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Visualization Analysis of Research on Maize or Corn Intercropping System Based on Web of Science

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Abstract

Based on the Web of Science, this study analyzed 3,103 research articles and review articles of maize or corn intercropping system research from 1952 to 2022. Results showed that papers mainly written in English (2,925, 94.264%), were from 9,814 authors, 114 countries/territories and 2,201 organizations, listed in 496 Journals and two Book Series. The top five journals were *Field Crops Research* (181, 5.833 %), *Agronomy Journal* (107, 3.448 %), *Agroforestry Systems* (103, 3.319 %), *Plant and Soil* (97, 3.126 %) and *Indian Journal of Agricultural Sciences* (80, 2.578 %). Top five countries and regions were Peoples R China, USA, Brazil, India and Kenya, each more than 221 papers. The top three affiliations were China Agr Univ, Sichuan Agr Univ, and Wageningen Univ. Top 5 authors are Yang Wenyu, Yang Feng, Chai Qiang, van der Werf Wopke, Liu Weiguo, each published more than 36 papers. Based on the analysis of network map of VOSviewer, there is cooperation for authors, organizations and countries or regions. Visualizations offer exploratory information on the current state in a scientific field or discipline as well as indicate possible developments in the future. The analysis of all keywords showed that maize or corn intercropping system research were separated into ten clusters. So, authors can choose their ideal journal with a high impact factor or Q1 in Category to publish their papers in the English language related to their research field.

Abbreviations

ACPY: Average Citation Per Year
ESI: Essential Science Indicators
IF: Impact Factor
QR: Quartile Rank
PY: Publication Year
SCIE: Science Citation Index Expanded
SSCI: Social Science Citation Index
TC: Total Citations
TP: Total Publications
WoS: Web of Science

Introduction

Maize (*Zea mays* L.) was originally domesticated in Mexico 7000-10,000 years ago and the country also hosts the world's richest diversity of maize varieties. In Mexico, maize is the most important staple crop and is cultivated under varied agro-climatic and socio-economic conditions (Juárez-Hernández *et al.*, 2019). Now, maize is an important cereal crop all over the world and has been recently ranked at first among all cereal crops (Shafiq *et al.*, 2019). Intercropping is the agronomic practice of simultaneously growing two or more crop species in the same field in close proximity for a considerable proportion of their growing season. The maize or corn are also intercropped with other crops, especially the legume crops (Latati *et al.*, 2016; Liu *et al.*, 2017; Yang *et al.*, 2017; Du *et al.*, 2018; Iqbal *et al.*, 2019; Raza *et al.*, 2020; Chen *et al.*, 2021; Feng *et al.*, 2021; Hussain *et al.*, 2021; Li *et al.*, 2021; Raza *et al.*, 2021; Zaeem *et al.*, 2021; Blessing *et al.*, 2022; Li *et al.*, 2022; Pierre *et al.*, 2022; Xu *et al.*, 2022).

Bibliometrics is a powerful method for analyzing the development of scientific literature in a research field from a quantitative perspective, and it has been widely used in many global studies (Fu and Waltman, 2022). Bibliometric analysis provides useful means to collate existing publications, track research output, and summarize scholarly trends in particular fields. In recent years, bibliometrics has been broadly used as a quantitative analysis method in many scientific research fields, such as

exploring the role of companies in scientific research: a case study of genetically modified maize (Liu *et al.*, 2021), trends in plant research using molecular markers (Garrido-Cardenas *et al.*, 2018), spatial-temporal evolution of scientific production about genetically modified maize (Santillán-Fernández *et al.*, 2021), evolution of the global scientific research on the environmental impact of food production from 1970 to 2020 (Cimini, 2021), worldwide research trends on wheat and barley (Giraldo *et al.*, 2019), intercropping topics literatures as trends and features of agroforestry research based on bibliometric analysis (Liu *et al.*, 2019), a scientometric analysis of worldwide intercropping research based on Web of Science Database between 1992 and 2020 (Lv *et al.*, 2021), agronomic practices to increase the yield and quality of common bean (Karavidas *et al.*, 2022), transgenic maize (Li *et al.*, 2018), mapping the scientific research on maize or corn: a bibliometric analysis of top papers during 2008–2018 (Yuan and Sun, 2020).

VOSviewer is a freely available computer program developed to construct and view bibliometric maps with detailed approach in an easy-to-interpret way (www.vosviewer.com). VOSviewer software supported the bibliometric analysis. Using bibliometric analysis, we can further understand the status of global maize intercropping system research.

The purpose of this paper was to use bibliometric methods and VOSviewer to analyze 3,103 papers on maize or corn intercropping system research during period from 1952 to 2022, hoping to gain a deeper understanding on research status through analyzing its publication year, category, author, affiliations, country, journals, all keywords and other key features. Co-authorship network visualization of author, organizations and countries, co-occurrence network visualization of all keywords were done by VOSviewer.

Materials and methods

WoS

Clarivate Analytics's Web of Science (WoS) is the world's leading scientific citation search and analytical information platform. The publication counts from the WoS Core Collection were derived from the following two editions both Science Citation Index Expanded (SCIE)-- 1900-present and Social Science Citation Index (SSCI) --1900-present.

Data collection and analysis

This study aims at analysing the trend of maize or corn intercropping system research. This study surveyed papers in the SCIE and SSCI database of the WoS published from January 1900 to June 9, 2022 (retrieval data last updated: 2022-6-9). We used the keywords 'maize or corn' and 'intercropping' to search the database, with the query TS = (Maize or corn and intercropping), in terms of topic to retrieve the bibliographic records. The document types were refined by articles and review articles. The records were downloaded and saved as plain text format by selecting the export format "full records and cited references", and then imported into VOSviewer (version 1.6.18, 2022, Leiden University, Leiden, the Netherlands) for further citation analysis.

The following ranks were obtained: document type, language, output, subject category, journal, country, institute, source title, keywords were all analyzed. The contribution of different countries and institutes were estimated by the location of the affiliation of at least one author of the published papers. The impact factors (IF 2021 and IF 5 year) were taken from the Journal Citation Report (JCR 2021) that was updated at the end of June 2022 (Clarivate, Journal Citation Reports ™ 2021, 2022). The Journal Citation Reports™ includes journals from the SCIE and SSCI.

VOSviewer

VOSviewer is a software tool for the processing of keywords and the grouping analysis used for the visualization of network maps through a coincidence matrix, which allows grouping by co-authorship and by co-occurrence (Van Eck and Waltman, 2010). Co-authorship and co-occurrence networks were visualized using VOSviewer software, which was used for visual analysis, mapping network diagram of keyword co-occurrences and co-authored authors, countries and organizations. For the network map, full counting method was used, meaning that each co-occurrence link carried the same weight. The default "association strength method" was used for normalization of the co-occurrence matrix with default values of attraction and repulsion (Van Eck and Waltman, 2022).

Results and Discussion

Web of Science Index and Publication Output

With the aim of knowing the research trend on maize or corn intercropping system, a total number of 3,103 publications were obtained from the online version of SCIE between 1952 and 2022. The all 3,103 research articles and review articles were from SCIE (3,091, 99.613%), SSCI (104, 3.352%), Conference Proceedings Citation Index-Science (47, 1.515 %), Book Citation Index- Science (4, 0.129 %) of WoS Index.

Figure 1 shows the publication trend of research on maize or corn intercropping system, which they were power increased after 1980. The annual number of publications is increasing over the past years with some

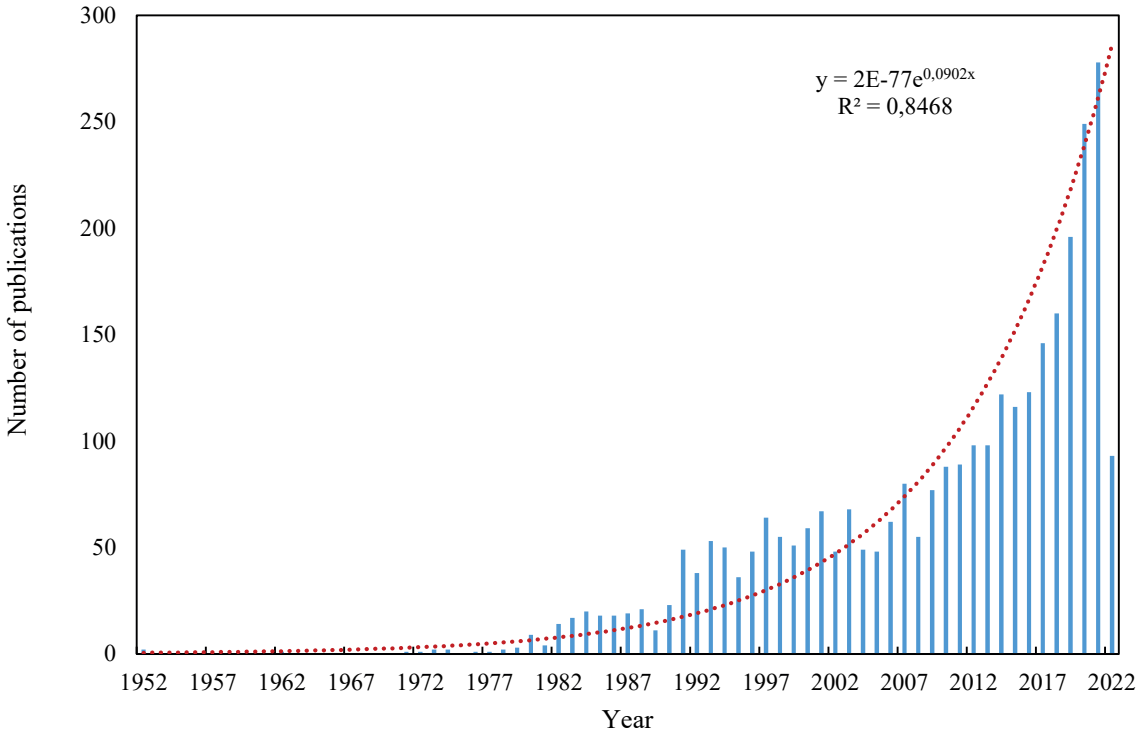

Fig. 1 -Number of papers for maize or corn intercropping system research from 1952 to 2022.

fluctuations, especially recent about 30 years after 1990. The growth of publications can be fixed to the exponential growth (R^2=0.8468). The h-index was initially proposed as a measure of a researcher's scientific output based on counting the number of publications (N) by that researcher cited N or more times (Hirsch, 2005). For the total 3,103 papers, the *h*-index was 92, the sum of the times cited was 55,301, and the average citation per item is 17.82 till to June 9, 2022.

