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Review

Science Mapping of Meta-Analysis in Agricultural Science

Weiting Ding [1,2], Jialu Li [1], Heyang Ma [1], Yeru Wu [1] and Hailong He [1,2,3,*]

[1] College of Natural Resources and Environment, Northwest A&F University, Yangling 712100, China; weiting.ding@nwafu.edu.cn (W.D.); lijialu@nwafu.edu.cn (J.L.); maheyang@nwafu.edu.cn (H.M.); yeru.wu@nwafu.edu.cn (Y.W.)
[2] Key Laboratory of Plant Nutrition and the Agri-Environment in Northwest China, Ministry of Agriculture, Northwest A&F University, Yangling 712100, China
[3] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences (CAS) & Ministry of Water Resources (MWR), Northwest A&F University, Yangling 712100, China
* Correspondence: hailong.he@nwafu.edu.cn

Abstract: As a powerful statistical method, meta-analysis has been applied increasingly in agricultural science with remarkable progress. However, meta-analysis research reports in the agricultural discipline still need to be systematically combed. Scientometrics is often used to quantitatively analyze research on certain themes. In this study, the literature from a 30-year period (1992–2021) was retrieved based on the Web of Science database, and a quantitative analysis was performed using the VOSviewer and CiteSpace visual analysis software packages. The objective of this study was to investigate the current application of meta-analysis in agricultural sciences, the latest research hotspots, and trends, and to identify influential authors, research institutions, countries, articles, and journal sources. Over the past 30 years, the volume of the meta-analysis literature in agriculture has increased rapidly. We identified the top three authors (Sauvant D, Kebreab E, and Huhtanen P), the top three contributing organizations (Chinese Academy of Sciences, National Institute for Agricultural Research, and Northwest A&F University), and top three productive countries (the USA, China, and France). Keyword cluster analysis shows that the meta-analysis research in agricultural sciences falls into four categories: climate change, crop yield, soil, and animal husbandry. Jeffrey (2011) is the most influential and cited research paper, with the highest utilization rate for the *Journal of Dairy Science*. This paper objectively evaluates the development of meta-analysis in the agricultural sciences using bibliometrics analysis, grasps the development frontier of agricultural research, and provides insights into the future of related research in the agricultural sciences.

Keywords: scientometrics; science mapping; VOSviewer; CiteSpace; meta-analysis; agriculture

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1. Introduction

Meta-analysis is a widely used statistical technique that systematically integrates data from multiple related but independent studies and analyzes them together to better estimate the real impact of specific interventions or exposures on specific outcomes [1,2]. This allows researchers to draw more robust conclusions than via the analysis of any separate study [3]. Individual studies are often insufficient to provide clear results, while larger studies often fail to fully estimate the difference in the risk of rare adverse events [4]. Therefore, a systematic combination of multiple research results, even if they are uncertain or contradictory, helps to more clearly identify true measurements [2,5,6]. With the number of subjects increasing, large differences between subjects, or cumulative effects and results, the conclusions of the meta-analysis are statistically stronger than those of any single study [7,8]. Meta-analysis has developed from being used only by some unknown statisticians to becoming a major academic industry [9]. Meta-analysis was initially popular in the biomedical literature and gradually attracted attention from the mainstream media. There are numerous references in the medical and statistical literature on the theory and correct procedure of meta-analysis [10]. Later, meta-analysis was also used in other different disciplines, including ecology [11], plant pathology [12], animal science [13], psychology [14], and agriculture [15].

With the continuous innovation of research methods and technologies, meta-analysis, as a promising method, has been applied more and more in agricultural science and has made remarkable progress [16]. Agriculture faces an increasing number of challenges, such as ensuring ecosystem services and resolving apparent conflicts between them [17]. Papers published in agricultural journals provide a large amount of experimental data, which can be reviewed, integrated, and analyzed through statistical techniques, providing theoretical guidance for solving these challenges [18]. Meta-analysis can more accurately quantify the interaction between farming system performance and soil and climate conditions in the environmental and socio-economic contexts [17,19,20]. Miguez and Bollero [21] quantitatively summarized and described the impact of several mulching crops on corn yield using meta-analysis, and estimated the corn yield after winter mulching based on 37 studies conducted in the United States and Canada. Miguez et al. [22] used 31 published studies to analyze the dry biomass in different seasons in recent years, and determined the effect of management factors (planting density and nitrogen fertilizer) on mango. Badgley et al. [23] compared two agricultural systems: organic agriculture and traditional agriculture or low-intensity agriculture using 293 global data sets, and through a review of published studies, they raised important questions about crop rotation under organic and conventional agriculture. Philibert et al. [24] reviewed the 73 meta-analyses and argued that meta-analysis techniques would be beneficial to agricultural research. They also encouraged the appropriate use of meta-analysis methods and provided a better understanding of published system reviews [4].

Indeed, there are many research reports on meta-analysis in agricultural disciplines [25–33]. Therefore, the application status, research hotspots and development trend of meta-analysis in agriculture still need to be better characterized. Bibliometrics can accurately process the relevant literature information, systematically analyze the overall development of a given field, and track the development of the field [34,35]. Many scholars have used bibliometrics to analyze the collaboration between authors, institutions, and disciplines in related fields, and understand the knowledge structure and hot trends in the research fields [36,37]. As an effective method for analyzing big data, bibliometrics is widely used in research from various disciplines [38]. Lv, Zhao, Wu, Lv, and He [37] used bibliometric methods to analyze and evaluate the current situation and evolution of intercropping research, and made suggestions for future research on intercropping. Han et al. [39] performed a bibliometric analysis of publications on the genotoxicity of organic contaminants in soil and summarized the current hotspots, mechanisms of genotoxicity from the overall perspective, and future research direction. Although meta-analysis has been widely used in agronomy, ecology, and other disciplines [11,40,41], there is no report on the bibliometric analysis of the meta-analysis literature.

