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Review

Study on the General Situation and Trend of Pesticide in Global Soil System

Wei Li[1], Xianjin An[2,3]*

[1]College of Biology and Environmental Engineering, Guiyang University, Guizhou, Guiyang, China
[2]School of Karst Science, Guizhou Normal University, Guizhou, Guiyang, China
[3]State Engineering Technology Institute for Karst Desertification Control, Guizhou, Guiyang, China

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Abstract

Based on the core collection database of the Web of Science (WoS), the related papers research on pesticides in global soil system were analyzed. The development history, present situation and dynamic development trend of pesticides in soil system all over the world were analyzed by using the CiteSpace knowledge map analysis tool. The results showed that it was an active period of rapid development after 21 century in this field with number of annual papers was 143.95. The institution with the greatest number of papers, the highest total global citation frequency and the highest H index was the Chinese Academy of Sciences; the researchers with the greatest number of papers and the highest total global citation frequency were Qi S.H. from the College of the Environment, China University of Geosciences (Wuhan) and Kookana R.S. from the Commonwealth Scientific and Industrial Research Organization, respectively; and the highest citation per paper was Jones K.C. from Lancaster University. The hotspots in this field mainly were pesticide degradation, the content of pesticide in the water, pesticide residues, organochlorine pesticides, pesticide sorption and so on. The research shows that the effect of pesticides on soil ecosystem and the evaluation of ecological toxicity, the remediation methods of pesticides in soil, the management and control strategy of pesticide application in soil will be paid more attention to in the future.

Keywords: pesticide, soil, general situation, bibliometric analysis, CiteSpace

Introduction

Pesticide is a kind of toxic synthetic chemicals with large quantities production and many kinds, and it is easy to be accumulated in environmental media and do harm to ecological environment safety and human health by air, agricultural products, drinking water and other ways. At present, pesticide is an indispensable "double-edged sword", which is not only a reliable guarantee of global crop output, but also an important pollution resource of air, soil and water. The global amount of pesticide was 2.63 kg·ha^{-1} at farm farmland, so the global use amount of pesticide reached 4.692 million tons in 2017 according to the global total farmland area of 1.784 billion hectares by the Food and Agriculture Organization of the United Nations counted [1]. Pesticide safety problem was also more prominent in China. According to the China Statistical

*e-mail: xianjin_an@163.com

Yearbook data, the amount of raw pesticide production reached 2.083 million tons in 2018 [2]. Soil was the main collection storage of pesticide residues in crops. The pesticides residues on crops entered the soil system through rainwater erosion, volatile dry settlement, and residues of crops themselves, which led a significant impact on soil physical and chemical properties and soil live organisms. Therefore, the study of pesticides in soil was crucial to explore the changes of soil system and their coupling relation, which was important to guarantee for the "quality production" of agricultural products, ecosystem safety and human health.

There were many reviews of pesticides in soil [3-5], but the traditional review ways with literature reading, summary and qualitative discussion had some limitations, which could not objectively and comprehensively reflect the development context and research trends in this field. Therefore, it was necessary to analyze the research situation of pesticides more intuitively in soil system with bibliometric analysis, and to play a guiding role to predict the future research direction and in-depth research by analyzing research hotspots and trends. In 2004, Chen [6] firstly established VOSviewer visual analysis software taking the lead in introducing the concept of bibliometric statistical analysis for the development of disciplines. In 2004, Hu and Chen [7] were the first to carry out research on citation visualization to discuss how to visualize citation networks by using computers in China. Bibliometric analysis had been used by multiple disciplines to explain the development trends with the advantages of objectivity, quantification and modelling, such as gesneriaceae study [8], heavy metal pollution [9], biochar [10], etc. However, bibliometric analysis on pesticides in soil systems had not been reported. Therefore, it is necessary to analyze the relevant papers of pesticide research in the global soil system by bibliometric analysis, so that researchers can quickly master the research situation and frontier dynamics, understand the overall situation and also provide references for the future research directions.

Data Sources and Statistical Methods

Data Sources

The data came from the core collection database of the Web of Science (WoS), which was a globally recognized natural science retrieval platform. To obtain accurate pesticide research articles, the articles were retrieved with the advanced retrieval TI = (soil* AND pesticide) OR TI = (soil* AND biocide) OR TI = (soil* AND pesticides) including all languages, and the articles type was journal paper, and the retrieval time span was 1900-2020, with a deadline of 30 November 2020. A total of 1858 papers were obtained (including 496 papers of Chinese science citation database [SM]).

Research Method

According to the statistical results of WoS platform, Excel and CiteSpace (5.2.R2 Version) software were used to analyze and visualize the datas, and Coreldraw X9 and Originpro 9.1 were drawn (note: all map materials in the article were from the National Center for Basic Geographic Information, and Adobe Illustrator software (24.1.1Version) was used for regional color editing).