Document types and languages of publication

From WoS Index, the 3,103 publications were identified in WoS Core Collection between 1952 and 2022, and the firstly two papers of " The importance of nitrogen and water in reducing competition between intercrops and corn" wrote by Kurtz T, Melsted SW, Bray RH was published in 1952 in *Agronomy Journal* (44(1):13-17), and another paper was "Further trials with intercropping of corn in established sods" wrote by Kurtz T, Melsted SW, Bray RH, Breland HL was published in 1952 in *Soil Science Society of America Proceedings* (16(3):282-285). The document types and languages were displayed in the Table 1.

The research articles were the dominant document type comprising of 97.97 % (3,040 of the total 3,103) and review articles (63, 2.03 %), they were also proceeding paper (48, 1.547 %), early access (20, 0.645 %), book chapters (4, 0.129 %). Here, the proceedings papers and the book chapters are belong to the research article or review articles. The sum of the articles and review articles are main document types which were usually statistic the citations and the journal impact factor.

Of the 3,103 publications, a total of 2,925 (94.264%) papers were in English, followed by Portuguese (147,

Table 1 - Document types and languages for maize or corn intercropping system research.

Document Types	Records	% of 3,103	Languages	Records	% of 3,103
Articles	3040	97.97	English	2925	94.264
Review Articles	63	2.03	Portuguese	147	4.737
Proceedings Papers	48	1.547	Spanish	11	0.354
Early Access	20	0.645	French	8	0.258
Book Chapters	4	0.129	Czech	4	0.129
			German	4	0.129
			Hungarian	2	0.064
			Japanese	2	0.064

Table 2 - Top 20 Web of Science categories and research areas for maize or corn intercropping system research

Rank	Web of Science Categories	TP	Ratio of 3,103 (%)	Research areas	TP	Ratio of 3,103(%)
1	Agronomy	1,369	44.119	Agriculture	2,308	74.38
2	Agriculture Multidisciplinary	624	20.11	Plant Sciences	463	14.921
3	Plant Sciences	463	14.921	Environmental Sciences Ecology	343	11.054
4	Soil Science	408	13.149	Science Technology Other Topics	161	5.189
5	Environmental Sciences	278	8.959	Forestry	143	4.608
6	Ecology	157	5.06	Entomology	132	4.254
7	Forestry	143	4.608	Food Science Technology	87	2.804
8	Entomology	132	4.254	Water Resources	69	2.224
9	Multidisciplinary Sciences	91	2.933	Biotechnology Applied Microbiology	44	1.418
10	Food Science Technology	87	2.804	Life Sciences Biomedicine Other Topics	43	1.386
11	Green Sustainable Science Technology	70	2.256	Chemistry	34	1.096
12	Water Resources	69	2.224	Geology	34	1.096
13	Agriculture Dairy Animal Science	66	2.127	Meteorology Atmospheric Sciences	31	0.999
14	Horticulture	61	1.966	Engineering	28	0.902
15	Biotechnology Applied Microbiology	44	1.418	Microbiology	26	0.838
16	Biology	43	1.386	Veterinary Sciences	22	0.709
17	Agricultural Engineering	39	1.257	Business Economics	21	0.677
18	Environmental Studies	39	1.257	Biodiversity Conservation	17	0.548
19	Meteorology Atmospheric Sciences	31	0.999	Energy Fuels	15	0.483
20	Microbiology	26	0.838	Biochemistry Molecular Biology	13	0.419

TP: Total publications.

4.737 %), Spanish (11, 0.354 %), French (8, 0.258 %), Czech (4, 0.129%), German (4, 0.129 %), Hungarian (2, 0.064 %) and Japanese (2, 0.064 %) (Table 1). The English was the dominating language from the WoS (Kolle and Shankarappa, 2017; Kolle *et al.*, 2018; Mo *et al.*, 2018). Almost papers were published in English as the database of SCIE and SSCI mostly consists of English journals rather than journals in other languages, and scholars tend to publish their articles in English as they want them to be widely accepted.

Web of Science categories and research areas

Each article indexed by the WoS belongs to one or more subject categories. These papers belong to total of 67 WoS subject categories in the science edition and 48 research areas. Table 2 shows the top 20 WoS categories and research areas for maize or corn intercropping system research. Among these, the top five WoS categories included Agronomy (1,369, 44.119 %), Agriculture Multidisciplinary (624, 20.11 %), Plant Sciences (463, 14.921 %), Soil Science (408, 13.149 %), Environmental Sciences (278, 8.959 %). The five top research areas included Agriculture (2,308, 74.38%), Plant Sciences (463, 14.921 %), Environmental Sciences Ecology (343, 11.054 %), Science Technology Other Topics (161, 5.189 %), Forestry (143, 4.608 %). Journals or papers may be classified in two or more categories in the WoS, showed the multidisciplinary character of this research field (Elango and Ho, 2018).

Core Journals

All the 3,103 papers were published in 496 Journals and two Book Series Titles of *Advances in Agronomy* (3) and *Annual Review of Phytopathology* (1). The top 20 core journals were displayed in the Table 3 with total articles each more than 32 papers, Journal impact factor as IF 2021 and IF 5 year, Quartile Rank, as the data from the 2021 edition of Journal Citation Reports (published in 2022). These top 20 journals have produced 1,286 (41.444 %) publications on the total of 3,103 papers. The top five journals were *Field Crops Research* (181, 5.833 %), *Agronomy Journal* (107, 3.448 %), *Agroforestry Systems* (103, 3.319 %), *Plant and Soil* (97, 3.126 %) and *Indian Journal of Agricultural Sciences* (80, 2.578 %).

For the top 20 journals in Table 3, there are 17 journal with impact factor in 2021 and 5 years, and eight journals belong to the Q1 quartile in Category, six journals belong to the Q2 quartile in Category, one journal belongs to the Q3 quartile in Category, two journals belong to the Q4 quartile in Category. Here, the title of *Journal of Sustainable Agriculture* was changed as *Agroecology and Sustainable Food Systems* from 2013.

According to citation sources analysed by VOSviewer, for the publication data in the citation of 496 journals, 126 journals resulted meeting the thresholds of 5 publications, and 125 journals were connected to each

Table 3 - Top 20 Journals published on maize or corn intercropping system research based on WoS

Rank	Journal	Records	Ratio of 3,103(%)	IF2021	IF5year	QR
1	*Field Crops Research*	181	5.833	6.145	7.234	Q1
2	*Agronomy Journal*	107	3.448	2.65	2.963	Q2
3	*Agroforestry Systems*	103	3.319	2.419	2.672	Q2
4	*Plant and Soil*	97	3.126	4.993	5.44	Q1
5	*Indian Journal of Agricultural Sciences*	80	2.578	0.374	0.447	Q4
6	*Pesquisa Agropecuaria Brasileira*	79	2.546	1.1	1.404	Q3
7	*Agriculture Ecosystems Environment*	76	2.449	6.576	7.088	Q1
8	*Experimental Agriculture*	72	2.32	2.234	2.208	Q2
9	*Indian Journal of Agronomy*	69	2.224			
10	*European Journal of Agronomy*	60	1.934	5.722	6.384	Q1
11	*Planta Daninha*	43	1.386	0.859	0.998	Q4
12	*Agronomy Basel*	41	1.321	3.949	4.117	Q1
13	*Journal of Sustainable Agriculture*	40	1.289			
14	*Agricultural Water Management*	35	1.128	6.611	6.574	Q1
15	*Crop Protection*	35	1.128	3.036	3.32	Q1
16	*Nutrient Cycling in Agroecosystems*	35	1.128	3.866	4.504	Q2
17	*PloS One*	35	1.128	3.752	4.069	Q2
18	*Tropical Agriculture*	34	1.096			
19	*Journal of Agricultural Science*	32	1.031	2.603	3.152	Q2
20	*Soil Tillage Research*	32	1.031	7.366	7.829	Q1

Note: IF2021 and IF 5years means impact factor for 2021 and 5 years. QR: Quartile rank in Category. Data from the 2021 edition of Journal Citation Reports.

other in Figure 2. The network map of citation for 125 journals showed ten clusters with different colors, the size of circles reflected a total number of journal publication records. Journals in the same color cluster usually suggested that they published the similar content papers and had close relations with each other. The first cluster (red) had twenty-four journals and centred as *Agriculture Ecosystems & Environment*, the second cluster (green) had twenty-two journals and centred as *Agroforestry Systems*, the third cluster (blue) had twenty-one journals and centred as *Field Crops Research*, the fourth cluster (yellow) had twenty journals and centred as *Indian Journal of Agricultural Sciences*, the fifth cluster (violet) had thirteen journals and centred as *Agronomy Journal*, the sixth cluster (light blue) had nine journals and centred as *Soil & Tillage Research*, the seventh cluster (orange) had six journals and centred as *Agricultural Water Management*, the eighth cluster (brown) had six journals and centred as *Nutrient Cycling in Agroecosystems*, the ninth cluster (pink) had three journals and centred as *European Journal of Agronomy*, the tenth cluster had only one journal of *Archives of Agronomy and Soil Science*.

