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AGRONOMY

Bibliometric Analysis of Cotton (*Gossypium* spp.) Research Based on Web of Science Agronomy Category

Bao-Zhong Yuan* and Jie Sun

ABSTRACT

Cotton is the main source of renewable fiber in the world and is primarily used for textile production. This study analyzed 3,487 papers on cotton research published during 1990 to 2021 from the agronomy category of the Web of Science (WoS). Papers were mainly written in English (96.329%), from 8,860 authors, 87 countries/territories, 1,661 organizations, and published in 107 journals and book series. The top five core journals were *Crop Science* (433, 12.418%), *Agronomy Journal* (310, 8.89%), *Weed Technology* (205, 5.879%), *Field Crops Research* (203, 5.822%), and *Euphytica* (189, 5.42%) with each publishing more than 189 papers. The top five countries and regions were the U.S., Peoples Republic of China, India, Brazil, and Australia. The top five organizations were USDA ARS, Texas A&M Univ., North Carolina State Univ., Univ. Georgia, and Cotton Incorporated. The top five authors were Johnie N. Jenkins, Don C. Jones, Jack C. McCarty, Jr., Jinfa Zhang, and C. Wayne Smith, with each publishing 72 papers or more. Visualizations using VOSviewer were conducted on WoS data to determine co-occurrence and clusters of connected publications, country input, organizations, and author collaboration (coauthorship) as well as clusters of all keywords of interrelated research topics. Based on the analysis of the network map of VOSviewer, there is cooperation among authors, organizations, and countries or regions. All keywords of the cotton research papers published during 1990 to 2021 from WoS agronomy category separated into six clusters based on different research topics.

B.Z. Yuan*, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei Province, PR China, 430070 and J. Sun, Library of Huazhong Agricultural University, Wuhan, Hubei Province, PR China, 430070.
*Corresponding author: yuanbz@mail.hzau.edu.cn

Cotton (*Gossypium* spp.) is one of the most important economic crops globally, an important fiber crop with large-scale production, and one of the key raw materials for the global textile industry (Stopar et al., 2021; Wang et al., 2020; Xiao et al., 2019). Cotton fibers are naturally hollow; they produce textiles regarded as soft, cool, breathable, and absorbent—holding 24 to 27 times their weight in water. They are dye absorbent and withstand abrasion wear. Because cotton wrinkles, mixing it with polyester fibers or applying some type of permanent finish can provide additional desirable properties to cotton garments. Cotton fibers are often blended with other fibers such as nylon, linen, wool, and polyester to utilize the best properties of each fiber.

According to the category description for agronomy in Scope Notes of Science Citation Index–Expanded, agronomy covers resources that focus on the selection, breeding, management, and post-harvest treatment of crops including crop protection and science, seed science, plant nutrition, plant and soil science, soil management and tillage, weed science, agroforestry, agroclimatology, and agricultural water management (Clarivate, 2021). For the word, cotton, or *Gossypium*, in the title and published during 1990 to 2021, the three Web of Science (WoS) categories most often used were Plant Sciences, Materials Science Textiles, and Agronomy. This paper focuses on the WoS agronomy category.

The study employs bibliometrics and the closely related informetrics or scientometrics, which are based on quantitative analysis and mapping of research in scholarly literature. Bibliometric indicators have been employed frequently to analyze scientific and technological production in different fields of knowledge. Bibliometric techniques have been adopted in clothing and fibers research, such as knowledge mapping of protective clothing based on CiteSpace visualization methodology (Tian and Jun, 2019) and trends in fiber crops (Bartol and Mackiewicz-Talarczyk, 2015). Bibliometric evaluation by Li et al. (2020)

of textile schools around the world benchmarked their productivity related to textiles. For cotton literature, bibliometric analyses of publications include research into cotton leaf curl disease (Khan et al., 2020), mapping and visualization of research topics and publishing patterns of cotton fiber (Stopar et al., 2021), soil and water conservation in the Loess Tableland-Gully Region of China (Wang et al., 2019), and advances in water-use efficiency in agriculture and sustainable water use in agriculture (Velasco-Muñoz et al., 2018a, b). Other applications of bibliometric analysis include those by Sun and Yuan that analyzed rice with fertilizer using Citespace (Sun and Yuan, 2019), identification of the top papers in world rice research (Sun and Yuan, 2020a), identification of the top papers in Library and Information Science based on essential science indicators (Sun and Yuan, 2020b), in the field of water resources (Sun and Yuan, 2020c), green and sustainable science and technology (Yuan and Sun, 2019), in agronomy (Sun and Yuan, 2021), cotton research from Plant Sciences category based on Web of Science (Yuan and Sun, 2021), and in research on maize or corn (Yuan and Sun, 2020a, b).