Results and Discussion

Annual Published Articles and Subjects Distribution

The number of papers could reflect the development speed and development process of this field to a certain extent. A total of 1858 pesticide-related articles in the soil system were included in the WoS database, involving 80 subjects, which mainly concentrated in five research directions, such as environmental sciences ecology, agriculture, chemistry, toxicology, and public environmental occupational health. According to the number of annual papers, the published papers showed an exponential upward trend (Fig. 1). The research of pesticides in the soil system showed a rapid growth trend since 2000, with the average annual amount of 143.95. Fig. 1, it showed that the pesticide research was paid more and more attention, which was the most active and powerful development stage in this field at present. Through analysis on the fitting curve of annual publication combination with focus on crop products safety in the world, the research on pesticides in soil system will still be the focus of researchers in the future for a long time. In 1958, the researchers [11-13] firstly reviewed the effects of pesticides on the population of original microorganisms in soil, and since then the interrelationship between pesticides and soil had been extensively studied.

Main Research Countries and Institutions

The number documented in important databases and citation frequency of published articles reflected the overall research capacity and influence of the country and institutions. The statistic papers involved 80 countries or regions. From Table 1, the greatest number of papers was China with 657, followed by the United States with 379, and Germany and Spain ranked third with 141. China occupied an important position in this field, in addition to the closely related to a large of pesticide production, also because food security gradually was strengthened the attention in recent years. In addition, from Fig. 2, the use of farmland on all continents showed that Asia where China lived and North America where the United States lived were all very large areas of pesticide use. The citation per paper

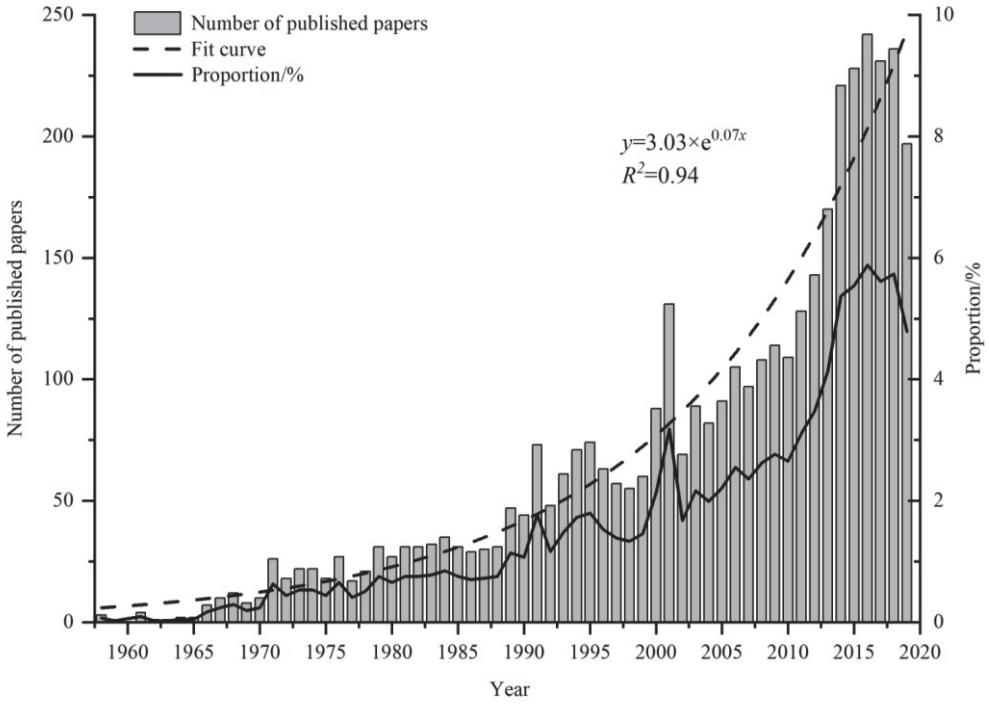

Fig. 1. The development trend of pesticide research published papers in soil systems.

ranked tenth for China, and the most total global citation score was America, which ranked fourth for the citation per paper and ranked first for the H index, respectively. The citation per paper of the UK was reached 42.32, so the pesticide research of the UK was prominent in the world and published more high-level papers. In general, according to the number of papers, total global citation score, citation per paper, self-citation rate and the H index the scientific research level of the United direction was relatively good in this field.

There were 3,102 pesticide-related research institutions in the global soil system, among which the top 10 had published 562 papers (Table 2), accounting for 30.25%. The greatest number of papers was the Chinese Academy of Sciences (CAS), which published 129 articles. From Table 2, the research institutions were mainly concentrated in scientific research institutes, with few universities, and the proportion of published papers was about 11.5:1. This field research was mainly concentrated in the United States, with three institutions ranked in the top 10, while only the CAS ranked in the top 10 for China. According to citation per paper, the Commonwealth Scientific and Industrial Research Organization (CSIRO) was

Table 1. Top 10 countries of pesticide research published papers in soil systems in the world.

Rank	Country	Number of papers	Total global citation frequency	Citation per paper	Self-citation rate	H index**
1	China	657	9876	15.03	15.07	46
2	USA	379	12338	32.55	2.20	57
3	German	141	3294	23.36	2.25	32
4	Spain	141	5050	35.82	3.13	38
5	UK*	136	5755	42.32	1.55	40
6	India	129	2466	19.12	3.49	25
7	France	105	2800	26.67	1.82	27
8	Canada	103	3684	35.77	3.34	35
9	Japan	61	1627	26.67	3.07	19
10	Italy	57	1510	26.49	1.13	18

* The combined Statistics results of ENGLAND and UK. ** h pieces papers cited at least for h times, and the index also related to whether the source publication included in the database, the same below.