Scientometrics is a discipline that quantitatively analyzes researchers and research results with mathematical methods, reveals the scientific development process, quantifies scientific research activities with citation analysis and other methods, and provides a basis for scientific decision making and management [42–44]. The map of scientific knowledge is a bibliometric method [45]. Based on the similarity and measurement of information units through statistical analysis and computer technology, a matrix is constructed for a large number of document information (e.g., keywords, alternative citation frequency, references), and the relationship and structure between information units are displayed through visual analysis (e.g., network diagram, concept structure diagram) [46]. The visual software based on bibliometrics can extract, process, and analyze citation data, form a visual network atlas, reduce workload, and facilitate interpretation and analysis [35,47]. The visualization software can be used not only to present the cooperative relationship between different authors, countries and institutions, but also to show the co-occurrence network relationship of research topics and fields [46]. It can also conduct an analysis of co-citation and coupling of the literature, and reveal research hotspots, research trends, and research frontiers. The data visualization software VOSviewer and CiteSpace are widely used in different countries and fields [48] to analyze research hotspots and research frontiers in different periods of soil science development locally and abroad and researching the most influential research topics [49].

In this study, the scientific knowledge map analysis of meta-analysis publications published in the field of agricultural science in the last 30 years (1992–2021) was conducted based on Web of Science Core Collection (WoSCC) database and bibliometrics methods. Using VOSviewer and CiteSpace, a meta-analysis of countries/regions, research institutions, journal sources, and highly cited publications in agricultural science research was conducted from the evaluation indicators of the number of papers issued, the total citation frequency, and the citation frequency per article, and a cooperative relationship between countries and research institutions was established. We focus on the analysis of keyword co-occurrence network spectrum locally and abroad in different time periods to reveal the changes in high-frequency keywords or keywords with high centrality in relevant research fields in different periods, and then summarize the latest research progress, hotspots, and historical development context in this research field, providing theoretical guidance for future research in agricultural science.

2. Methods

The Science Citation Index Expanded (SCI-EXPANDED—1992–present) of the Web of Science Core Collection (WoSCC) is one of the most comprehensive, widely utilized high-quality databases in scientific metrological analysis [50–56]. The data from 1992 to 2021 were exported from the WoSCC on 9 October 2022 based on query sets: "TS = (meta-analysis)", where TS indicates "topics". The search results were further refined by research areas (agriculture) and languages (English). A total of 2226 publications were retrieved based on the above criteria, and these publications were saved as text files containing "Full Record and Cited References".

The VOSviewer (version 1.6.17) [57] and CiteSpace (version 6.1.R3) [58] (Drexel University, Philadelphia, PA, USA) were used to analyze and visualize the retrieved data. According to bibliometric network data, performance related analysis, includes creating, visualizing, and exploring scientific maps in cluster format by the VOSviewer. The co-authorship of the author, organization, country, and the keyword co-occurrence are also implemented in VOSviewer. Based on the theory of each co-author, a complete counting method is used. The weight of co-occurrence is the same regardless of the number and order of authors in the co-author list. Based on the number of articles published by the co-author, the relevance of the project is determined to conduct a co-author analysis. The relevance of items was determined based on the number of concurrent articles to perform co-occurrence analysis. The burst time of keywords was analyzed using CiteSpace. "Burst time" refers to a period of time during which the number of publications is significantly increased. Origin 2021 was used to visualize the year-to-year changes in publications, and the journals with high contribution rate and utilization rate of national publications.

3. Results and Discussion

3.1. Overview of Annual Publication Trends

Bibliometric methods were used to check the volume of publications on this subject published each year to better understand the application status and development trend of meta-analysis in the agricultural field. According to the preset procedures and control standards, there were 2226 publications (1822 or 81.85% articles, 401 or 18.01% reviews, and 67 or 3.01% others) by 8005 authors in 249 journals from WoSCC for the 30-year period, 1992–2021. This study included all meta-analysis publications related to agriculture from January 1998 to December 2021. There were in the five categories: Agriculture Dairy Animal Science (N = 790 or 35.49%), Agronomy (N = 614 or 27.58%), Soil Science

(N = 432 or 19.41%), Agriculture Multidisciplinary (N = 313 or 14.06%), and Food Science Technology (N = 267 or 12.00%). It is noteworthy that the number of publications in these five categories exceeds 2400, mainly because some journals belong to multiple categories of the Web of Science database. The annual volume of publications increased from 1992 through to 2021 (Figure 1). The results show an increasing trend in the recognition and application of meta-analysis in agriculture. It is expected that there will be numerous meta-analysis publications in the future.