Bibliometric analysis is a novel way to identify innovations and important interconnections. It can also indicate areas of duplicate research. The aim of this study is to assess research publications and review articles on cotton (*Gossypium* spp.) from the WoS agronomy category during 1990 to 2021 using bibliometric science mapping and visualization tools. Objectives include an assessment of the scatter of publications in citation databases, classification of topics, and progress over the years. Country input and author collaboration (coauthorship) are also addressed. Special attention is given to research topics and research fronts.

MATERIALS AND METHODS

Web of Science. Clarivate Analytics' Web of Science is the world's leading scientific citation search and analytical information platform, and the one of the world's largest and most comprehensive academic information resources covering more than 12,187 core academic journals. The publication counts from the WoS Core Collection were derived from the following databases: Science Citation Index–Expanded, 1900-present; Social Science Citation Index, 1900-present; Conference Proceeding Citation Index–Science, 2015-present; Conference Proceedings Citation Index–Social Science & Humanities, 2015-present; Current Chemical Reactions, 1985-present; and Index Chemicus, 1993-present.

Data Collection and Analysis. This study surveyed papers in WoS Core Collection (1900-present) (retrieval data last updated: 2 Feb. 2021). We used the keywords in the title with the query: Title: (*Gossypium* or cotton) AND Year Published: (1990-2021); refined by Document Types: (Article or Review) and WoS Categories: Agronomy.

Based on the WoS Core Collection data of cotton research paper types of article and review, fully 70% were published after 1990. Consequently, detailed analysis focused on the period of 1990 to 2021 in this paper. There were 3,487 papers from WoS Core Collection from which full record and cited references of the included papers were extracted and imported into VOSviewer (version 1.6.16, 2020, Leiden Univ., Leiden, The Netherlands) for further citation analysis. The impact factors (IF 2019 and IF 5 year) were taken from the Journal Citation Report (JCR, 2019) published in 2020, which had the latest data available.

VOSviewer. Visualizations (network and overlay) using the program VOSviewer were conducted on WoS data to determine co-occurrence and clusters of connected publications, country, organization, and author collaboration (coauthorship) as well as clusters of interrelated research topics (text data). In this work, we used VOSviewer to show the international collaboration among authors, organizations, countries, and research trends using all keywords (Van Eck and Waltman, 2010). VOSviewer is widely used for mapping and visualization of research topics and publishing patterns of cotton fiber in WoS and Scopus (Stopar et al., 2021). In the figures in this paper, items are represented by a label and circle. Circle size reflects the weight (relative importance) of an item. Some items are not displayed to avoid overlapping circles. The colors in network visualization represent clusters of similar items as calculated by the program. Distance between the items indicates the strength of relationships. For a given item, the links and total link strength attributes indicate, respectively, the number of links of an item with other items and the total strength of the links of an item with other items.

RESULTS AND DISCUSSION

Document Type and Language of Publication. Based on Clarivate Analytics' WoS Index, a total of 3,487 papers were cited in Science Citation Index–Expanded, duplicated with citations in Conference Proceedings Citation Index–Science (40), Social Sciences Citation Index (27), and Book Citation Index–Science (2).

Document types and languages are displayed in Table 1. Among document types, articles comprised the majority (3,433, 98.451%), followed by reviews (54, 1.549%), proceedings papers (40, 1.147%), early access (28, 0.803 %), book chapters (2, 0.057%), and data papers (1, 0.029%). Most papers were published in English (3,359, 96.329%), others were French (66, 1.893%), Portuguese (59, 1.692%), Spanish (2, 0.057%), German (1, 0.029%), and Japanese (1, 0.029%). English was the dominate language from the WoS, probably because scholars believe that English-language papers are more widely accepted (Khan et al., 2020).