Table 2. Top 10 institutions of pesticide research published articles in soil systems in the world.

Rank	Institution	Country	Number of papers	Total global citation frequency	Citation per paper	Self-citation rate	H index
1	CAS*	China	129	4088	31.69	6.09	34
2	USDA	USA	83	2463	29.67	1.26	27
3	INRAE	France	66	1425	21.59	1.82	20
4	CSIC	Spain	61	2071	33.95	2.75	25
5	UCS	USA	45	2025	45.00	1.23	22
6	HA	Germany	44	1070	24.32	1.78	19
7	AAFC	Canada	38	1244	32.74	1.45	18
8	EPA	USA	37	648	17.51	4.01	16
9	CNRS	France	32	682	21.31	0.59	12
10	CSIRO	Australia	27	1393	51.59	2.51	18

Abbreviation: CAS-the Chinese Academy of Sciences, USDA-United States Department of Agriculture, INRAE-National Research Institute for Agriculture, Food and Environment, CSIC-Consejo Superior de Investigaciones Cientificas, UCS-the University of California System, HA-Helmholtz Association of German Research Centres, AAFC-Agriculture and Agri-Food Canada, EPA-Environmental Protection Agency, CNRS-Centre national de la recherche scientifique, CSIRO-Commonwealth Scientific and Industrial Research Organization.* the total results of all institutes of CAS and University of Chinese Academy of Sciences. The same below.

in a core position, with all the papers citation as high as 51.59, and combined with the H index, the institution had more high citation papers. From Fig. 3, the top ten research institutions concentered time was different in the field, United States Department of Agriculture (USDA) and Agriculture and Agri-Food Canada (AAFC) were main research institutions before 2000, and the CAS rapidly became a "leader" after 2000. Meanwhile, AAFC and Environmental Protection Agency (EPA) paid more attention to the pesticide-related research in the last century, with less attention in this century, so the number of papers decreased.

Main Authors and High-Cited Papers

Through the comprehensive analysis of researchers in pesticide-related fields in the global soil system, it was helpful for readers to understand the main leaders in this field, and to focus on the research results of these researchers, and to grasp the latest research trends

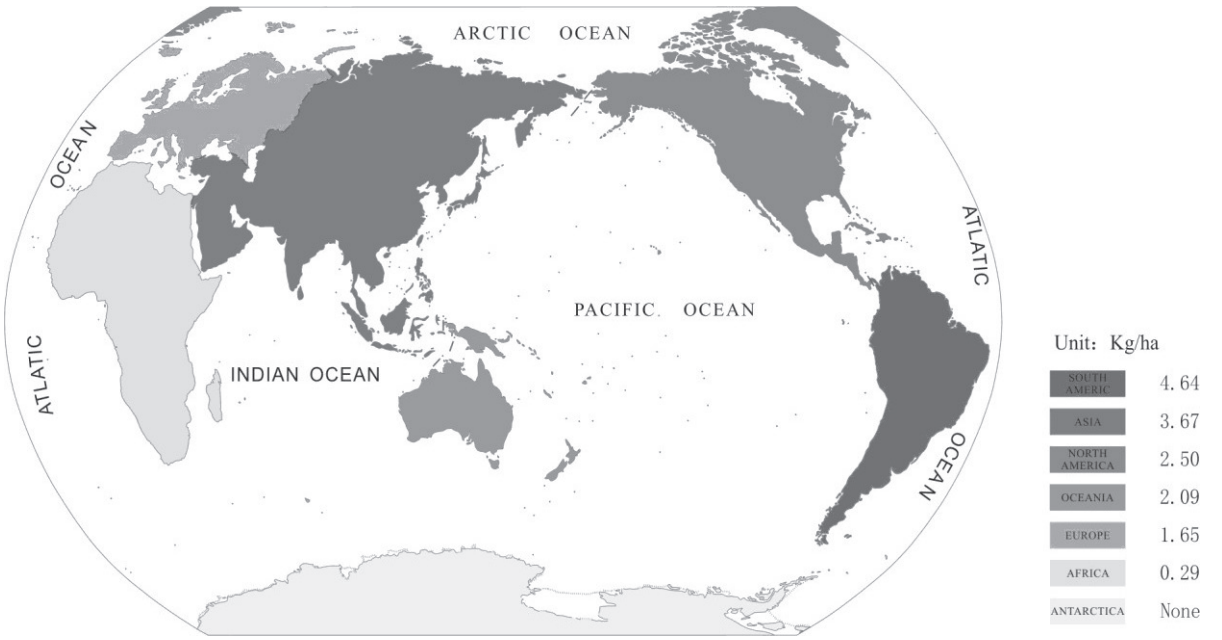

Fig. 2. Global distribution of pesticide use in farm land of seven continents in 2017 (data from FAO).

and results, and to strengthen academic exchanges and cooperation. There were 14, 222 researchers in this field, and the top 10 authors were listed in Table 3. From Table 3, the researchers with the greatest number of papers was Qi S.H. from the College of the Environment, China University of Geosciences (Wuhan), who published 28 papers; and Kookana R.S. of CSIRO ranked second, who published 25 papers; and Jiang X. of Nanjing Institute of Soil Research of CAS ranked third, who published 22 papers. The most citation per paper was Jones K.C. from Lancaster University. Chinese researchers accounted for three of the top 10 publications, which fully showed that the research was prominent in this field and the leaders were more in China.

