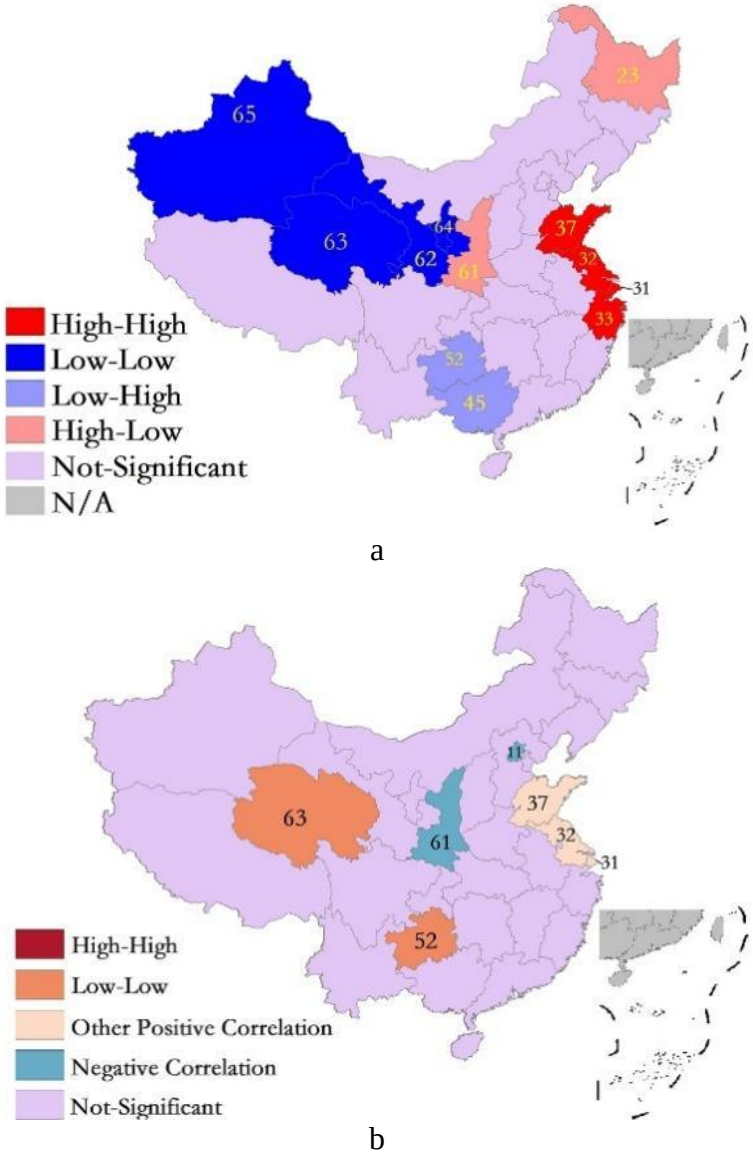

Figure 8. *The spatial autocorrelation analysis of provincial ecological agriculture research based on the number of literatures: (a) visualized by Local Moran's I index; (b) visualized by Geary's C index*

From a spatial statistical perspective, the Eastern region demonstrates advanced academic research and well-established cooperative relations. The Northwestern and Southwestern regions exhibit relatively lagging academic research, to some extent, reflects the underdevelopment of ecological agriculture in these respective regions.

Discussion

Research trends

Based on cluster and timeline analysis, research on ecological agriculture in China has demonstrated a sustained level of activity in various themes over the past decade. Time line analysis and keywords with strongest citation bursting indicated that

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ecological tourism, rural revitalization, and ecological planting are the future research directions. Moreover, the bibliometric and spatial statistical analysis indicates several potential trends for future research:

Regional cooperation: Spatial statistical analysis of published literature indicates the lack of regional collaboration in ecological agriculture research in China, particularly in Central, Southwestern, and Northwestern regions, even though their geographical and agricultural conditions are similar. Academic cooperation in these regions is crucial for promoting integrated and balanced development of regional ecological agriculture. Such cooperation can involve either intra-regional institutions researching regional problems or institutions in eastern regions and backward regions cooperating research on general topics or regional issues.