Authors co-authorship analysis

Co-authorship analysis identifies collaboration networks between researchers. Analyzed total 3,103 papers data by VOSviewer, the number of the authors, affiliations and countries for each paper were all less than twenty-five. Collaborations among researchers, research institutions and countries play a pivotal role in contemporary science. Internationally collaborative articles had the highest visibility and scientific impact followed by inter-institutional collaborative articles, single-country articles and single-author articles, respectively (Wambu and Ho, 2016). Collaboration networks are used to show how authors or institutions relate to others in the field of scientific research. Here, the most common kind of collaboration co-author network which the maps were made by VOSviewer.

The network visualization of authorship in the field of maize or corn intercropping system research is shown in Figure 3, each circle represents an author, and the circle sizes indicate the number of published articles. The link connecting two circles stands for the cooperative relation between two authors, and the thickness of the link stands for the intensity of cooperation, the closer the circles the closer the collaboration. Of the all 9,814 authors, there were 288 authors meet the minimum five thresholds, but only 124 authors connected to each other in Figure 3, there were divided into 70 clusters with different colors, authors in the same cluster usually suggested that they studied in a similar field and had close cooperation with each other.

Table 4 shows top 20 authors who published more than 22 papers, citation and average citations analyzed by VOSviewer. The 20 authors mainly come from Sichuan Agr Univ of China (7), Gansu Agr Univ of China (6), Chi-

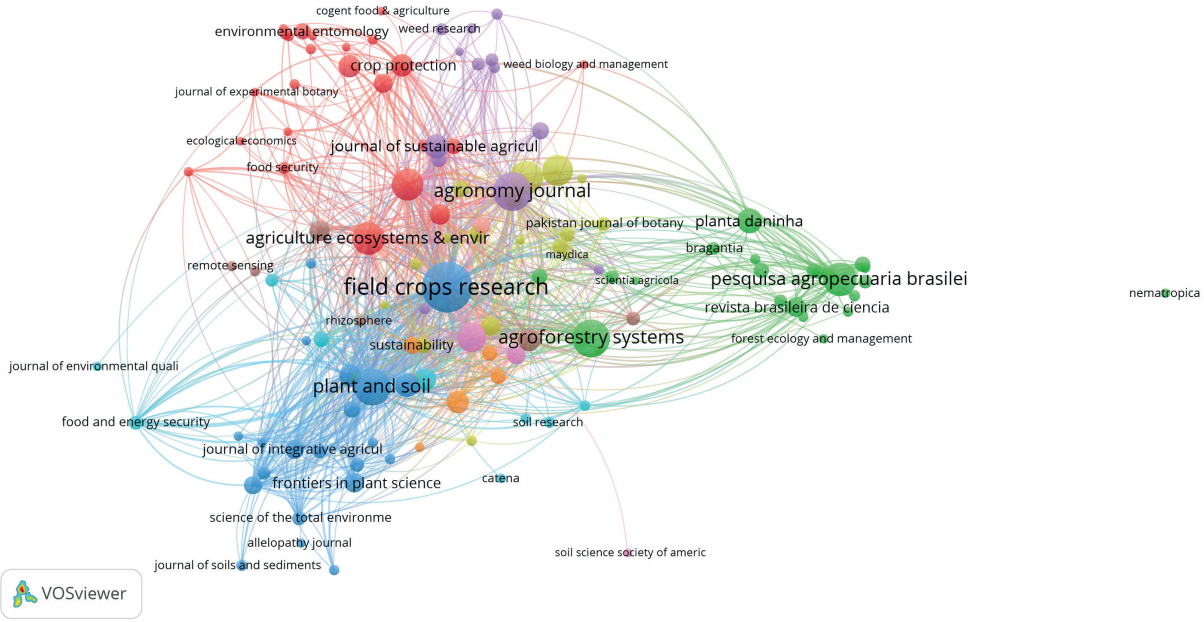

Fig. 2 -Network visualization maps of citation journals in the field of maize or corn intercropping system research based on WoS with 125 circles and 10 clusters.

na Agr Univ of China (2), Int Ctr Insect Physiol & Ecol Icipe of Kenya (2), Wageningen Univ of Netherlands (1), UNESP of Brazil (1) and Rothamsted Res of England (1). Among the 20 authors, the top five authors were Yang Wenyu, Yang Feng, Chai Qiang, van der Werf Wopke, Liu Weiguo, each published more than 36 papers. Based on the average citations, the top five mostly highly cited authors were Li Long, Pickett John A., Khan Zeyaur R., Zhang Fusuo, Midega Charles A.O., each published paper cited more than 45.3 times.

Countries/regions co-authorship analysis

Co-authorship with countries as unit is the relation of items based on the number of co-authors in papers highlighting their respective countries. There are 114 countries contributing the 3,103 papers in this study, Table 5 list the top 20 countries with more than 43 papers and ranked by the number of total publications. People R China was identified as the largest contributor, USA was in the second place, and the third is Brazil. Then other countries followed as India, Kenya, Nigeria, Germany, England, Canada, Netherlands. From the average citations, the top five countries were Malawi, England, Australia, Zimbabwe and Netherlands, which their citations are more than 27.3 times per paper.

By exploring the scientific literature co-authored between countries, we developed the international country co-authorship network map using VOSviewer software (Figure 4). In Figure 4, a circle represents a country/region, the size of each circle represents the number of articles of each country and it denotes the activity of the country/region. A line is established when two countries/regions have a collaborative relationship. The thickness of the each line reflects the tightness of co-operation and the number of collaborations between countries/regions. We set the threshold as 5, there are 74 countries/regions meeting the requirement among all 114 countries. The VOSviewer software divides these 74 circles into 9 clusters.

In Figure 4, the first cluster consisted of 14 countries (red color), which are Kenya, Nigeria, Tanzania, Ghana, Uganda, Benin, Mali, Egypt, Dem Rep Congo, Rwanda, Burkina Faso, Morocco, Niger, Senegal. The second cluster consisted of 13 countries (green), Netherlands, France, Iran, Italy, Zambia, Poland, Austria, Malaysia, Saudi Arabia, Bangladesh, Algeria, Czech Republic, Russia. The third cluster consisted of 11 countries (blue), India, Australia, Pakistan, Japan, Switzerland, Indonesia, Philippines, Thailand, Sri Lanka, South Korea, Laos. The fourth cluster consisted of 8 countries (yellow), USA, Brazil, Mexico, Spain, Colombia, Norway, Scotland, Peru. The fifth cluster consisted of 8 countries (violet), Zimbabwe, Malawi, Denmark, Nepal, Wales, Israel, Mozambique, Portugal. The sixth cluster consisted of 7 countries (shallow blue), Germany, England, Canada, Turkey, Cameroon, Argentina, Costa Rica. The seventh cluster consisted of 6 countries (orange), Belgium, Cuba, Greece, Cote Ivoire, Madagascar, Serbia. The eighth cluster (brown) consisted of only 4 countries, Peoples R China, Sweden, North Ireland, Finland. The ninth cluster (pink) consisted of only 3 countries or regions, South Africa, Ethiopia, Swaziland. Therefore,

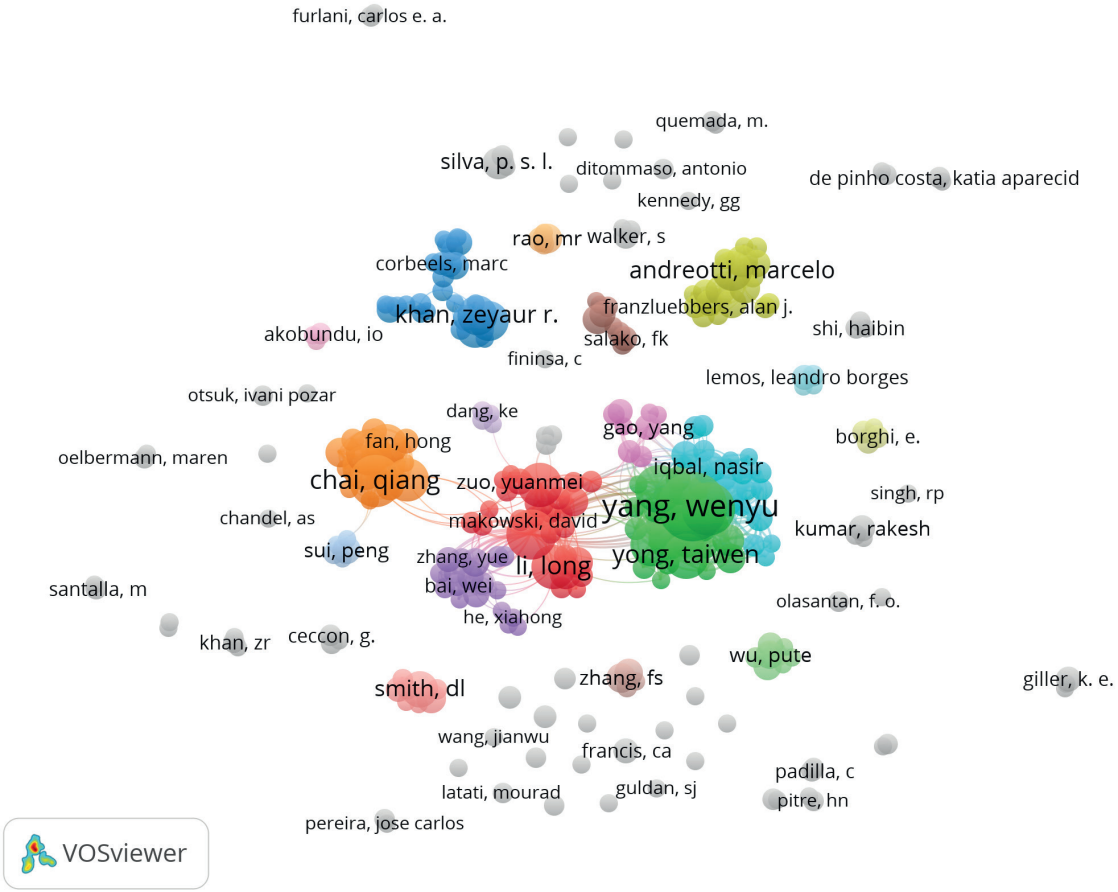

Fig. 3 -Network visualization map of authors for maize or corn intercropping system research

geographical location is an important factor that determines international cooperation, and increasing international exchanges have promoted academic communications.