The content of highly cited papers was the core of the research field, which often had an important guiding role in this field. From Table 4, the highest total global citation frequency was the research on pesticide migration and degradation in soil and effect on ground water pollution in 2008 by Simal-Gandara J., which were cited 628 times. The top 10 highly cited papers were cited 3, 802 times, accounting for 7.31% of the total papers cited frequency. All the top ten papers were mean cited 380.2 times, which was 14.6 times the average of the total number of papers.

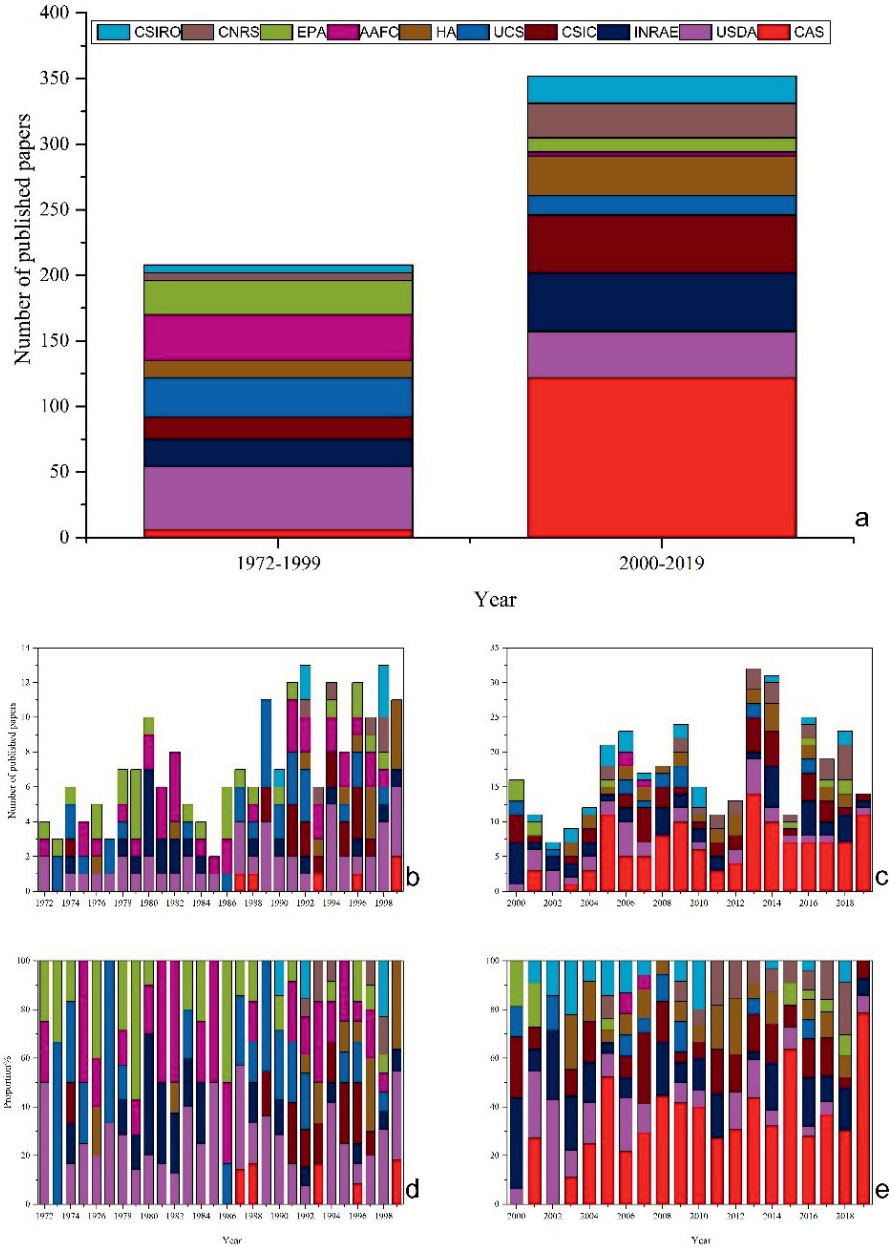

Fig. 3. Top 10 institutions of pesticide research annual published articles in soil systems in the world. (A comparison of the top ten publications between 1972-1999 and 2000-2019, b cumulative number of the top 10 institutions from 1972 to 1999, c the proportion of the annual number by the top 10 institutions from 1972 to 1999, d cumulative number of the top 10 institutions from 2000 to 2019, e the proportion of the annual number by the top 10 institutions from 2000 to 2019).

Table 3. Top 10 authors of pesticide research published articles in soil systems in the world.

Rank	Author	Country	Number of papers	Total global citation frequency	Citation per paper	Self-citation rate	H index
1	Qi S.H.	China	28	438	15.64	7.08	13
2	Kookana R.S.	Australia	25	1414	56.56	2.48	17
3	Jiang X.	China	22	386	17.55	1.81	11
4	Bidleman T.F.	Canada	19	1198	63.05	4.42	16
5	Sanchez-Martin M.J.	Spain	17	473	27.82	3.81	14
6	Boesten J. J.T. I.	New Zealand	16	375	23.44	1.87	10
7	Jones K.C.	Britain	16	1341	83.81	1.42	12
8	Barriuso E.	France	15	476	31.73	1.26	8
9	Brown C.D.	Britain	15	631	42.07	2.06	11
10	Wang T.Y.	China	15	233	15.53	5.15	12

The highly cited paper was only Professor Zeng G.M. from Hunan University study the bioremediation theory of composting effect on soil pollution of pesticides in 2015 in China.