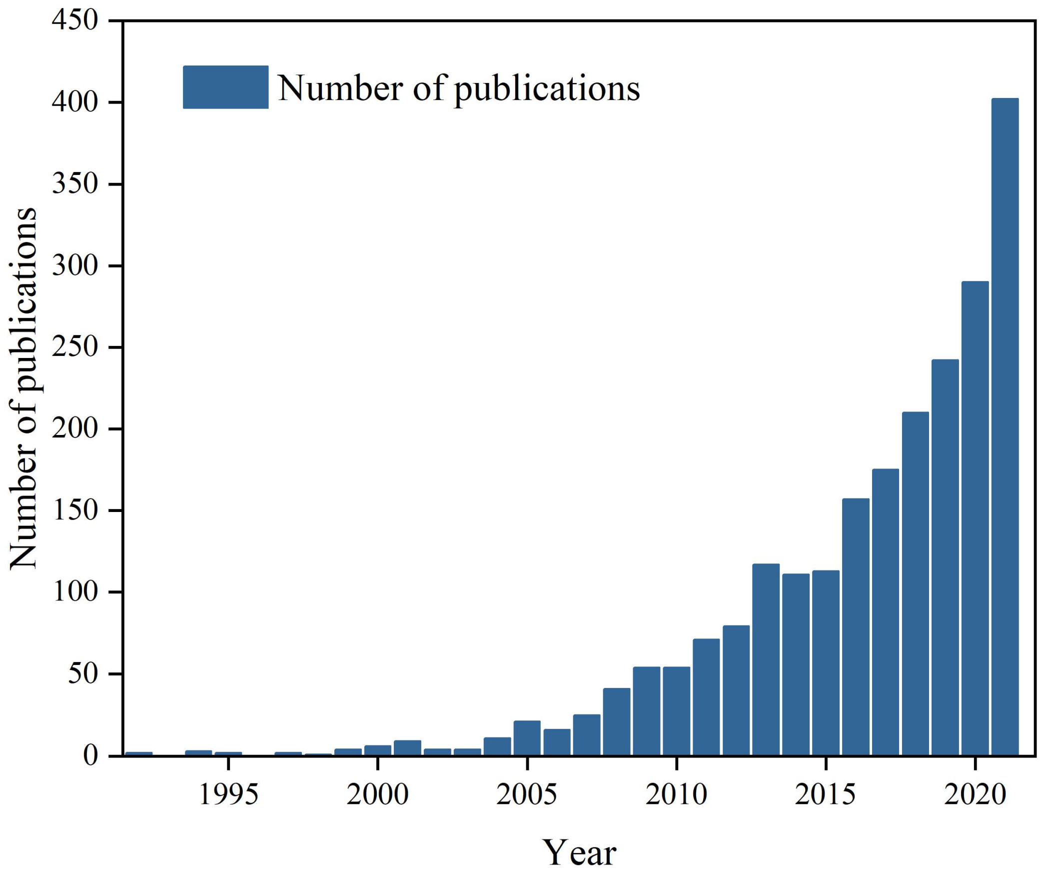

Figure 1. Annual trend of meta-analysis in agricultural science-related research publications from 1992 to 2021.

More than 100 countries or regions have published meta-analysis research in agricultural science, with the USA (N = 581), China (N = 521), France (N = 203), Australia (N = 197), and Brazil (N = 193) ranking as the top five. Meta-analysis accounts for a large proportion in the WoSCC Categories of Agriculture Dairy Animal Science, Agronomy, and Soil Science. The journal *Agriculture Dairy Animal Science* (790 publications) was ranked first, accounting for 35.49% of the total publications, followed by Agronomy (614 publications) and Soil Science (432 publications), accounting for 27.58% and 19.41%, respectively. In addition, most papers were research articles (1822 publications), which accounts for 81.85% of the total number of articles, followed by reviews (18.01%) and proceeding papers (2.16%).

3.2. Co-Authorship of Authors, Organizations, and Countries

Of the 8777 authors, 135 reached the threshold of at least five publications (Figure 2). They were divided into 43 groups, 1 of which represented a group of authors cooperating closely together. The largest group of relevant authors is 13, which are concentrated in Figure 2a. The colors in Figure 2b represent the author's active period: "yellow" indicates that researchers have published meta-analysis research recently, "green" represents papers published around 2016, and "blue" indicates that they were published around 2010. For instance, Sauvant, D [13,59,60] from University Paris Saclay (France), Kebreab, E [61,62] from University of California Davis (USA), and Huhtanen, P. [63,64] from Agriculture & Agri Food Canada have been publishing on meta-analysis (Table 1). Other productive researchers such as Zhu, Biao [65,66] (Peking University, China) and Fan, Junliang [67] (Nanjing University of Information Science & Technology, China) were active around 2020, while Chen, Qingshan (Northeast Agricultural University, China) [68,69] and Glasser, Frederic (L&L Prod Europe SAS, France) [70,71] were active around 2010.