Focus on food security issues: Given the constraints of limited arable land, both central and local governments in China exhibit a durative concern on potential conflicts between ecological agriculture and food security. Therefore, it is essential for research efforts to prioritize the food security concerns and explore effective strategies for ecological agriculture within the context of food security. Such research should encompass a national-wide strategic discussion level as well as case studies conducted at the provincial or prefectural level. The valuable findings derived from academic research can serve as a fundamental basis for decision-making processes, instilling confidence in governments at all levels, and facilitating the development of ecological agriculture in China.

Applicability of new technology: Western countries boast a plethora of new technologies and innovative models in ecological agriculture. Chinese researchers should conscientiously take China's conditions into account and examine the suitability of these innovative technologies within the Chinese context. These studies may include the evaluation of economic costs associated with technology implementation, on-site cost-benefit analyses, as well as comparative studies. Undertaking such research allows for the attainment of the coordinative development between novel ecological technologies and intensive agricultural production.

Suggestions and countermeasures

The implementation of food security in China will not only reduce its imports from the global grain market but also enable the possibility of its grain exports. This could significantly contribute to the global goal of fighting against malnutrition in undeveloped regions. Ecological agriculture is a vital pathway to promote the resolution of the food security problem in China. In addition to suggestions frequently mentioned in other literature such as the use of new technologies, intelligent and smart management, regional cooperation, and policy incentives, the following specific recommendations are proposed for the development of ecological agriculture in China:

Farmer Education: Farmers, as the primary practitioners of ecological agriculture, have often been overlooked in current research and implementation efforts in China. Therefore, it is crucial to strengthen the educational and training programs specifically designed for farmers. These initiatives aim to equip them with comprehensive knowledge and practical skills necessary for effective ecological planting and production practices in rural areas. It is proposed to rebuild or rehabilitate county-level agricultural machinery schools and village-level agricultural training stations as training places for farmers. Furthermore, in alignment with national initiatives such as the 'Beautiful Waters and Green Mountains' campaign and the 'Rural Revitalization'

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strategy, it is recommended to provide fiscal subsidies, tax benefits, and land policies that serve as incentives and facilitators for the transformation of rural areas into dedicated ecological agricultural zones.

Policy stability: In 2002, China implemented the policy of 'Conversion of Farmland Back to Forests', aiming to transform farmland adjacent to mountainous and arid regions into forested areas. However, in 2020, driven by the issue of insufficient food production, the government introduced an antithetical policy known as 'Conversion of Forests Back to Farmland'. This new policy calls for cutting down the forest that was expanded under the previous policy and turning it back into farmland. These disorderly and illogical policies have significantly weakened food production and the implementation of ecological agriculture in China. To maintain stability and ensure the legitimacy of policymaking, it is imperative to decentralize decision-making authority to provincial governments. Provincial governments can formulate tailor-made policies and plans that align with their specific geographical and agricultural conditions.

Regional differentiated development: Northeastern China is the primary grain production area and bears significant responsibility for food security (*Fig. 9*). Therefore, this region still needs to perform intensive production. Given the high pressure for grain production in this region, it is essential to actively adopt diverse ecological restoration technologies that can sustain soil fertility without reducing food production. These measures may include green fertilizer mulching, microbial restoration, and other relevant techniques. The Central, Northern, and Eastern regions of China also serve as major grain production areas but face challenges of soil degradation and chemical pollution. Ecological restoration in these regions should primarily focus on necessary land fallow or rotation to mitigate soil degradation. Intensive grain production is also the main model of these regions; the Jiangsu and Zhejiang provinces in the Eastern region, which are close to developed cities, experience high consumer demand for organic agricultural products. Consequently, it can prioritize the development of organic agriculture to achieve better market profits; the Northwestern region of China is ecological-fragile and unsuitable for intensive agricultural production. Instead, this region should primarily engage in ecological tourism and low-density planting to alleviate the ecological pressure; the Southwestern and Southern regions of China benefit from favorable water and thermal conditions but face challenging geographical conditions for agricultural production. Mountainous areas within this region are well-suited for developing alternative crops and cultivating traditional medicinal herbs, while plains can focus on rice cultivation. Thereby, this region can be a supplementary backup in ensuring food security.

Thereby, food security and ecological agriculture can be synchronously promoted through differentiated regional development, and the integration of ecological agriculture can be gradually realized in the whole country.