Journal Sources

Statistical analysis of publications could provide a clear knowledge of some major and top journals for readers, which helped scholars to select important and excellent journals to read and submit. From Table 5, the total number of papers published in the top 10 journals in this field was 613, accounting for 32.99% of the total papers. Among them, "Chemosphere" published papers most with 115, at the same time which was also the most citation and the highest H index. The highest citation per paper was "Environmental Science & Technology" with 57.42 times. From the division of the journal analysis, six of the top ten journals were located Q1 in the Journal Citation Reports(JCR) division of environmental science, such as "Chemosphere" ,"Journal of Agricultural and Food Chemistry" ,"Science of The Total Environment", "Environmental Pollution", "Journal of Chromatography

Table 4. Top 10 references of pesticide research citations in soil system in the world.

Rank	Year of publication	Corresponding author	Article title	Total global citation frequency
1	2008	Simal-Gándara J.	The mobility and degradation of pesticides in soils and the pollution of groundwater resources	628
2	2000	Gevao B.	Bound pesticide residues in soils: a review	476
3	1996	Flury M.	Experimental evidence of transport of pesticides through field soils - a review	395
4	1970	Bailey G.W.	Factors influencing the adsorption, desorption, and movement of pesticides in soi	379
5	2002	Wauchope R.D.	Pesticide soil sorption parameters: theory, measurement, uses, limitations and reliability	369
6	1991	Kladivko E.J.	Pesticide and nutrient movement into Subsurface tile drains on a silt loam soil in Indiana	369
7	2015	Zeng G.M.	Bioremediation of soils contaminated with polycyclic aromatic hydrocarbons, petroleum, pesticides, chlorophenols and heavy metals by composting: applications, microbes, and future research needs	319
8	2003	Sheng G.Y.	Enhanced pesticide sorption by soils containing particulate matter from crop residue burns	308
9	1992	Senesi N.	Binding mechanisms of pesticides to soil humic substances	283
10	1964	Bailey G.W.	Review of adsorption-desorption of organic pesticides by soil colloids with implications concerning pesticide bioactivity	276

Table 5. Top 10 journals of pesticide research published articles in soil systems in the world.

Rank	Journal name	Number of papers	Total global citation frequency	Citation per paper	Self-citation rate	H index
1	Chemosphere	115	4491	39.05	1.22	36
2	Journal of Agricultural and Food Chemistry	73	3059	41.90	0.72	34
3	Environmental Science & Technology	71	4077	57.42	1.67	34
4	Science of The Total Environment	69	2287	33.14	1.79	26
5	Bulletin of Environmental Contamination and Toxicology	60	902	15.03	1.44	18
6	Journal of Environmental Science and Health Part B-Pesticides Food Contaminants and Agricultural Wastes	58	950	16.38	1.37	17
7	Environmental Science and Pollution Research	44	488	11.09	2.46	15
8	Journal of Environmental Quality	43	2185	50.81	1.09	23
9	Environmental Pollution	43	2237	52.02	0.72	23
10	Journal of Chromatography A	37	1949	52.68	0.97	25

A", "Environmental Science & Technology", and the journals located in Q2 of environmental science were "Environmental Science and Pollution Research", "Journal of Environmental Quality", and the journals located in Q3 of environmental science were "Bulletin of Environmental Contamination and Toxicology", "Journal of Environmental Science and Health Part B-Pesticides Food Contaminants and Agricultural Wastes". Therefore, it could be seen that the research papers were favored by many top journals in this field. The Chinese journal statistics from WoS database involved in the Chinese science citation [SM] was analyzed, which was helpful for researchers selectively to submit Chinese journals. The Chinese journals of the top ten were "Journal of Agro-Environmental Science", "Environmental Science", "Environmental Monitoring in China", "Chinese Journal of Analysis Laboratory", "Rock and Mineral Analysis", "Environmental Chemistry", "Acta Scientiae Circumstantiate", "China Environmental Science", "Agrochemicals".

Keywords and Research Hotspots

Key words were a high summary of the research topic of the articles, from which the readers could roughly judge the theme of the articles and paved the way for the readers to innovatively create new research in this field. The results from the hotspots cluster analysis of keywords showed that the research of pesticide in the global soil system mainly focused on 10 clusters, such as soil, DDT, macropores, diuron, benomy, carbofuran, land use, nitrification, picloram, and biocides, and the research boom had been continued since 1985. Fig. 4 and 5 showed that there were the main hotspots of top 25 with frequency more than 50, and they were pesticides, soil, degradation, water, residue, organochlorine pesticide, sorption, adsorption, atrazine, herbicide, sediment, DDT, contamination, biodegradation, agricultural soil, persistent organic respectively pollutant, gas chromatography, polycyclic aromatic hydrocarbon, transport, persistence, insecticide, fate, extraction, groundwater, and polychlorinated biphenyl. From Fig. 4, the denser and thicker the network lines the closely connected they were. For example, the association among polychlorinated biphenyls, persistent organic pollutants and residues was stronger in recent years, indicating the high frequency of simultaneous occurrence of these research contents. It could be seen that the research focused on pesticide degradation, water, pesticide residue, organochlorine pesticide adsorption and pesticide sorption.