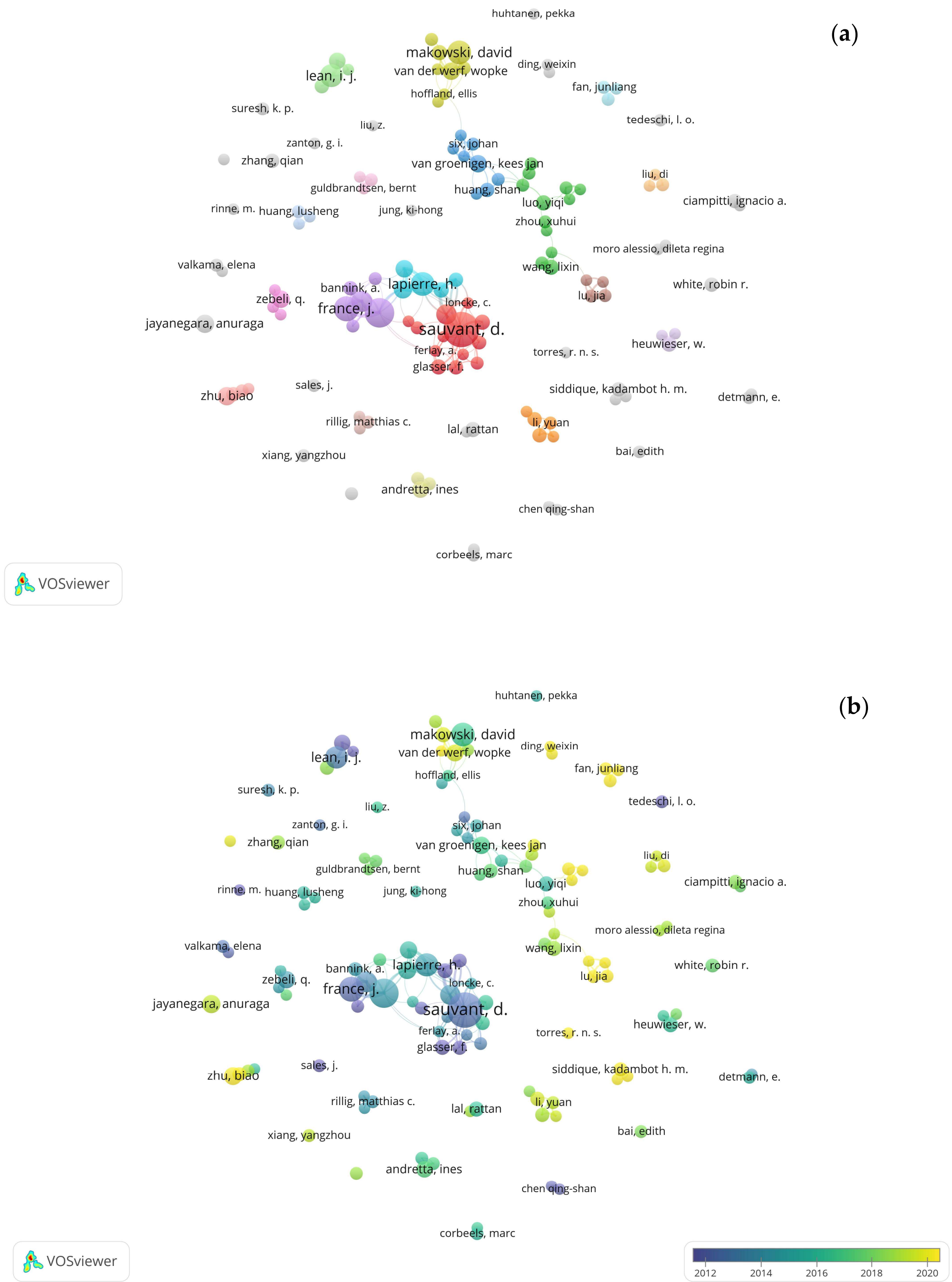

Figure 2. A co-authorship network visualization (**a**) and overlay visualization (**b**) map of 135 authors with more than 5 publications. The larger the circle and font in the network diagram, the stronger the link and the more references. The color of a circle indicates the cluster to which it belongs.

Table 1. Top 15 authors on meta-analysis publications.

NO.	Author	N	C	C/N	TLS
1	Sauvant, D (Univ Paris Saclay, France)	35	1370	39.14	63
2	Kebreab, E (Univ Calif Davis, USA)	25	616	24.64	49
3	Huhtanen, Pekka (Nat Resources Inst Finland LUKE, Finland)	20	895	44.75	13
4	France, J (Univ Guelph, Canada)	19	496	26.11	35
5	Lapierre, H (Agr & Agri Food Canada, Canada)	17	372	21.88	54
6	Makowski, David (Univ Paris Saclay, France)	17	993	58.41	12
7	Lean, I. J (Scibus, Australia)	16	1065	66.56	18
8	Dijkstra, J (Wageningen Univ & Res, Netherlands)	14	397	28.36	30
9	Noziere, Pierre (Univ Clermont Auvergne, France)	13	349	26.85	33
10	Jayanegara, Anuraga (Swiss Fed Inst Technol, Switzerland)	11	249	22.64	0
11	Martineau, R (Univ Laval, Canada)	11	180	16.36	35
12	Zhu, Biao (Peking Univ, China)	11	321	29.18	1
13	Ouellet, D. R (Agr & Agri Food Canada, Canada)	10	195	19.50	29
14	van der werf, wopke (Wageningen Univ & Research, Netherlands)	10	461	46.10	23
15	van groenigen, kees jan (University of Exeter, UK)	10	1109	110.90	19

The number of documents (N), citations (C), and total link strength (TLS) were analyzed based on VOSviewer. N and C are recorded from WosCC data between 1992 and 2021, where C/N represents the calculated average number of citations per paper. TLS represents the total strength of an item's links to other items.

There were 2166 organizations that published meta-analysis studies in Agricultural science, with the Chinese Academy of Sciences ranking first in the number of publications (N = 112), followed by the World INRA (N = 104), Northwest A&F University (N = 61), University of California Davis (N = 57), and University of Chinese Academy of Science (N = 49) as shown in Table 2. In terms of average citations, Wageningen University leads (C/N = 88), followed by Ohio State University (C/N = 80.79), and USDA ARS (C/N = 73.51). The average citations of publications from University of California Davis, Agr & Agri Food Canada, INRA, and Swedish University of Agricultural Sciences are ≥40, which shows that these institutions have high influence. In addition, the Chinese Academy of Science, INRA, and University of California Davis have more cooperation with other organizations, based on their high TLS (over > 90).

Table 2. Top 15 organizations on meta-analysis publications.