Organizations (Affiliations) co-authorship analysis

The affiliations presented were described on the profile of each researcher in WoS. They were updated according to the last paper published by the author until June 9, 2022. Organization co-authorship analysis reflects the degree of communication between institutions as well as the influential institutions in this field (Reyes-Gonzalez *et al.*, 2016). The contribution of different institutes was estimated by the institute of the affiliation of at least one author of the published papers. Among the 2,201 organizations, there were 252 organizations meet the thresholds of 5, but 10 organizations no connected to each other, so, left 242 organizations in Figure 5. In Figure 5, each circle represents one organizations, the size of each circle represents the number of articles of each organization and denotes the activity of the organization. A line is established when two organizations have a collaborative relationship, the thickness of the each line reflects the tightness of cooperation and the number of collaborations between organizations, the closer the circles the closer the collaboration. The VOSviewer software divided these 242 institutes into 15 clusters with different colors. The top three affiliations were China Agr Univ, Sichuan Agr Univ, and Wageningen Univ.

Authors co-authorship analysis

The affiliations presented were described on the profile of each researcher in WoS. They were updated according to the last paper published by the author until June 9, 2022. Organization co-authorship analysis reflects the degree of communication between institutions as well as the influential institutions in this field (Reyes-Gonzalez *et al.*, 2016). The contribution of different institutes was estimated by the institute of the affiliation of at least one author of the published papers. Among the 2,201 organizations, there were 252 organizations meet the thresholds of 5, but 10 organizations no connected to each other, so, left 242 organizations in Figure 5. In Figure 5, each circle represents one organizations, the size of each circle represents the num-

Table 4 - The top 20 most prolific authors for maize or corn intercropping system research.

Rank	Author	Papers	Citations	Avg. citations	Affiliations	Country
1	Yang, Wenyu	78	1,570	20.1	Sichuan Agr Univ	China
2	Yang, Feng	45	1,244	27.6	Sichuan Agr Univ	China
3	Chai, Qiang	44	819	18.6	Gansu Agr Univ	China
4	van der Werf, Wopke	39	1,324	33.9	Wageningen Univ	Netherlands
5	Liu, Weiguo	36	865	24.0	Sichuan Agr Univ	China
6	Yong, Taiwen	33	904	27.4	Sichuan Agr Univ	China
7	Yu, Aizhong	32	566	17.7	Gansu Agr Univ	China
8	Li, Long	31	1,973	63.6	China Agr Univ	China
9	Zhang, Fusuo	31	1,428	46.1	China Agr Univ	China
10	Zhao, Cai	31	436	14.1	Gansu Agr Univ	China
11	Wang, Xiaochun	30	631	21.0	Sichuan Agr Univ	China
12	Yin, Wen	29	353	12.2	Gansu Agr Univ	China
13	Hu, Falong	28	403	14.4	Gansu Agr Univ	China
14	Liu, Jiang	26	588	22.6	Sichuan Agr Univ	China
15	Khan, Zeyaur R.	25	1,293	51.7	Int Ctr Insect Physiol & Ecol Icipe	Kenya
16	Midega, Charles A. O.	24	1,087	45.3	Int Ctr Insect Physiol & Ecol Icipe	Kenya
17	Andreotti, Marcelo	24	341	14.2	UNESP	Brazil
18	Fan, Zhilong	23	222	9.7	Gansu Agr Univ	China
19	Pickett, John A.	22	1,262	57.4	Rothamsted Res	England
20	Raza, Muhammad Ali	22	449	20.4	Sichuan Agr Univ	China

ber of articles of each organization and denotes the activity of the organization. A line is established when two organizations have a collaborative relationship, the thickness of the each line reflects the tightness of cooperation and the number of collaborations between organizations, the closer the circles the closer the collaboration. The VOSviewer software divided these 242 institutes into 15 clusters with different colors. The top three affiliations were China Agr Univ, Sichuan Agr Univ, and Wageningen Univ.

All Keywords co-occurrence analysis

For a specific scientific field study, keyword plays a large role as it can reflect the root contents of articles and compilation of keywords can reveal the pattern and trends of specific academic research (Badaluddin *et al.*, 2021). To analyze the co-occurrence of the keywords, author keywords, keywords plus and all keywords as unit were chosen and analyzed.

For the author keywords by full counting method for co-occurrence analysis, there were total 5,837 author keywords, and 402 keywords met the threshold level of more than five times and were separated into eleven cluster in network visualization (Figure 6a). The same data were then arranged by a period of maize or corn intercropping system research as overlay map (Figure 6b). The size of the node is proportional to the frequency of occurrence of the keyword, and the thickness of the line represents the intensity of co-occurrence between individual keywords (Leal *et al.*, 2022). The top twenty-one co-occurrence author keywords were intercropping, maize, *Zea Mays*, yield, soybean, land equivalent ratio, agroforestry, competition, intercrop, legumes, cowpea, nitrogen, wheat, grain yield, corn, soil fertility, no-tillage, cropping systems, phaseolus vulgaris, cropping system, crop rotation, *et al.*, each author keywords occurred more than 40 times.

For the keywords plus by full counting method for co-occurrence analysis, total 4,044 keywords plus resulted, and 612 keywords met the threshold level of more than five times and were separated into seven cluster in network visualization (Figure 6c) and overlay map (Figure 6d). The top twenty-one co-occurrence keywords plus resulted maize, yield, growth, management, productivity, soil, nitrogen, systems, corn, wheat, competition, diversity, use efficiency, tillage, quality, cropping systems, grain-yield, performance, cover crops, system, water, *et al.*, each keywords plus occurred more than 94 times.

For the all keywords by full counting method for co-occurrence analysis, among the total 8,841 all keywords, the 953 all keywords met the threshold level of more than five times included in the map. There are ten main clusters that represent different viewpoints on maize or corn intercropping system research in network visualization (Figure 6e) and overlay map (Figure 6f). The top twenty-one co-occurrence all keywords included maize, intercropping, yield, growth, management, productivity, nitrogen, soil, corn, systems, wheat, competition, *Zea Mays*, diversity, cropping systems, tillage, use efficiency, quality, cowpea, cover crops, legumes, *et al.*, each all keywords occurred more than 121 times.

Table 5 - Top 20 countries/regions publishing papers in the field of maize or corn intercropping system research

Rank	Countries/Regions	Cluster	Records	Total link strength	Citations	Avg. citations
1	Peoples R China	8	636	311	14,317	22.5
2	USA	4	422	308	8,780	20.8
3	Brazil	4	397	78	3,904	9.8
4	India	3	232	36	1,844	7.9
5	Kenya	1	221	289	5,905	26.7
6	Nigeria	1	153	73	1,688	11.0
7	Germany	6	136	149	3,181	23.4
8	England	6	124	151	4,275	34.5
9	Canada	6	118	68	2,589	21.9
10	Netherlands	2	106	156	2,899	27.3
11	Australia	3	85	105	2,852	33.6
12	Pakistan	3	84	86	957	11.4
13	South Africa	9	80	89	1,778	22.2
14	France	2	75	92	1,737	23.2
15	Ethiopia	9	57	51	616	10.8
16	Zimbabwe	5	54	71	1,784	33.0
17	Iran	2	51	14	608	11.9
18	Tanzania	1	51	72	602	11.8
19	Malawi	5	50	76	1,843	36.9
20	Mexico	4	43	26	598	13.9

The same data were then arranged by a period of maize or corn intercropping system research as overlay map for most frequent author keywords (Figure 6b), plus keywords (Figure 6d) and all keywords (Figure 6e). Blue colors indicated earlier research topics, whereas, yellow and green colors indicated more recent topics of interest. Yellow and green circles present those research fronts.

For the 8,841 all keywords by full counting method for co-occurrence analysis, 953 all keywords with co-occurrence more than five times were separated into ten clusters in Figure 6e, about twenty all keywords in each cluster were list and ranked.

The first cluster (Red) is focused on cropping systems management, including all keywords terms management, nitrogen, systems, cropping systems, tillage, agroforestry, biomass, soil fertility, carbon, dynamics, agriculture, conservation agriculture, Africa, organic-matter, rotation, cropping system, food security, yields, sustainable intensification, sustainability, *et al.*, each keywords occurred more than 45 times.