The Dynamic Analysis of Pesticides in Soil System

This paper summarized the current research dynamics of this field, through the hotspots analysis of keywords and combing some highly cited papers and total cited papers, to provide some references for the future research in this field.

Impact of Pesticide on Soil Ecosystem and Ecological Toxicity Evaluation

Pesticide spraying played a vital role in improving the yield of soil crops, because of the continuous accumulation of pesticide application, the purification ability of soil itself no longer accommodated the gradually increasing concentration of pollutants. The harm of pesticides to soil ecosystem was more and

more obvious, and the soil pollution of pesticides had developed from point source pollution to surface source pollution. Studies had shown that after pesticide application, 80%~90% pesticide entered into the soil environment and further migrated to other environmental reservoirs (e.g. underground water)

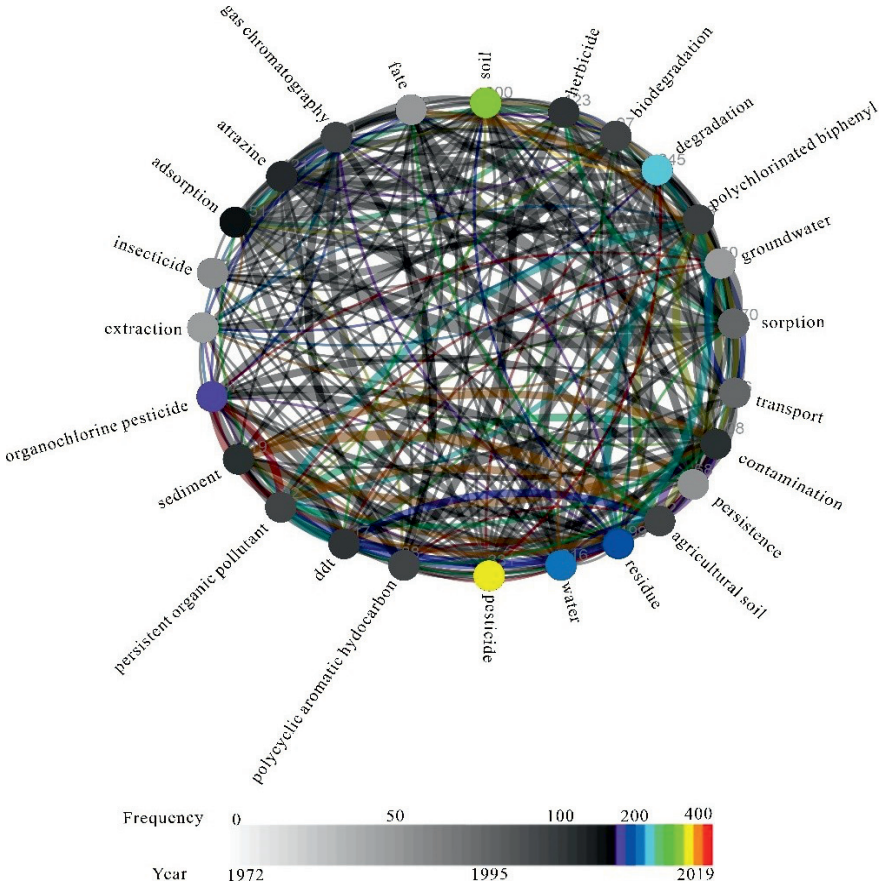

Fig. 4. Top 25 keywords co-occurrence (frequency≥50) of pesticide research in soil systems in the world. (Keyword circle filling color represented the various size of the frequency, the color of the lines represented the different year of the keywords occurred, and a thicker line with different color meant that the two keywords had a higher co-occurrence).