Publication Output. With the aim of knowing the trend in numbers of papers published in cotton research within the agronomy category, a total of 3,487 publications were obtained from the online version of WoS database between 1990 and 2021 (Fig. 1). The highest numbers of papers published in a year were 210 and 203 in 2019 and 2020, respectively. In general, cotton research literature exhibited fast growth after 2004. There were 707, 1,052, and 1,505 papers published during 1990 to 1999, 2000 to 2009, and 2010 to 2019, respectively. 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 3,487 papers, the h-index is 84, and the average citation per item is 16.91.

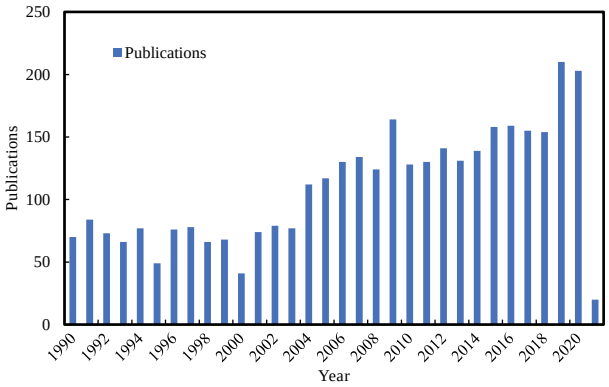

Figure 1. Number of published papers in cotton research from WoS agronomy category during 1990 to 2021.

WoS Categories and Research Areas. For cotton research from the agronomy category during 1990 to 2021, there are 29 WoS subject categories in the science edition (total, 254 categories) and 21 research areas. Table 2 lists the top 15 WoS categories and top 15 research areas in the subject of cotton research from Agronomy . The top five WoS categories include Agronomy (3,487, 100%), Plant Sciences (1,204, 34.528%), Horticulture (386, 11.07%), Soil Science (223, 6.395%), and Entomology (187, 5.363%). The top five research areas include Agriculture (3,487, 100%), Plant Sciences (1,204, 34.528%), Entomology (187, 5.363%), Water Resources (170, 4.875%), and Genetics Heredity (164, 4.703%). The journals or papers can be classified in two or more categories in WoS, which shows the multidisciplinary character of the research field (Elango and Ho, 2017, 2018). Documents were mapped to one or several research areas in WoS. Areas were assigned to publications and then mapped to each document (paper) in a publication. Publications can be mapped to several different areas. This broad database-specific mapping has several limitations but is nevertheless widely used in bibliometric assessments. In WoS, publications are also mapped to WoS categories, which are more detailed than areas (Stopar et al., 2021).

Table 1 Document type and language of publications of cotton research from the WoS agronomy category during 1990 to 2021

Rank	Documents included			Languages		
	Document type	No. Records	% of 3,487	Language	No. Records	% of 3,487
1	Article	3433	98.45	English	3359	96.32
2	Review	54	1.54	French	66	1.89
3	Proceedings Paper	40	1.14	Portuguese	59	1.69
4	Early Access	28	0.80	Spanish	2	0.05
5	Book Chapter	2	0.05	German	1	0.02
6	Data Paper	1	0.02	Japanese	1	0.02

Table 2. Top 15 WoS categories and research areas for cotton research from agronomy category during 1990 to 2021

Rank	Web of Science Categories	TP[z]	% of total	Research Areas	TP	% of total
1	Agronomy	3487	100	Agriculture	3487	100
2	Plant Sciences	1204	34.52	Plant Sciences	1204	34.52
3	Horticulture	386	11.07	Entomology	187	5.36
4	Soil Science	223	6.39	Water Resources	170	4.87
5	Entomology	187	5.36	Genetics Heredity	164	4.70
6	Water Resources	170	4.87	Biotechnology Applied Microbiology	110	3.15
7	Genetics Heredity	164	4.70	Chemistry	90	2.58
8	Agriculture Multidisciplinary	139	3.98	Meteorology Atmospheric Sciences	67	1.92
9	Biotechnology Applied Microbiology	110	3.15	Forestry	57	1.63
10	Agricultural Engineering	91	2.61	Life Sciences Biomedicine other Topics	43	1.23
11	Chemistry Analytical	88	2.52	Environmental Sciences Ecology	20	0.57
12	Meteorology Atmospheric Sciences	67	1.92	Science Technology other Topics	12	0.34
13	Forestry	57	1.63	Computer Science	5	0.14
14	Biology	43	1.23	Food Science Technology	5	0.14
15	Environmental Sciences	19	0.54	Business Economics	1	0.02