No.	Organizations	N	C	C/N	TLS
1	Chinese Academy of Science, China	112	3946	35.23	161
2	INRA, France	104	5485	52.74	107
3	Northwest A&F University, China	61	1114	18.26	80
4	University of California Davis, USA	57	4068	71.37	97
5	University of Chinese Academy of Science, China	49	1543	31.49	93
6	China Agriculture University, China	48	1269	26.44	58
7	Agr & Agri Food Canada, Canada	47	2503	53.26	70
8	University of Guelph, Canada	46	1412	30.70	76
9	Chinese Academy of Agricultural Sciences, China	45	1216	27.02	65
10	Wageningen University, Netherlands	44	3872	88.00	78
11	USDA ARS, USA	43	3161	73.51	87
12	Ohio State University, USA	39	3151	80.79	34
13	Swedish University of Agricultural Sciences, Sweden	37	1564	42.27	53
14	Kansas State University, USA	36	902	25.06	45
15	University Fed Vicosa, Brazil	36	491	13.64	39

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Figure 3a shows the cooperation among major countries or regions. According to the author's country/region, the academic contributions of different countries/regions are evaluated (Figure 3b). There were 100 countries that had published studies on meta-analysis in agricultural science, including the USA (N = 577), China (N = 528), France (N = 202), Australia (N = 195), and Brazil (N = 193), which were the top 5 (Table 3). Interestingly, the Netherlands led in the average citation (C/N = 56.26), followed by Spain (C/N = 55.86) and Sweden (C/N = 52.19). The USA had the most cooperation (TLS = 488), followed by China (TLS = 368) and France (TLS = 260). The top 15 countries in terms of total number of documents issued often cooperate with each other. The USA was the main partner with countries including France, China, and Canada, and had the most documents issued. The cooperation between the United States and China was the largest. The whole cooperation network had obvious characteristics of transcontinental cooperation.

Table 3. Top 15 countries based on meta-analysis publications.

No.	Country	N	C	C/N	TLS
1	USA	577	29,429	51.00	488
2	China	528	15,298	28.97	368
3	France	202	8985	44.48	260
4	Australia	195	10,045	51.51	230
5	Brazil	193	3288	17.04	125
6	England	177	8580	48.47	336
7	Germany	171	7508	43.91	222
8	Canada	169	6598	39.04	227
9	Netherlands	105	5907	56.26	209
10	Spain	98	5474	55.86	172
11	Italy	94	3750	39.89	154
12	India	68	1246	18.32	51
13	Sweden	53	2766	52.19	70
14	Denmark	52	1735	33.37	106
15	New Zealand	52	1769	34.02	89

The number of documents (N), citations (C), and total link strength (TLS) were analyzed based on VOSviewer. N and C are recorded from WosCC data between 1992 and 2021, where C/N represents the calculated average number of citations per paper. TLS represents the total strength of an item's links to other items.

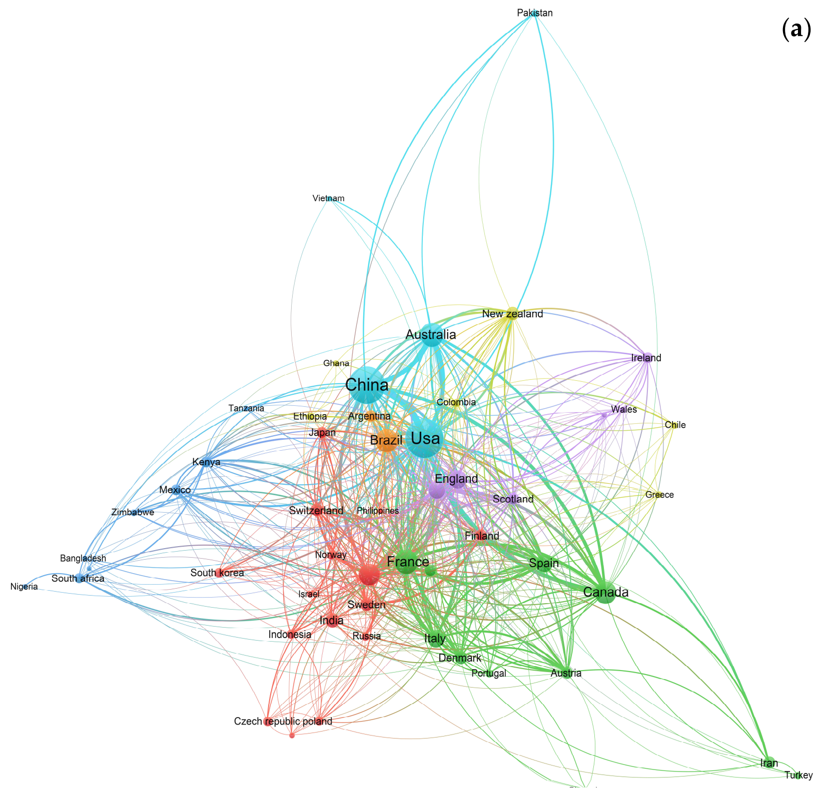

Figure 3. *Cont.*

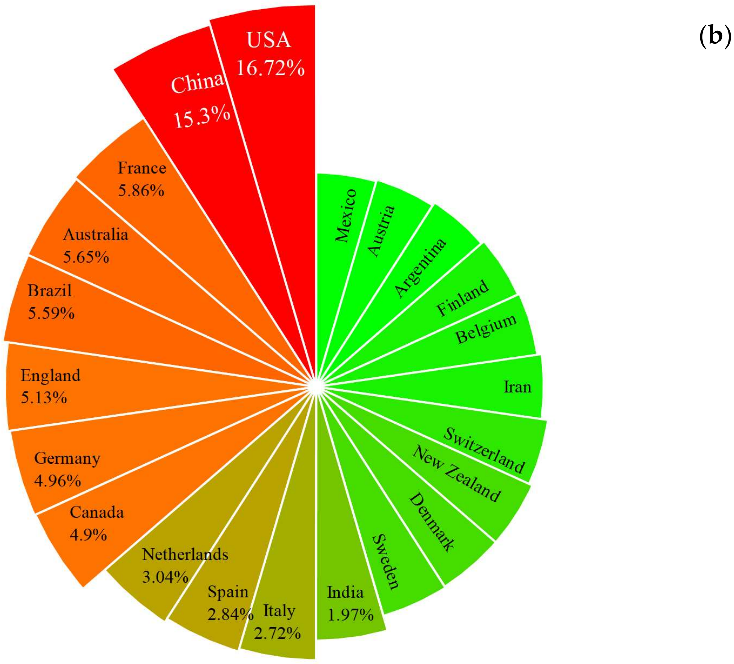

Figure 3. The co-authorship network visualization. (**a**) For the cooperation between major countries or regions, Node size represents the number of documents published, lines in the network represent cooperation between major countries or regions, and line thickness represents cooperation intensity. (**b**) Contribution of countries to published articles (only countries with more than 1% contribution are shown).