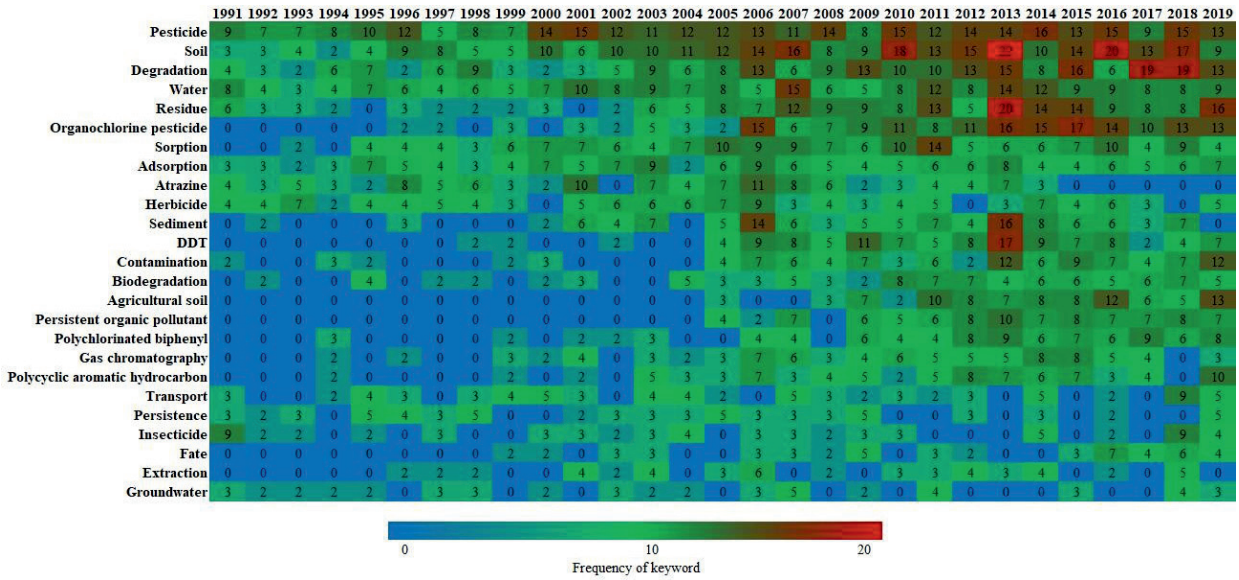

Fig. 5. Top 25 keywords of pesticide research annual trend in soil systems in the world.

[14]. The impact of pesticides on soil ecosystem was mainly reflected in three aspects. First, it affected the basic physical and chemical properties of soil. Soil was evolved through long-term time and spatial sequence, and its physical and chemical properties tended to be stable, providing a stable nutrient supply for the growth of crops. However, the transitional application of pesticides in soil significantly affected the physical and chemical properties and ecological function of soil. The studies showed that the pH of tea garden soil significantly reduced after pesticide application [15], and pesticide as a carbon source increased the content of soil organic matter [16], but the studies indicated that pesticide application reduced the content of organic matter in deep soil [17]. Wan et al. [18] believed that the long-term use of pesticides changed the porosity of the soil, and lead to soil compaction. Second, it affected the soil microbial community structure. Soil microorganisms were the link between soil environment and the healthy growth of the crops. Microbial community structure directly affected the health of soil ecosystems. The studies indicated that the root microbial community was continuously affected after leaf absorption pesticides into plant tissues [19]. Due to the toxicity of pesticide itself, the number of soil nematodes significantly reduced [20]. The addition of pesticide changed the community structure of soil nematodes and improved their richness and diversity of nutritional group [17]. Qian et al. [21] also showed that the application of herbicide pesticides reduced the biodiversity of the bacterial flora. Li et al. [22] showed that pesticide could affect the bacterial community structure which positively correlated with the amount of pesticide applied. Third, it affected the flow of nutrient elements in the soil. Soil was the main source of nutrient supplying for crops and the nutrient reservoir of soil microorganisms. The use of pesticides affected the species of the rhizosphere microbes, activity, and abundance in soil, thus changing the flow of nutrients and affecting the growth of crops [23]. Bai et al. [17] pointed out that pesticide application in pear garden soil improved the mass fraction of soil quick-acting potassium. Pesticides significantly inhibited the soil nutrients absorption of crop seedlings by hindering the activity of various enzymes [24].

Ecological toxicity evaluation of pesticides in soil systems was assessed according to the risk assessment of oral intake and skin exposure. At present, the risk assessment of pesticide residues in the soil system was mainly aimed at the risk assessment of the same site and the same pesticide, and earthworms were only chosen as most of the risk assessment objects. For example, some studies had evaluated the oral intake carcinogenic risk value of the contaminated soil with atrazine as 2.77 $mg \cdot kg^{-1}$ by this method [25]. Lei et al. [26] indicated that the maximum residues of propiononazole and phenylether mexazole in banana soil were lower than the semi-lethal concentration of earthworms in toxicological studies. Although the ecological risk assessment of pesticide residues in soil had been partially studied, there was no unified standard for the ecological risk assessment of pesticides in soil. Urzelai and Floreano [27] assessed the risk based on the toxic effect of contaminant on invertebrates in soil. Liu et al. [28] used the evaluation method of median average risk ERM and low risk assessment ERL. Different risk assessment results were obtained by different methods. Therefore, the risk assessment of pesticides in the soil system also needed to develop a set of systematic evaluation indicators according to different backgrounds in future.

Remediation Methods of Pesticides in Soil

Pesticides did direct harm to ecosystem and human health. Most of pesticide had benzene ring structures and stable properties, and strong hydrophobicity, so they existed stably in the environment for a long time and be accumulated gradually. The huge use of pesticides which were very persistent in the environment, decomposed slowly and had mutagenic, carcinogenic and teratogenic effects on organisms posed a severe challenge to the human living environment, so the remediation of pesticides was particularly important in the soil. The traditional methods of pesticides remediation in soil mainly included physical, chemical, and biological remediation, and finally changed their morphology from the soil or reduced or removed their toxic effect. In recent years, the hotspots of pesticide remediation in soil mainly focused on the following two aspects:1. Physicochemical union repair. In 1991, Acar et al. [29] firstly established extended capillary model based on pore pressure change with space and time, which was used for the restoration of heavy metal copper in soil, and then the physical and chemical remediation technology became a research hotspot for the removal of soil organic pollutants. The studies had pointed out that under the electric remediation technology, TX-100 could serve as an advanced oxidant to enhance the soil remediation effect of organochlorine pesticides, and significantly improved the removal rate of pesticides in the soil [30]. Cai et al. [31] showed that soil bioelectrochemical systems modified with highly conductive biochar effectively degraded pentaclorophol herbicides. The presence of Fe_3O_4 nanoparticles enhanced the removal rate of DDT by enhancing the Fenton reaction [32]. The study showed that the surfactant TX-100 and rhamnose fat could significantly enhance the degradation efficiency of HCH and DDT by surfactant-enhanced Fe/Cu bimetallic system [33].2. Bioremediation methods mainly included biostimulation, biofortification and biological attenuation, and biofortification remediation technology was currently considered the most effective and fastest developing bioremediation technology. It was a new green restoration technology aiming to add microorganisms with specific functions to the soil environment and to remove organic pollutants such as