[z] **TP: total publications**

Core Journals. Based on JCR 2019 data (published in 2020), there were 107 journals and book series in WoS categories for cotton research from Agronomy during 1990 to 2021. The top 15 core journals are listed in Table 3, each publishing at minimum, 67 papers, along with journal impact factor (IF) for IF 2019 and IF 5 year, rank, and quartile.

The top five, top 10, and top 15 journals published approximately 38%, 55%, and 66% of the total papers, respectively. *Crop Science* was the most productive journal with 433 papers (12.418%), followed by *Agronomy Journal* (310, 8.89%), *Weed Technology* (205, 5.879%), *Field Crops Research* (203, 5.822%), and *Euphytica* (189, 5.42%). Of the top 15 journals, there are seven journals in IF Quartile 1, four journals in IF Quartile 2, two journals in IF Quartile 3, and two journals in IF Quartile 4 in Agronomy (Table 3). White-Gibson et al. (2019) demonstrated the importance of publishing in the English language and in a journal with a high IF. Citation analysis is not a measurement of scientific quality, but it is reflective of the importance of journals or papers (White-Gibson et al., 2019).

Author Coauthorship Analysis. In general, 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) (Fig. 2). According to publication data, a total of 8,860 authors published 3,487 publications, with 474 authors publishing at least five. Of those, 283 authors were connected to each other. The network of authorship in the field of cotton research is shown as 19 clusters in Fig. 2, circle size reflects the total number of records. The total link strength attribute indicates the total strength of the coauthorship links of a given researcher with other researchers. Based on the clusters in Fig. 2, authors in the same cluster suggest that they have close cooperation with each other.

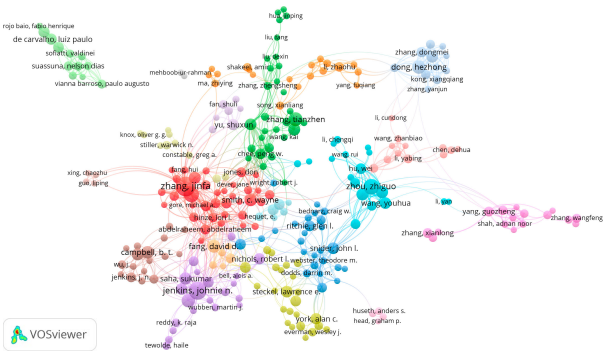

Figure 2. Network visualization maps of authors in cotton research from WoS agronomy category during 1990 to 2021.

Table 3. Top 15 journals on cotton research from agronomy category indexed in the WoS

Rank	Journal	TP[z]	% of 3,487	IF[y] 2019	IF5 year	QC[x]
1	Crop Science	433	12.41	1.878	2.096	Q2
2	Agronomy Journal	310	8.89	1.683	2.095	Q2
3	Weed Technology	205	5.87	1.259	1.349	Q3
4	Field Crops Research	203	5.82	4.308	4.816	Q1
5	Euphytica	189	5.42	1.614	1.883	Q2
6	Crop Protection	152	4.35	2.381	2.537	Q1
7	Agricultural Water Management	117	3.35	4.021	4.469	Q1
8	Theoretical and Applied Genetics	114	3.26	4.439	4.603	Q1
9	Journal of Plant Registrations	100	2.86	0.59	0.798	Q4
10	Industrial Crops and Products	91	2.61	4.244	4.583	Q1
11	Pest Management Science	89	2.55	3.75	3.861	Q1
12	Communications in Soil Science and Plant Analysis	88	2.52	0.767	0.887	Q4
13	Weed Science	77	2.20	2.258	2.441	Q1
14	Phytoparasitica	73	2.09	1.137	1.239	Q3
15	Plant Breeding	67	1.92	1.662	1.626	Q2

[z] TP: total publications

[y] IF 2019 and IF 5years

[x] QC: Quartile in WoS Category. Data were from the 2020 edition of Journal Citation Reports.