Limitation and applicability

Research that covers the entire country or general aspects cannot be classified into specific provinces. Nevertheless, even in such cases, this type of broad research can still demonstrate the degree of attention towards ecological agriculture within respective provinces. This allows bibliometric methods to align the authors' institutional affiliations with the number of regional publications, ensuring the reliability and effectiveness of data implemented in spatial statistical analyses.

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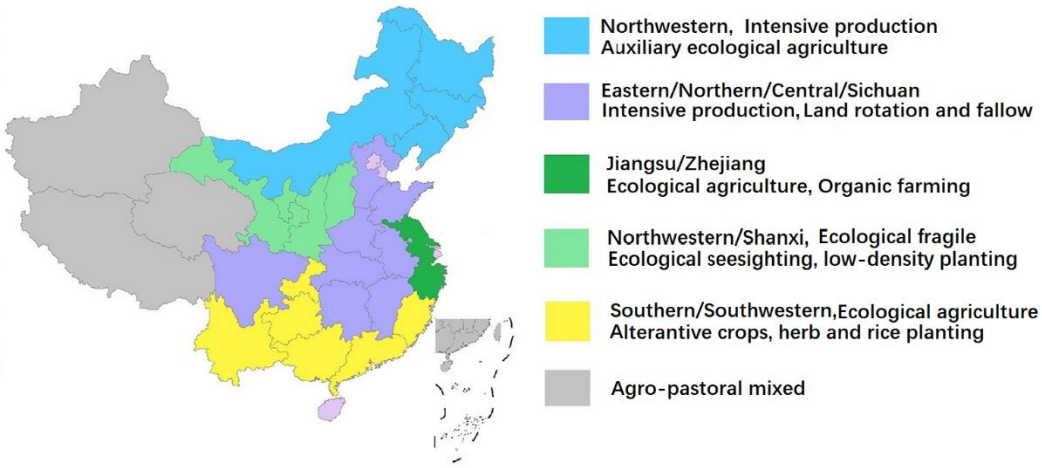

Figure 9. *Regional differentiated development of ecological agriculture in China*

This study employs spatial autocorrelation analysis to examine the quantity of published literature at the provincial level. While it does not provide detailed information regarding the spatial relationships of provincial ecological agricultural statuses, it does contribute to the academic reflection of research levels and collaboration within each region. Consequently, bibliometric indicators, derived from analyzing the number of publications, can be integrated into the evaluation system for ecological agricultural development. This integration effectively showcases the research level and support for specific practices in different regions, thereby enhancing the comprehensiveness and efficacy of research. Such an approach bears significance not only in evaluating ecological agricultural research topics but also in assessing other regional subjects such as tourism, social development, or industrial advancement.

Conclusion

Based on a bibliometric analysis of 1986 representative Chinese publications from 2012 to 2023, the following conclusions can be drawn:

The number of annual publications underwent fluctuations over the past decade. Beijing-based institutes that focused on macro-level research in ecological agriculture formed the main institutional network. Authors created multiple dispersed cooperative networks, with a dominant cluster conducting research related to alternative planting and herbal planting.

Keywords such as rural revitalization, modern ecological agriculture, and circular economy were most frequently cited in the literature. The keyword clusters can be broadly classified into three aspects: specific practical research, macro-level studies, and countermeasures to challenges, demonstrating the coverage of research from strategic planning to implementation details.

The time analysis indicates that research clusters related to ecological agricultural tourism, protection and remediation, and development mode have had longer durations over the past decade. Studies on ecological planting and rural revitalization began receiving more attention after 2016. Meanwhile, topics such as value development, carbon neutrality, and industrial integration represent the most recent research hotspots.

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Spatial statistical analysis reveals that provinces in the Eastern region show strong academic cooperation and exert a spillover effect in neighboring provinces. Provinces in the Northwestern, Northeastern, and Central regions share similar agricultural conditions but exhibit weaker collaboration in research. Further strengthening academic research cooperation among these provinces is needed.

This study proposes specific recommendations for promoting the sustainable development of ecological agriculture in China. These include conducting proper regional ecological restoration, implementing differentiated regional development, and enhancing farmer education.

In terms of research methodology, this paper suggests spatial statistical analysis of bibliometric data to obtain regional differences in academic research. This approach provides a quantitative supplement to bibliometric conclusions, particularly for topics related to regional factors.