The second cluster (Green) represents maize intercropping system diversity and functions, keyword terms

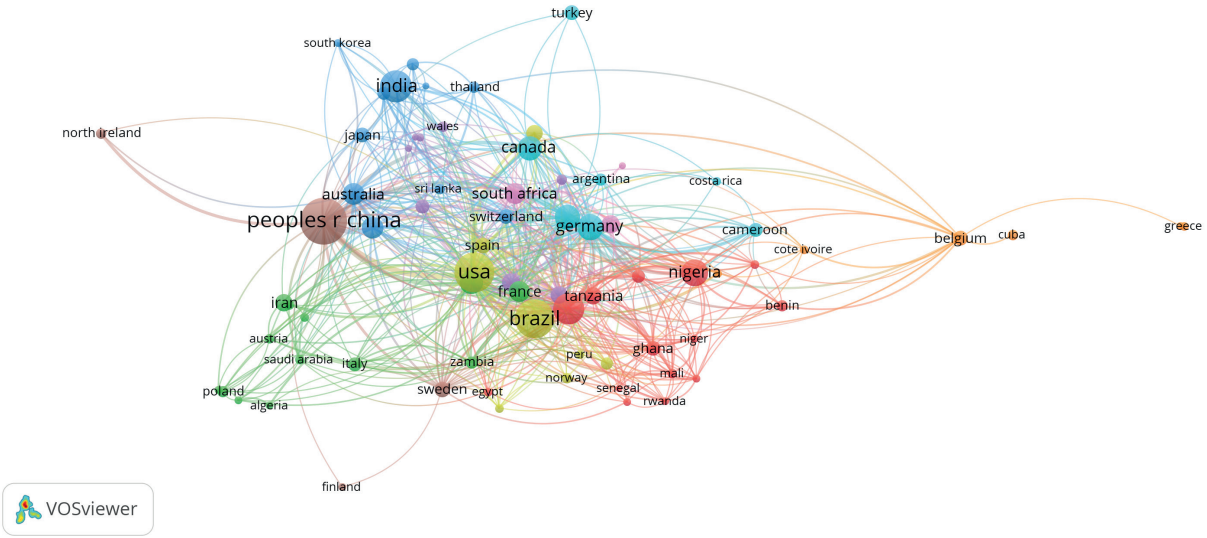

Fig. 4 -The country co-authorship network of maize or corn intercropping system research.

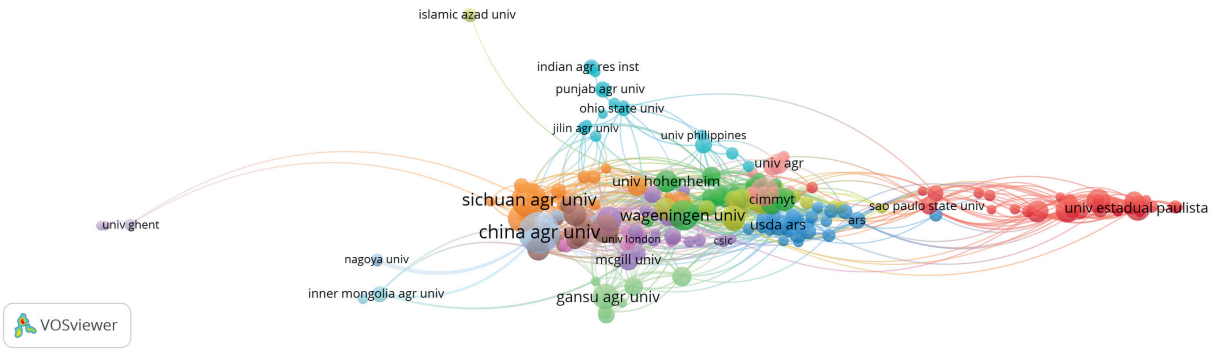

Fig. 5 - The organizations co-authorship network of maize or corn intercropping system research.

ranked as maize, diversity, cowpea, sorghum, plants, density, field, natural enemies, resistance, intercrops, phaseolus vulgaris, cassava, Kenya, lepidoptera, biological-control, weed management, striga, patterns, populations, strategies, weeds, *et al.*, each keywords occurred more than 23 times.

The third cluster (blue) is focused on soil features of corn intercropping system, including keyword terms as intercropping, soil, rhizosphere, phosphorus, legume, efficiency, pea, interspecific competition, N-2 fixation, Zea-Mays, nitrogen-fixation, biodiversity, plant, rice, roots, facilitation, interspecific interactions, accumulation, root, availability, peanut, *et al.*, each keywords occurred more than 33 times.

The fourth cluster (yellow) represents crop growth and yield, keyword terms ranked as yield, growth, productivity, wheat, competition, use efficiency, land equivalent ratio, water, soybean, yield advantage, Zea-Mays L., responses, photosynthesis, irrigation, wheat/maize, crop productivity, light interception, winter-wheat, light, model, *et al.*, each keywords occurred more than 42 times.

The fifth cluster (violet) is focused on crop quality, including keyword terms as quality, legumes, barley, mixtures, forage, economics, maize zea-mays, forage yield, grass, silage, clover, dry-matter, chemical-composition, nutritive-value, ratio, common vetch, digestibility, cereals, protein, advantages, crop production, forage quality, pearl-millet, *et al.*, each keywords occurred more than 21 times.

The sixth cluster (shallow blue) is focused on maize or corn grain-yield, keyword terms ranked as corn, *Zea Mays*, cover crops, grain-yield, performance, no-tillage, crop, system, intercrop, crops, fertilization, cultivars, decomposition, crop-livestock integration, brachiaria-brizantha, no-tillage system, glycine max, land-use efficiency, nitrogen-fertilization, release, *et al.*, each keywords occurred more than 26 times.

The seventh cluster (orange) is focused on fertilizer and soil greenhouse-gas emissions, keyword terms ranked as fertilizer, nitrate, weed suppression, N_2O emissions, denitrification, recovery, greenhouse-gas emissions, nitrification, nitrogen use efficiency, nitrous-oxide emissions, nitrogen fertilization, agricultural sustainability, catch crops, CO_2, respiration, soil-moisture, soil-nitrogen, fertilizer nitrogen, hairy vetch, no-tillage corn, soil respiration, *et al.*, each keywords occurred more than 9 times.

The eighth cluster (brown) is focused on soil fixation in intercropping system, keyword terms ranked as fixation, intercropping system, alfalfa, N-15, grain, *Vigna Unguiculata*, nitrogen transfer, fungi, selection, white clover, harvest index, sole cropping, biological nitrogen fixation, N-2-fixation, genotypes, infection, vetch, N-transfer, glycine-max, rhizobium, *Vigna-Unguiculata* L., *et al.*, each keywords occurred more than 8 times.

The ninth cluster (pink) is focused on grain yield in intercropping system, keyword terms ranked as grain yield, gliricidia sepium, interference, baby corn, relay cropping, green corn, sepium, soybeans, land equivalent ratios, land-equivalent ratio, strip cropping, uptake, prunings, *et al.*, each keywords occurred more than 5 times.

The tenth cluster includes two keywords both maize equivalent yield and system productivity occurred more than 5 times.

Top papers based on Essential Science Indicators (ESI)

Top papers are the sum of hot papers and highly cited papers, based on Clarivate Analytics' Essential Science Indicators (ESI). Highly cited paper is a paper that belongs to the top 1% of papers in a research field published in a specified year. The 1% is determined by the highly cited threshold calculated for the research field in the specified year. Hot paper is a paper published in the past two years that received a number of citations in the most recent two-month period that places