3.3. The Most Recognized Journals and Highly Impactful Studies

A total of 249 journals published meta-analysis research related to agriculture based on Web of Science, and two of them had published more than 100 papers each (Figure 4). The *Journal of Dairy Science* had the most publications with over 180 papers, followed by the *Journal of Animal Science and Agriculture Ecosystems Environment* with around 180 papers each. The result shows that meta-analysis is indispensable in research across various disciplines, which may also provide hints for selecting appropriate journals for future meta-analysis studies.

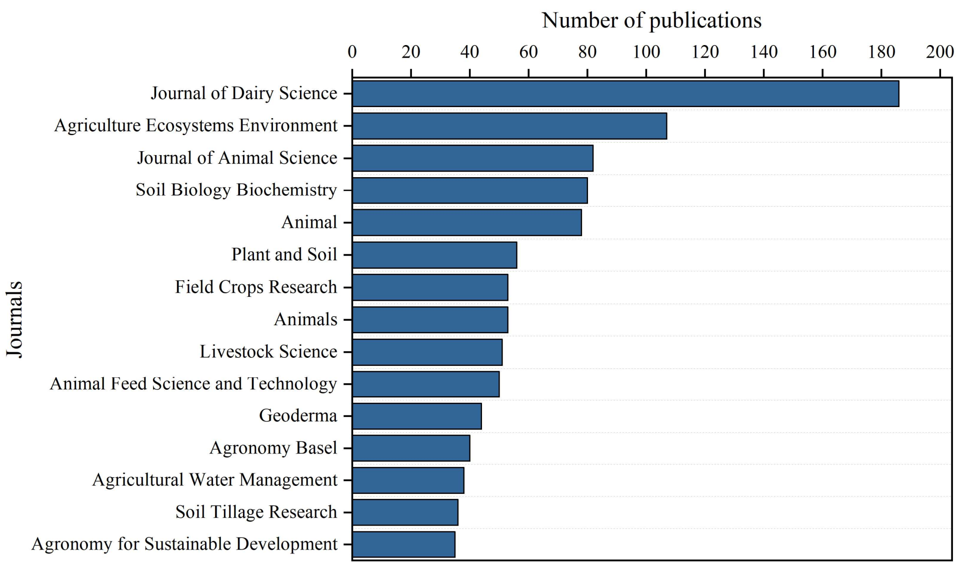

Figure 4. Top 15 journals and their publications.

Among the 2226 publications, 193 were cited more than 100 times, which were divided into 69 clusters, with the largest group consisting of 17 papers (Figure 5). Jeffery et al. [72], Westoby [73], and Saiya-Cork et al. [74] were the first three studies to be cited more than 100 times, with the three journals focusing on biochar application, ecology or nitrogen deposition in agriculture.

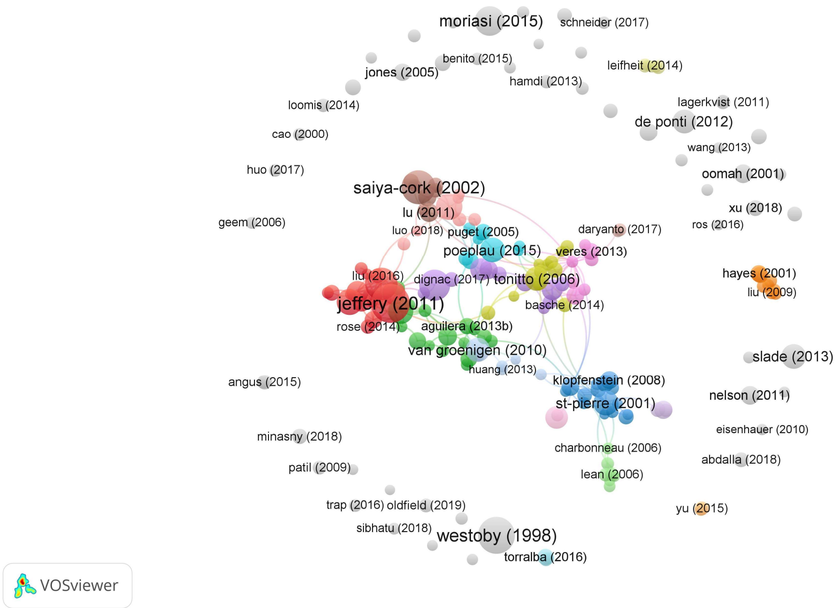

Figure 5. The VOSviewer is used to visualize a network map of 193 publications with more than 100 citations. Each node represents a paper. The larger the node, the more references. The lines represent the co-citation relationship between documents. The thickness of the lines represents the strength of the connection.

3.4. Co-Occurrence and Burst Time of Keywords

A total of 12,004 keywords are extracted by VOSviewer from the titles, abstract, and keyword lists, among which 161 keywords appeared more than 20 times. These keywords can be divided into four clusters represented by the colors red, green, yellow, and blue (Figure 6). Each cluster represents a class of related studies. The red-colored cluster represents the analysis of livestock as indicated by high frequency keywords "growth", "performance", "cattle", "pigs", "milk production", and "dairy cow". The green-colored cluster is associated with "climate-change" as indicated by keywords of "carbon", "nitrogen", "soil organic carbon", and "land use change". The blue-colored cluster is themed around "management" as indicated by keywords of "cover crops", "tillage", "systems", and "greenhouse-gas emissions". The top 15 keywords with greatest occurrences are listed in Table 4.