Table 4 lists the 24 most published authors (at least 26 articles) and number of citations, average number of citations, organization, and country of residence. The five most published authors are Johnie N. Jenkins, Don C. Jones, Jack C. McCarty, Jr., Jinfa Zhang, and C. Wayne Smith. The five authors with the most citations per paper are Wangzhen Guo (Guo, WZ), K. Raja Reddy (Reddy, KR), Tianzhen Zhang (Zhang, TZ), Andrew Paterson (Paterson, AH), and Hezhong Dong (Dong, HZ). The 24 most prolific authors are from the U.S., 19, Peoples Republic of China (PRC), 4; and Australia, 1.

Country/Region Coauthorship Analysis. There are 87 countries or regions contributing the 3,487 papers in this study. Table 5 lists the top 15 countries/regions, each having at least 23 publications. Table 5 also lists the number of clusters per country/region, total link strength, number of citations, and average number citations. U.S., PRC, India, Brazil, and Australia are leading countries in total publications. Publications from Spain, Germany, England, Israel, and U.S. were each cited an average of 20 times.

We developed the country coauthorship network map using VOSviewer (Fig. 3). We set the threshold as five publications with international collaboration. Figure 3 reveals there are 43 countries/regions meeting this requirement. Circle size reflects the total number of records and the distance between the countries indicates the strength of relationships. VOSviewer groups these circles into nine clusters using color to indicate the different clusters formed by sets of countries.

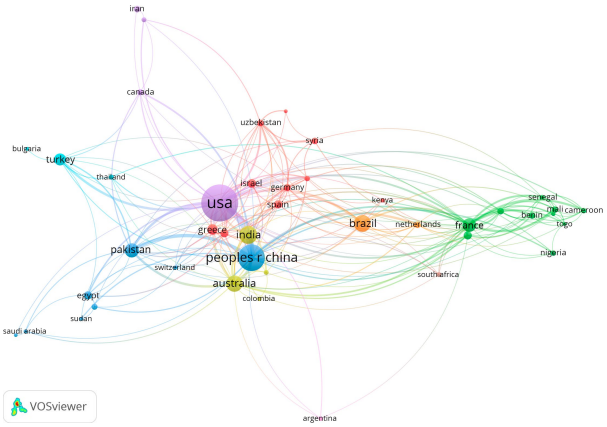

Figure 3. The country coauthorship network of cotton research from WoS agronomy category during 1990 to 2021 with 43 nodes and 9 clusters.

Table 4. The top 24 most prolific authors published papers in the field of cotton research from Agronomy category during 1990 to 2021