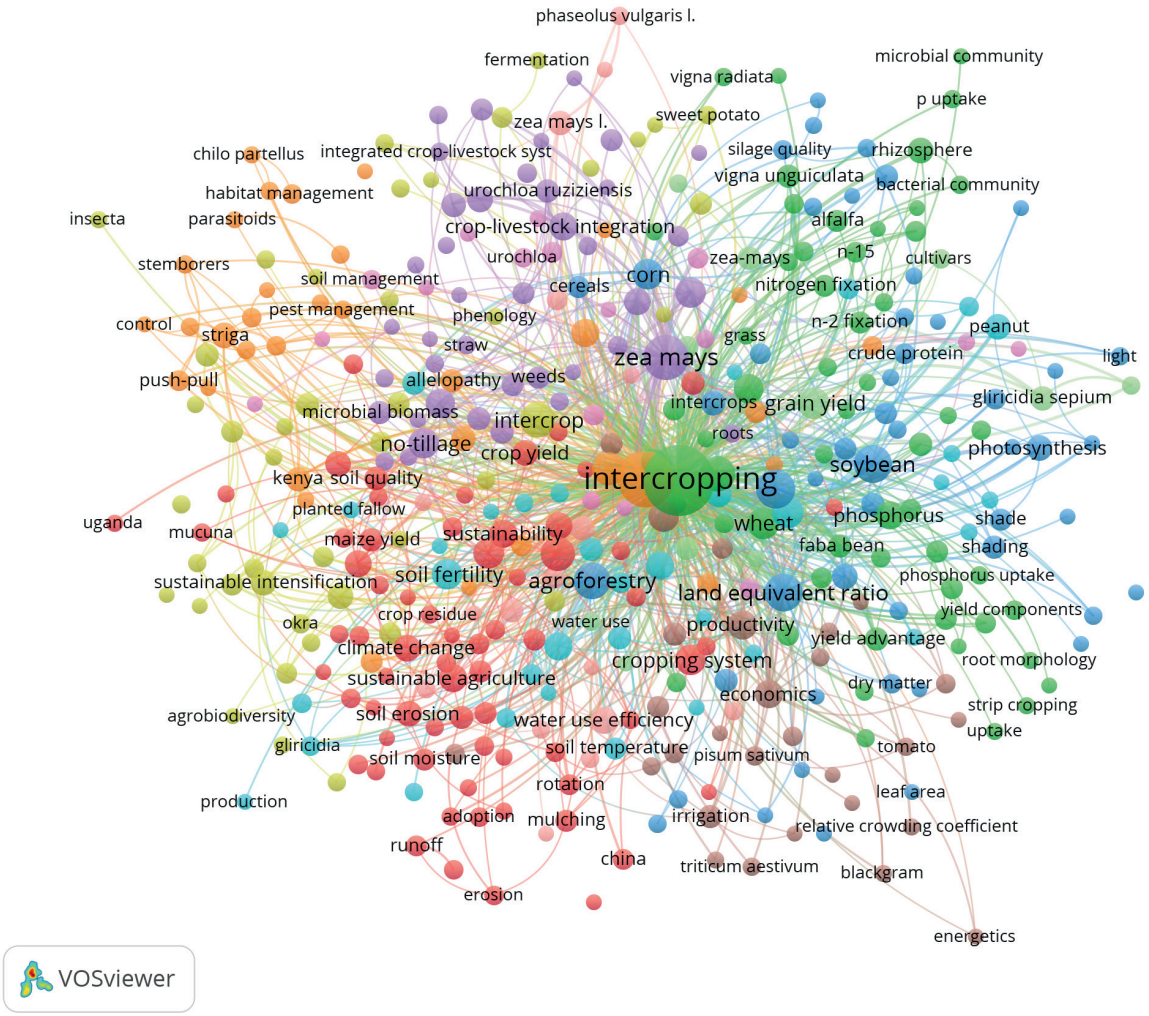

Fig. 6 A - VOSviewer co-occurrence network visualization mapping of most frequent author keywords.

it in the top 0.1% of papers in the same field. Here, the Essential Science Indicators database covers over a 10-year 2-month period: January 1st, 2012 - February 28th, 2022 (Clarivate, 2022. Essential Science Indicators Help).

Based on ESI database, these top papers are 12 highly cited papers, with no hot paper (Table 6). From 2012 to 2021, there are top papers as 1 (2012), 1 (2013), 1 (2014), 1 (2015), 4 (2017), 1 (2018), 1 (2019) and 2 (2020), respectively. These 12 top papers are published in *Field Crops Research* (6), *Crop Protection* (2), *Catena* (1), *Agricultural Water Management* (1), *European Journal of Agronomy* (1), *Nature Plants* (1), *et al.* For the 12 top papers, the h-index is 12, the sum of total citations are 1,507, and the average citation per item is 125.58.

The most frequently cited articles

The total citation count was obtained from SCIE, and this shows the total number of times that a particular article was cited by the journals listed in the SCIE database. Although a great many articles have been published, a relatively small number of individuals accounts for a large proportion of the citations within the period. Figure 7 shows the six most frequently cited articles that have been cited more than 396 times since their initial publication to June 9th, 2022. The six papers were written by Bondeau et al (2007) in *Global Change Biology*, Kromp (1999) in *Agriculture Ecosystems & Environment*, Liebman and Dyck (1993) in *Ecological Applications*, Li et al (2007) in *Proceedings of the National Academy of Sciences of the United States of America*, Zhang and Li (2003) in *Plant and Soil*, Lithourgidis *et al.* (2011) in *Australian Journal of Crop Science*. The total citations for six papers were 805, 588, 523, 487, 403, 396 times. The average citations per year for six papers were 50.31, 24.5, 17.43, 30.44, 20.15, 33 times.

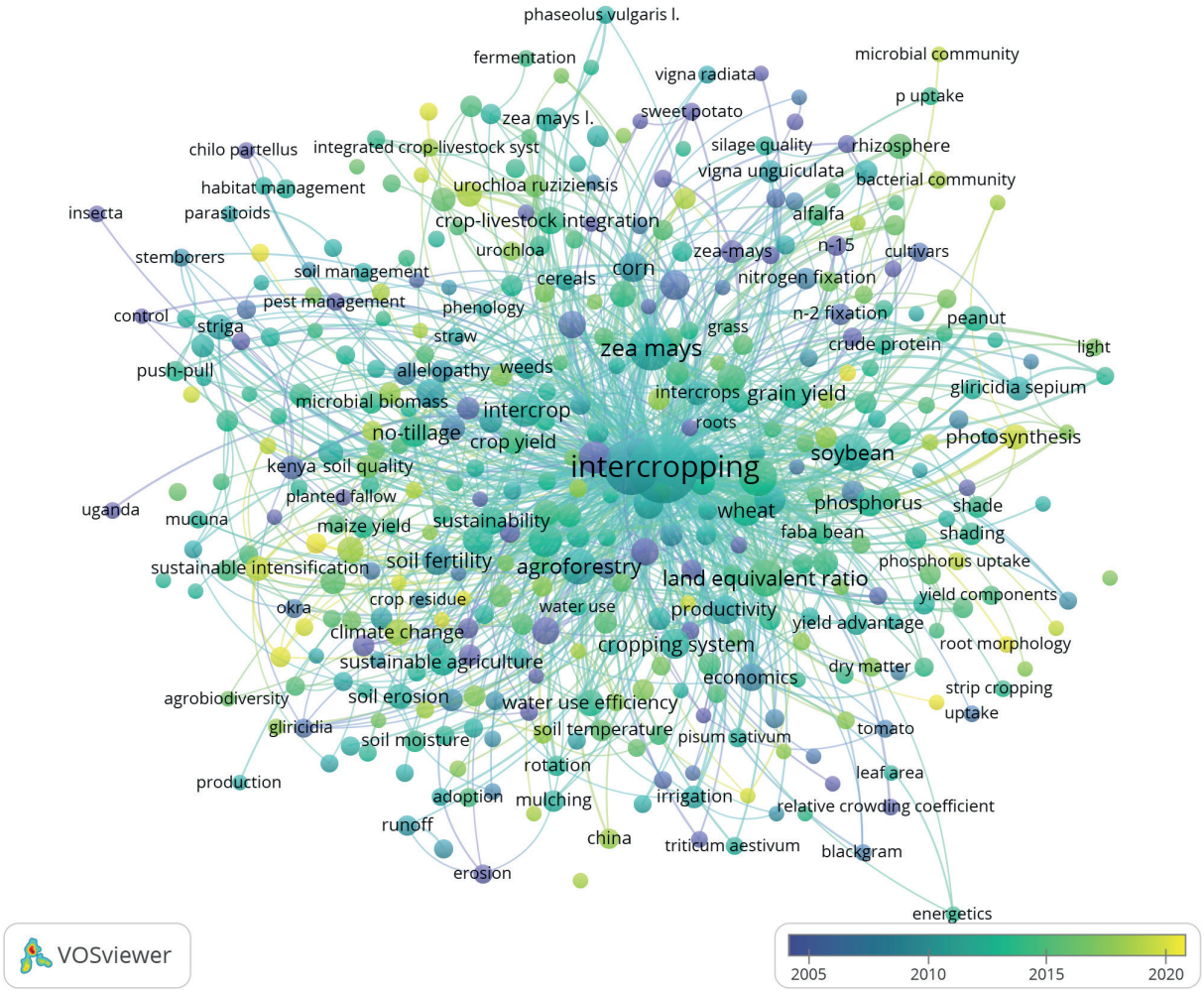

Fig. 6 B - VOSviewer co-occurrence overlay visualization mapping of most frequent author keywords.