Table 4. Top 15 keywords on meta-analysis publications.

No.	Keyword	Occurrences	TLS
1	meta-analysis	837	2842
2	growth	160	576
3	yield	152	610
4	performance	146	504
5	nitrogen	141	668
6	management	138	613

Table 4. *Cont.*

No.	Keyword	Occurrences	TLS
7	climate-change	135	605
8	dairy cow	128	424
9	cattle	101	378
10	soil organic carbon	96	483
11	soil	92	388
12	quality	91	318
13	productivity	85	390
14	carbon	84	417
15	milk production	84	300

The number of documents (N), citations (C), and total link strength (TLS) were analyzed based on VOSviewer. N and C are recorded from WosCC data between 1992 and 2021, where C/N represents the calculated average number of citations per paper. TLS represents the total strength of an item's links to other items.

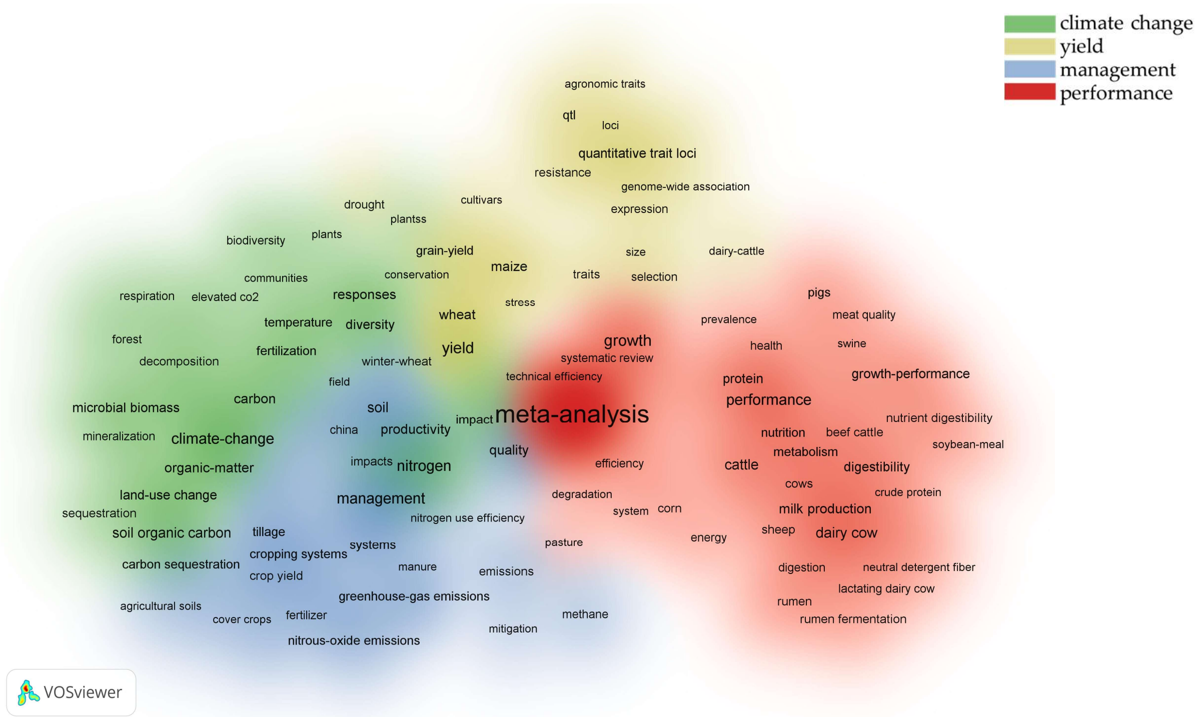

Figure 6. A co-occurrence diagram of 161 keywords with more than 20 occurrences. The font size and background color of the keyword are used to represent the total link strength (TLS). Larger fonts and darker colors indicate larger TLS. The distance between keywords indicates the relevance of research topics.

The keywords burst analysis was performed using CiteSpace. The temporal change in the strongest citation burst map is shown in Figure 7. The blue line shows when the keyword appears, and red line represents the time range in which keyword bursts are strong. The burst time of keywords shows the development trend and evolution of the research field. For instance, "somatic cell count" has the earliest and longest bursts. Other keywords include "energy metabolism", and "bacteria" related with biont. Most of the research focusing on "agronomic trait" starts in the 2010s. At present, the research themes of agricultural meta-analysis have shifted to "terrestrial ecosystem" under climate change.