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APPENDIX

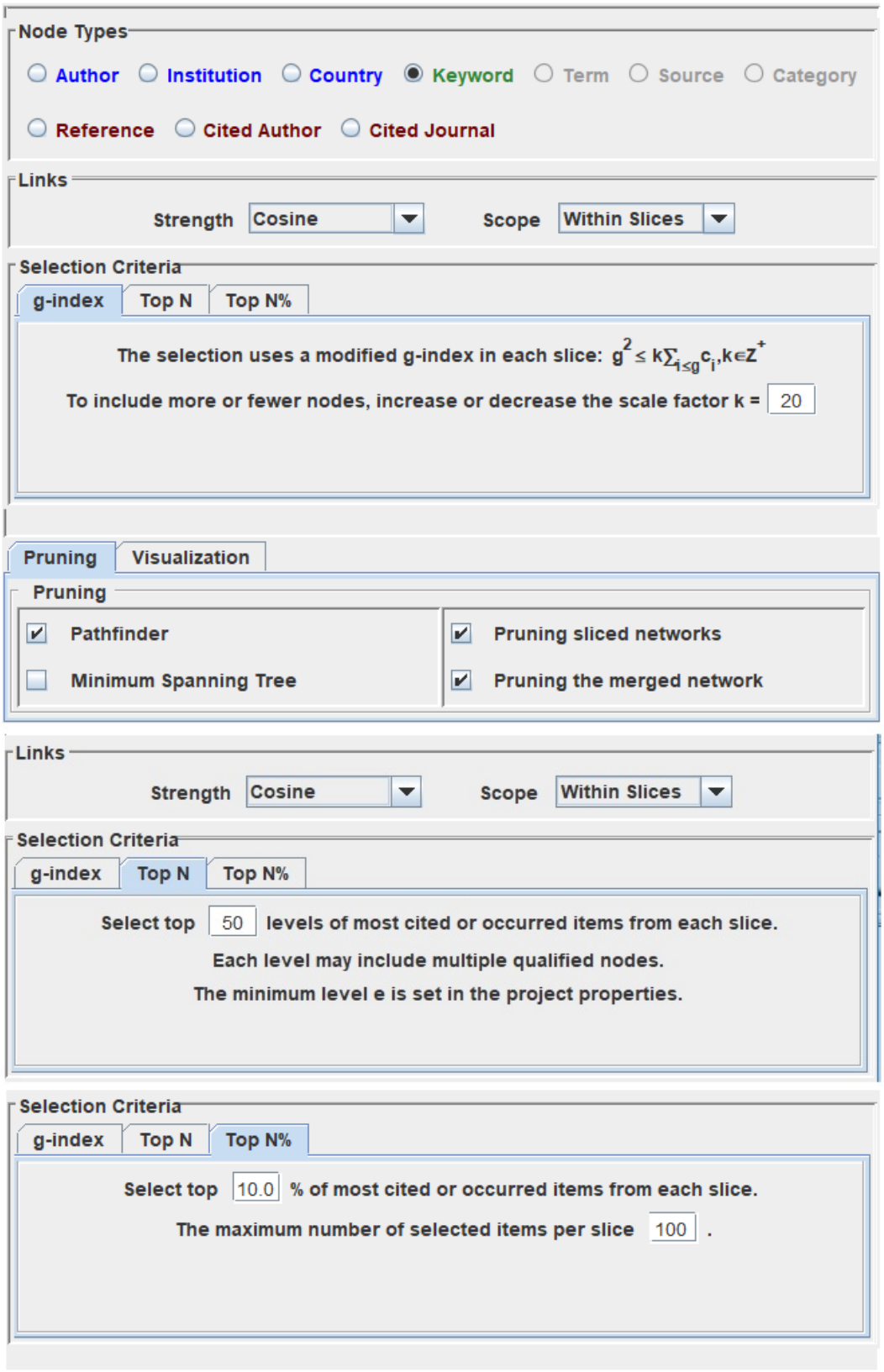

Figure A1. *The parameter of keyword/author/institutions analysis in Citespace*

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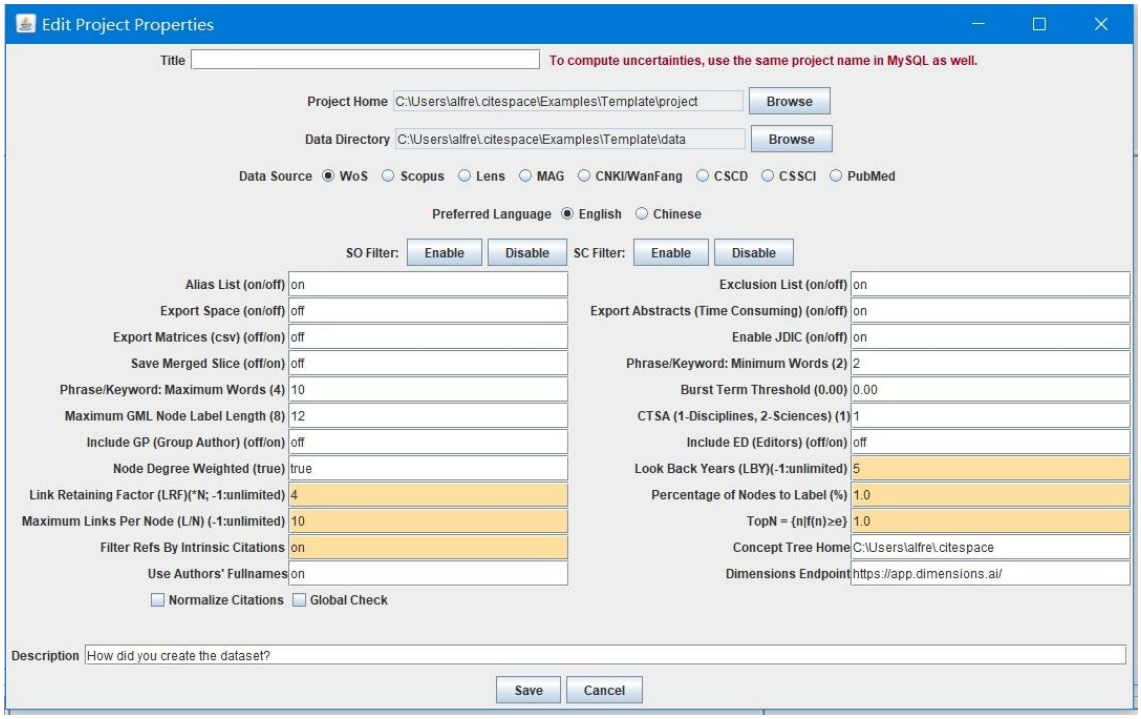