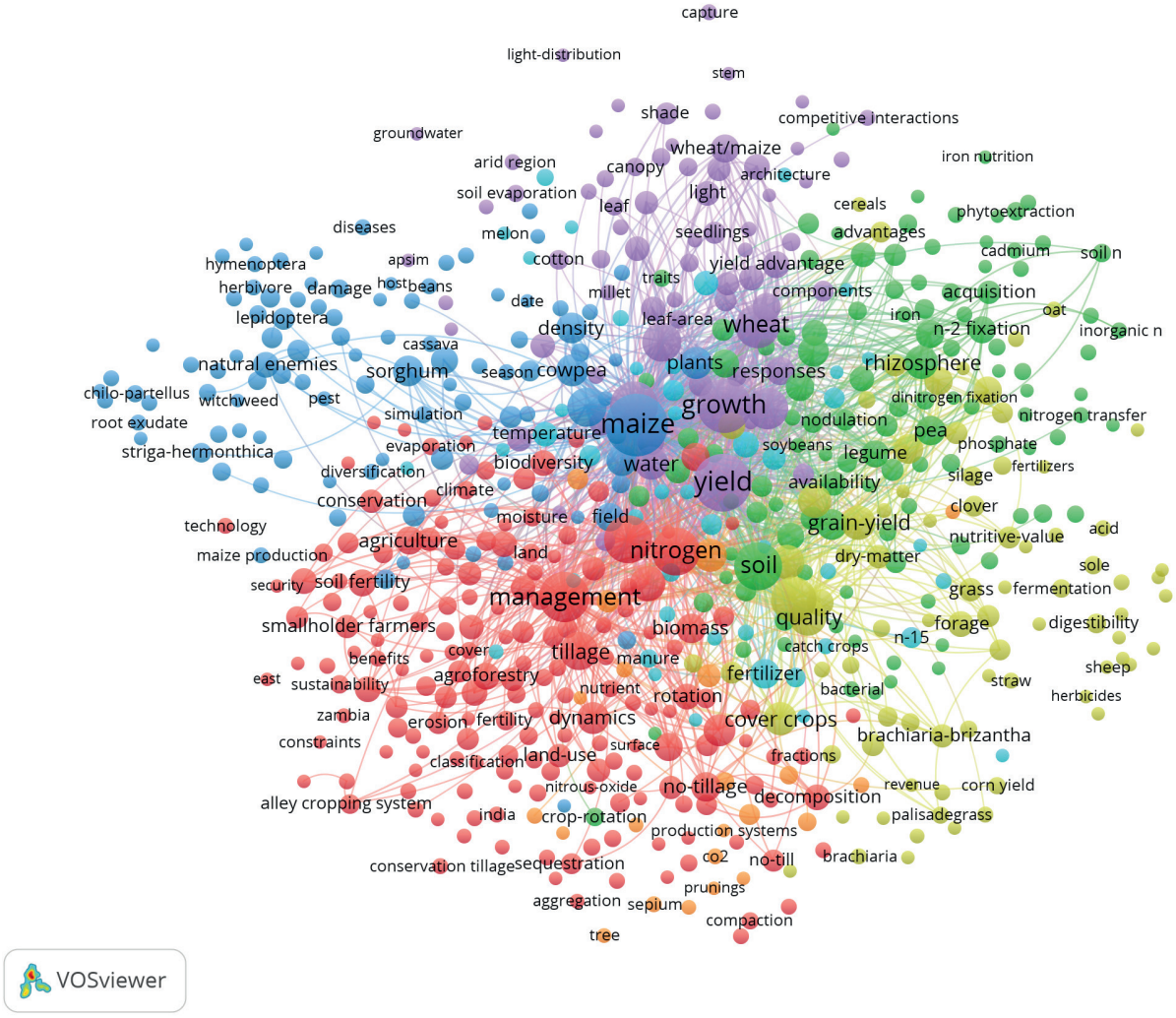

Fig. 6 C - VOSviewer co-occurrence network visualization mapping of most frequent plus keywords

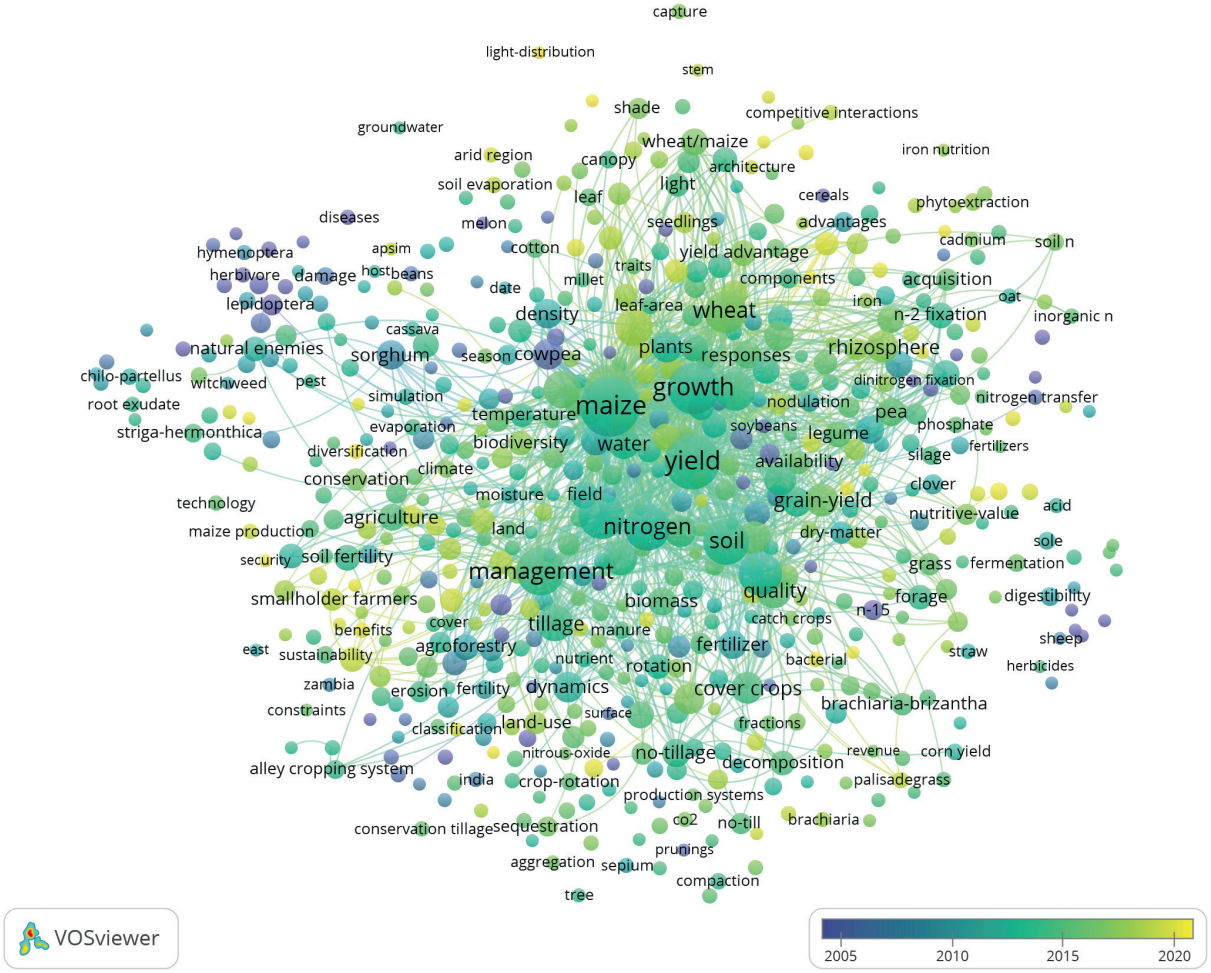

Fig. 6 D - VOSviewer co-occurrence overlay visualization mapping of most frequent plus keywords on maize or corn intercropping system research (minimum of five occurrences) from 1952 to 2022

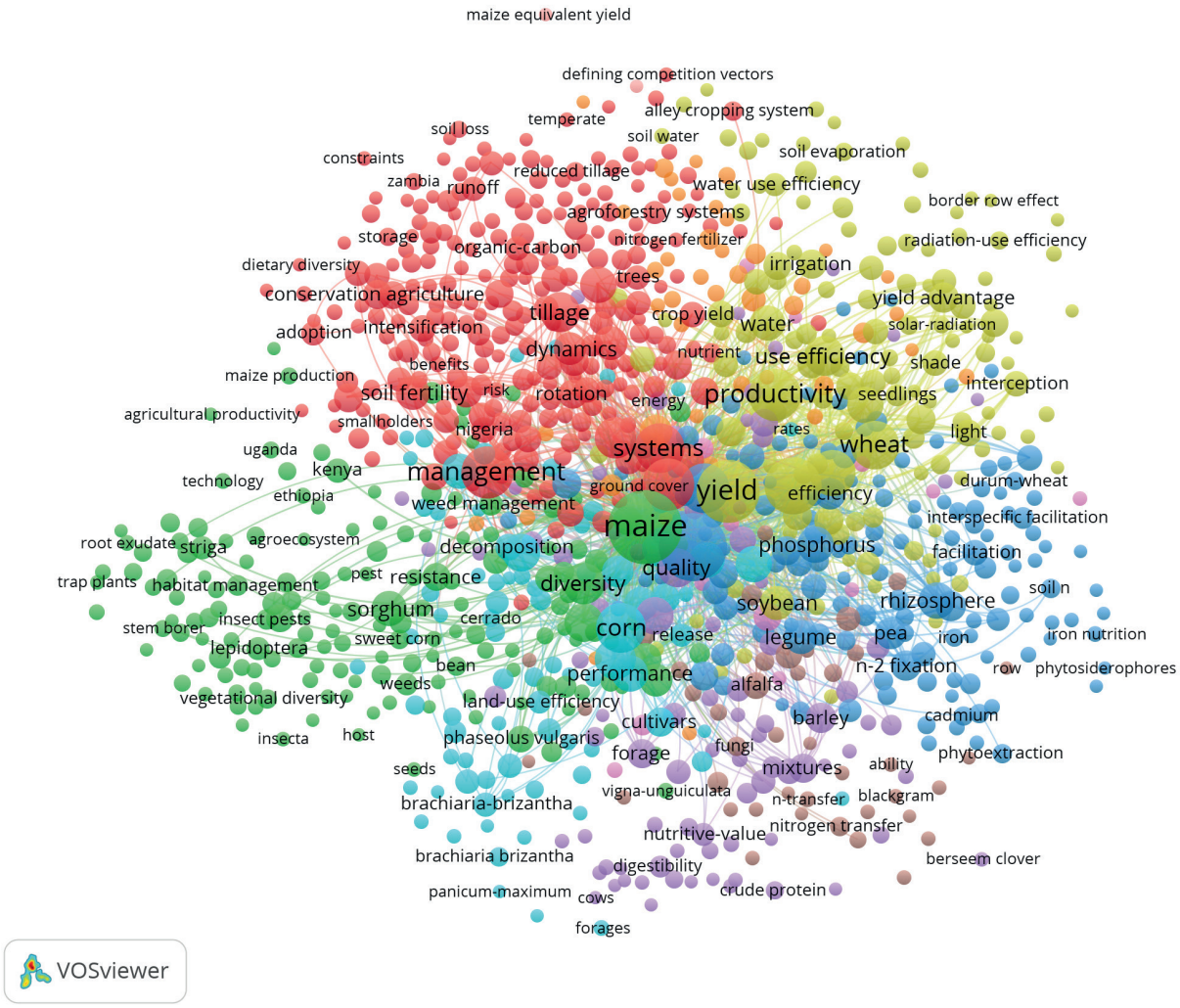

Fig. 6 E - VOSviewer co-occurrence network visualization mapping of most frequent all keywords