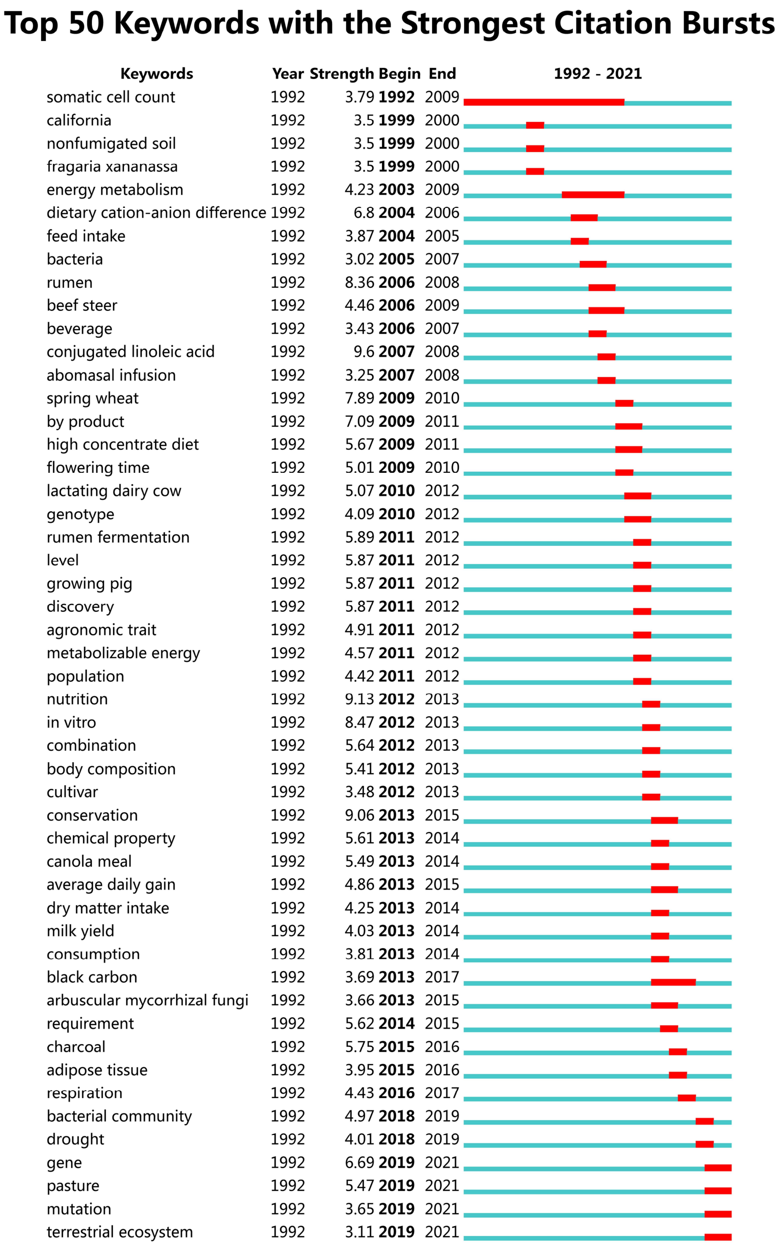

Figure 7. Based on the data retrieved from the WoSCC from 1992 to 2021, 50 mutation keywords were found using the keyword emergence time domain diagram analyzed using CiteSpace. The blue line and the red line indicate the time when the keyword appears and the period when the keyword is suddenly highly cited, respectively.

4. Conclusions and Perspectives

This study investigated the overall research status of agricultural meta-analysis and research from 1992 to 2021 through bibliometric methods. The analysis revealed the growth of the scientific research literature in this 30-year period, provided insights into authors' geospatial distribution, discussed the scientific research strength and cooperation between different research institutions and countries, and identified research hotspots and development trends from a keyword analysis. The annual number of publications applying meta-analysis to agricultural science increased rapidly in the during the 30 years. The results indicated that Sauvant Daniel from University Paris Saclay (France), Kebreab Ermias from University of California Davis (USA), and Huhtanen Pekka from Agriculture & Agri Food Canada are the top three authors, who have each published more than 20 papers on meta-analysis. Chinese Academy of Science, INRA, and Northwest A&F University were the top three productive organizations, while the USA, China, and France were the top contributors to the meta-analysis. The most influential studies were Jeffery, Verheijen, van der Velde and Bastos [72], Westoby [73], and Saiya-Cork, Sinsabaugh, and Zak [74], which focused on soil fertility, crop productivity, and ecology. The *Journal of Dairy Science* had the most publications (180 papers) relating to meta-analysis. The co-occurrence analysis showed that meta-analysis research in agricultural science focused on four aspects, which are represented by keywords such as climate change, crop yield, soil, and animal husbandry. Scientometrics is an effective tool for studying certain themes and is hoped to guide the application of agricultural meta-analysis methods.

There is a marked increased trend in applications of meta-analysis in agricultural sciences. Meta-analysis is a more objective and informative approach to summarizing information and is gradually replacing traditional or narrative commentary [75,76]. Meta-analysis can provide quantitative information (i.e., effect size), as well as qualitative information (i.e., research trends and current knowledge gaps) [77]. In addition, meta-analysis is a more powerful and less biased approach than traditional methods such as narrative reviews [78,79]. The introduction of meta-analysis also makes an additional contribution to increasing the focus on reporting standards for primary studies [80,81]. The findings of initial studies often cannot be confirmed by subsequent studies or the synthesis of research institutions. Meta-analysis can therefore provide more accurate and comprehensive evidence than individual studies [5,82].

Meta-analysis is essential for scientific progress. However, Whittaker [83] was the first person to criticize this method. He believed that meta-analysis would lead to highly different results. Inappropriate classification of data sets would lead to incorrect introduction and increase from one meta-analysis to the next. Hillebrand and Cardinale [2] worried that Whittaker [83] suggested that we "throw away the baby and bath water together". He said that this statement completely ignored many improvements in data processing and analysis developed for meta-analysis in the past decades [84]. In general, the process of meta-analysis is not complicated, but the requirements for detail require sufficient attention. Of course, there is no doubt that the implementation of meta-analysis needs to follow particularly rigorous rules. We agree with some suggestions of Whittaker [83], including the selection and analysis of data, to improve its transparency and quality control. There is no doubt that in the meta-analysis, if there is not enough quality control, there will be a certain risk of bias estimation, misunderstanding, and wrong conclusions. Meta-analysis is superior to narrative reporting, but it needs to be performed according to strict rules, and its quantitative results must be carefully explained. If inappropriate techniques are used, the value of meta-analysis may be significantly reduced. It is worth noting that conducting meta-analysis requires strict implementation of its quality standards and methods to improve its future performance.

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