Figure A2. *The parameter of project properties of this study in Citespace*

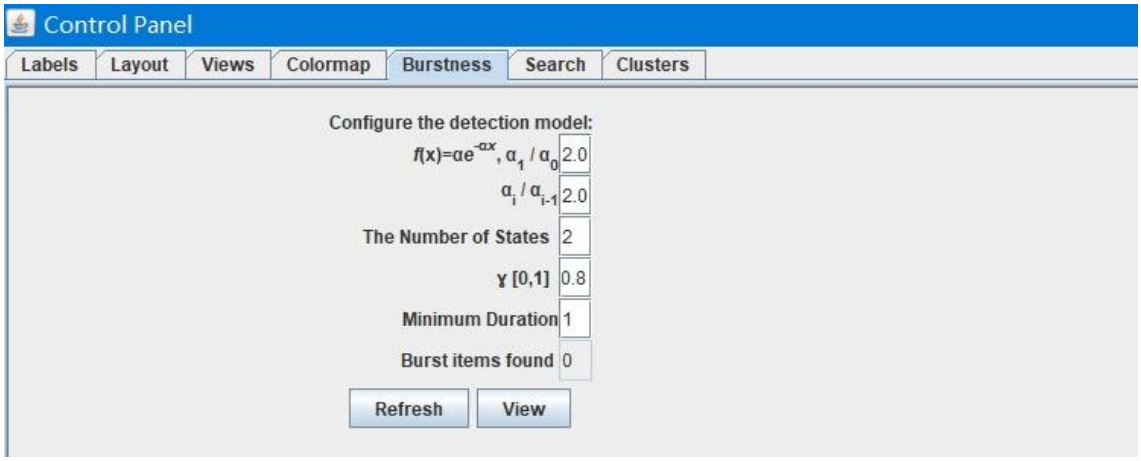

Figure A3. *The parameter of burstness (keywords with strongest citation bursting) search in Citespace*

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