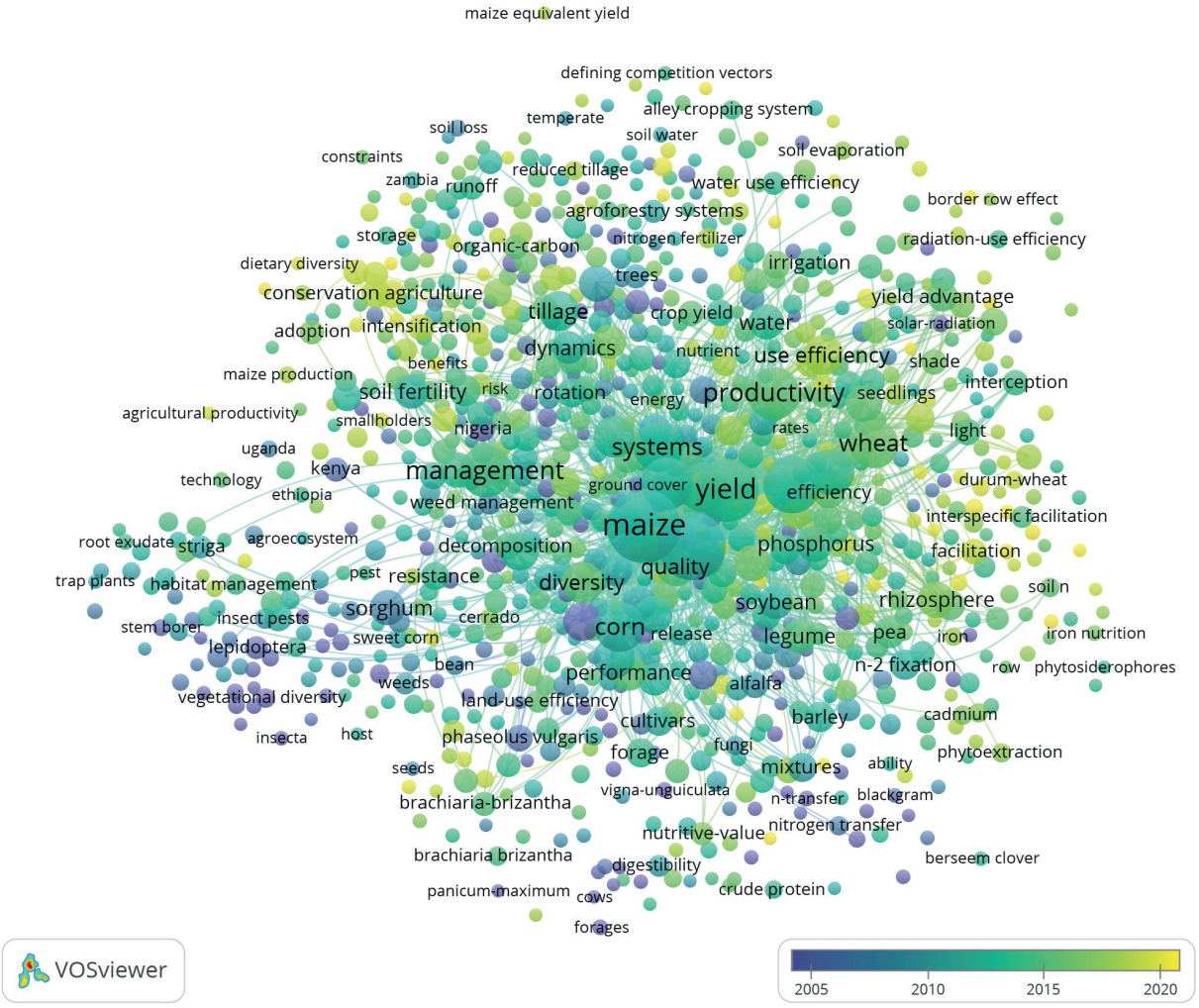

Fig. 6 F - VOSviewer co-occurrence overlay network visualization mapping of most frequent all keywords on maize or corn intercropping system research (minimum of five occurrences) from 1952 to 2022.

Table 6 - Twelve top papers based on ESI.

Rank	Author	Source Title	PY	TC	ACPY
1	El Kateb et al.	*Catena*	2013	193	19.3
2	Rusinamhodzi et al.	*Field Crops Research*	2012	191	17.36
3	Yu et al.	*Field Crops Research*	2015	156	19.5
4	Yang et al.	*Field Crops Research*	2014	147	16.33
5	Raseduzzaman & Jensen	*European Journal of Agronomy*	2017	129	21.5
6	Daryanto et al.	*Agricultural Water Management*	2017	129	21.5
7	Midega et al	*Crop Protection*	2018	126	25.2
8	Yang et al.	*Field Crops Research*	2017	106	17.67
9	Liu et al.	*Field Crops Research*	2017	106	17.67
10	Li et al.	*Nature Plants*	2020	88	29.33
11	Baudron et al.	*Crop Protection*	2019	81	20.25
12	Xu et al.	*Field Crops Research*	2020	55	18.33

Note: PY: Publication Year; TC: Total Citations; ACPY: Average Citation Per Year.

Conclusions

This study analyzed 3,103 research articles and review articles of maize or corn intercropping system research from 1952 to 2022, which the morepapers mainly written in English (2,925, 94.264%), were from 9,814 authors, 114 countries/territories, 2,201 organizations, and listed in 496 Journals and two Book Series. The top five journals were *Field Crops Research, Agronomy Journal, Agroforestry Systems, Plant* and *Soil and Indian Journal of Agricultural Sciences*. Top five countries and regions were Peoples R China, USA, Brazil, India and Kenya. The top three affiliations were China Agr Univ, Sichuan Agr Univ, and Wageningen Univ. Top 5 authors are Yang Wenyu, Yang Feng, Chai Qiang, van der Werf Wopke and Liu Weiguo. Visualizations offer exploratory information on the current state in a scien-

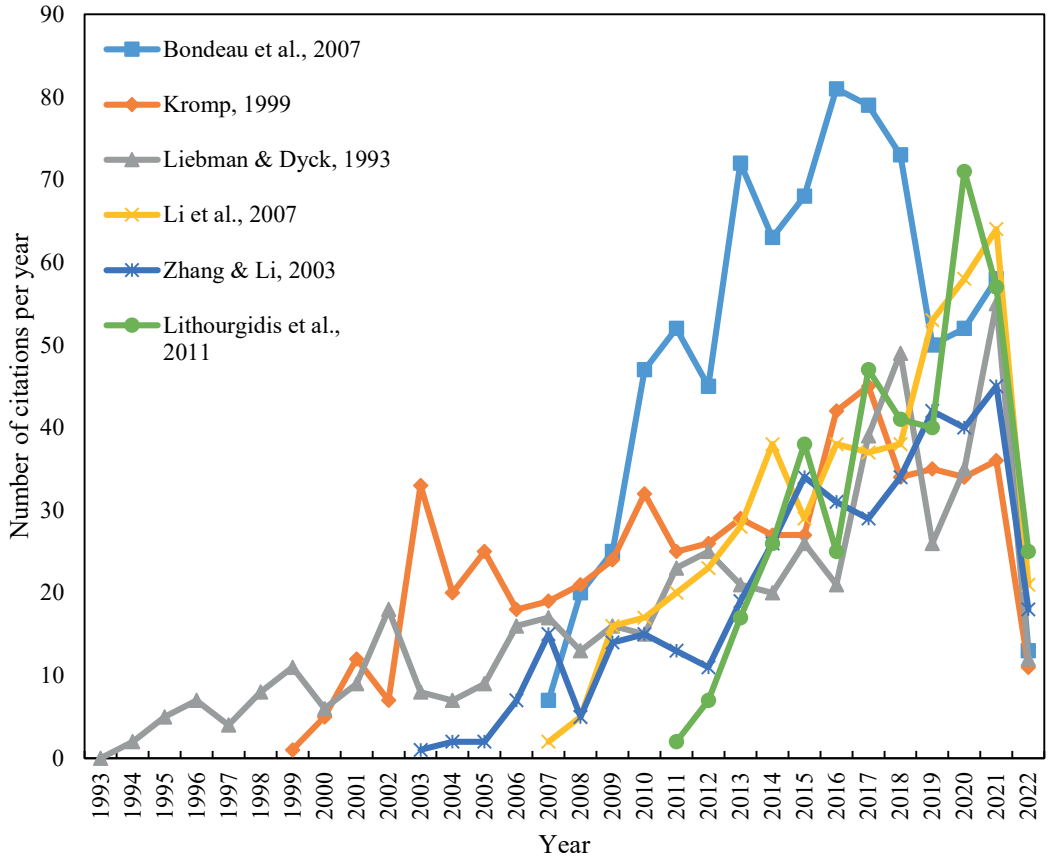

Fig. 7 Comparison of the most citations six papers from their initial publication year to June 9, 2022

tific field or discipline as well as indicate possible developments in the future. The analysis of all keywords showed that maize or corn intercropping systems research separated into ten clusters. So, as main output, authors can choose their ideal journal with a higher impact factor or Q1 in Category to publish their papers in the English language related to their research field.

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Conflicts of Interest

The authors declare no conflict of interest

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