pesticides. It significantly improved the environmental repair capacity, efficiently degraded of toxic pollutants, improved the treatment capacity and so on [34]. In 1991, Madsen [35] first described the mechanism of bioremediation technology in situ for repairing soil organochlorine and insecticide. Raimondo et al. [36] showed that the use of biofortification method by biostimulation significantly increased the removal rate of Lindan, up to 86.3%, and it also pointed out that the use of sugarcane bagasse life stimulation combination with biofortification with actinobacteria was a very effective strategic method. However, Castro-Gutiérrez et al. [37] studied the effect of biofortification on pesticide degradation and microbial community outcomes under biopurification systems and showed that biofortification did not affect pesticide removal efficiency or the structures of microbial communities (bacteria and fungi). In summary, there was no consensus on the impact of biofortification on pesticides, and further systematic research was needed in future.

Pesticide Application Management Strategies in Soil

The application and management of pesticides had become a global problem, because of the increase of types but the resources gradually decreased, and population, and resources gradually decrease. Pesticides in the soil could cause direct damage to plants and indigenous organisms through blocking the absorption of nutrient elements and destroying the cellular organization, besides pesticides could be further accumulated and transmitted in human by the food chain, to cause disaster just like Minamata disease in Japan. Therefore, it was necessary to make relevant pesticide management measures, such as the Stockholm Convention, and develop a restricted list of toxic pesticides. The management of pesticides in soil should be promoted by making efforts in the following four aspects. First, it was necessary to develop a stricter and more consistent with realities legal protection system and improve the policy management mechanism, from the national level to control the use of highly toxic and high-risk pesticides, and to timely update the negative list of pesticide use. The problem of pesticide control bottlenecks to be settled needed to converge forces from different areas and departments. United States, Britain and other developed countries and international organizations drafted a series of involving registration, testing, laboratory management, management, use guidance, supervision and law enforcement, risk monitoring, waste disposal management and technical specifications, built a complete technical management system, and made pesticide management not only including laws, but also standard-based. At the same time, a perfect management system and the formation of a top-down and effective management mechanism was an important means to solve the confusion of different departments in different regions. For example, the Pesticide Management Office in the United States was a department specialized in pesticide registration and related management work. Second, application management policies should be made according to the quantity of pesticide for different regions. At present, the use of pesticides needed to carry out relevant control measures according to local conditions of different levels of control and control line, to gradually reduce the use of pesticides. Third, make efforts for scientific research to find alternatives to highly toxic pesticides, to improve the plant's own characteristics to resist the invasion of pests and diseases, to reduce the use of traditional pesticides by developing biopesticides, to develop non-toxic or low-toxic biopesticides, to increase the natural enemies of pests, and to use safety pheromones to lure pests. One study pointed out that more than 80 different biopesticides had been used to efficiently remove about 70 species of weeds and insects [38]. Fourth, improve farmers' scientific and technological knowledge and intensify publicity and training to help farmers master scientific ways of field crop management, to reduce the invasion of pests and diseases, and more appropriate types of pesticides were chosen, and the quantity of pesticides were strictly controlled, and thus the use of pesticides was reduced from the source.

Conclusions

From the perspective of the number of papers, research on pesticides in the global soil system is in an active period since the 21st century.

China has the greatest number of pesticide research papers in the global soil system; and the institutions with the highest H index and the greatest number of papers and the most total global citation frequency are the CAS, among which Nanjing Institute of Soil Sciences has the highest total global citation frequency and H index in China. The institution with the highest citation per paper is the CSIRO. The researchers with the greatest number of papers and total global citation frequency are Professor Qi S.H. from College of Environment, China University of Geosciences (Wuhan) and Kookana R.S. of the CSIRO, respectively; and the highest citation per paper is Jones K.C. from University of Lancaster, and the journal with the greatest publications and total global citation frequency is "Chemosphere", and the journal with the highest citation per paper is "Environmental Science & Technology". The upsurge has continued in this field since 1985, which mainly concentrates in pesticide degradation, water, pesticide residue, organochlorine pesticide, pesticide adsorption and so on.

The paper shows that pesticides research in global soil system in future may mainly be focused on the impact of pesticides on soil ecosystem and ecological toxicity evaluation, the remediation method of pesticides in soil, and the management and control strategy of pesticide application in soil. At the same

time, pesticides not only have direct harm to the live organisms in the soil, but also affect the growth and development of plants and food security. At the same time, it is worth noting that the pesticides in the soil do not exist in an environmental system alone, and their impact on water and air is also a scientific issue worthy of further exploration in the future.

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Conflict of Interest

The authors declare no conflict of interest.

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