Rank	Author	No. papers	No. citations	Avg. no. citations	Organizations	Country
1	Jenkins, Johnie N. (Jenkins, J.N.; Jenkins, JN)	99	1993	20.13	ARS, USDA	USA
2	Jones, Don C. (Jones, Don; Jones, D.C.; Jones, DC; Jones, D.)	86	532	6.19	Cotton Inc,	USA
3	Mccarty, Jack C., Jr. (McCarty, J.C., Jr.; McCarty, J.C.; McCarty, JC)	78	1677	21.50	USDA ARS	USA
4	Zhang, Jinfa (Zhang, JF)	76	1219	16.04	New Mexico State Univ	USA
5	Smith, C. Wayne (Smith, C.W.; Smith, CW)	72	922	12.81	Texas A&M Univ	USA
6	Wilcut, John W. (Wilcut, JW)	50	1156	23.12	North Carolina State Univ	USA
7	Bourland, Fred M. (Bourland, FM; Bourland, F.M.)	48	291	6.06	Univ Arkansas	USA
8	Zhang, Tianzhen (Zhang, TZ)	43	1637	38.07	Nanjing Agr Univ	China
9	Percy, Richard G. (Percy, Richard; Percy, R.G.; Percy, RG)	41	664	16.20	USDA ARS	USA
10	Zhou, Zhiguo	38	540	14.21	Nanjing Agr Univ	China
11	Campbell, B. Todd (Campbell, B.T.)	37	421	11.38	USDA ARS	USA
12	Hequet, Eric F. (Hequet, Eric; Hequet, E.F.; Hequet, E.)	37	229	6.19	Texas Tech Univ	USA
13	Dong, Hezhong (Dong, HZ)	36	1136	31.56	Shandong Acad Agr Sci	China
14	May, O. Lloyd (May, OL)	34	658	19.35	Univ Georgia	USA
15	Saha, Sukumar (Saha, S.; Saha, S)	34	772	22.71	ARS, USDA	USA
16	Oosterhuis, Derrick M. (Oosterhuis, D.M.; Oosterhuis, DM)	33	903	27.36	Univ Arkansas	USA
17	Constable, Greg A. (Constable, G.A.; Constable, GA)	32	631	19.72	CSIRO Agr & Food	Australia
18	Meredith, William R., Jr. (Meredith, W. R., Jr.; Meredith, WR)	32	897	28.03	USDA ARS	USA
19	York, Alan C.(York, AC)	32	662	20.69	North Carolina State Univ	USA
20	Paterson, Andrew H. (Paterson, AH)	31	993	32.03	Univ Georgia	USA
21	Stelly, David M.(Stelly, D.M.; Stelly, DM)	30	799	26.63	Texas A&M AgriLife Res	USA
22	Guo, Wangzhen (Guo, WZ)	29	1451	50.03	Nanjing Agr Univ	China
23	Reddy, K. Raja (Reddy, KR)	27	1285	47.59	Mississippi State Univ	USA
24	Cantrell, Roy G. (Cantrell, R.G.; Cantrell, RG)	26	683	26.27	Wheelertex Consulting LLC	USA

Table 5. Top 15 countries/regions publishing papers in the field of cotton research from WoS Agronomy category during 1990 to 2021

Rank	Countries/Regions	Records	No. clusters	Total link strength	No. citations	Avg. no. citations
1	USA	1544	5	305	30555	19.8
2	PRC	664	3	261	12065	18.2
3	India	244	4	33	2248	9.2
4	Brazil	216	7	42	1376	6.4
5	Australia	187	4	101	3510	18.8
6	Pakistan	135	3	84	1761	13.0
7	France	121	2	144	1879	15.5
8	Turkey	93	6	32	1596	17.2
9	Greece	60	1	25	768	12.8
10	Israel	43	1	18	881	20.5
11	Egypt	35	3	16	459	13.1
12	England	35	1	40	940	26.9
13	Belgium	34	2	40	414	12.2
14	Spain	33	1	21	1058	32.1
15	Germany	23	1	29	666	29.0

The U.S., PRC, India, Brazil, and Australia are the five biggest circles. The first cluster consisted of 10 countries and regions (red): Greece, Israel, England, Spain, Germany, Uzbekistan, Syria, Italy, Kenya, and Portugal. The second cluster consisted of 10 countries or regions (green): France, Belgium, Benin, Burkina, Faso, Mali, Cameroon, Nigeria, Senegal, Cote Ivoire, and Togo. The third cluster consisted of eight countries (blue): PRC, Pakistan, Egypt, Japan, Sudan, Saudi Arabia, Switzerland, and Tunisia. The fourth cluster consisted of four countries and regions (yellow): India, Australia, Mexico, and Colombia. The fifth cluster also consisted of four countries (violet): U.S., Iran, Canada, and South Korea. The sixth cluster consisted of three countries (light blue): Turkey, Thailand, and Bulgaria. The seventh cluster consisted of two countries (orange): Brazil and Netherlands. The eighth cluster consisted of one country (brown): South Africa. The ninth cluster consisted of one country (pink): Argentina. More cooperation could bring more advanced achievements in scientific research. Therefore, geographical location is an important factor that determines international cooperation. Tang et al. (2018) suggested that increasing international exchanges have promoted academic communications and these data support that conclusion.

Organization Coauthorship Analysis. According to the publication data, 1,660 organizations produced 3,487 publications. Organization coauthorship analysis reflects the degree of communication between institutions as well as the identifies influential institutions in this field (Reyes-Gonzalez et al., 2016). Table 6 lists the top 20 organizations and institutions producing 48 or more publications between 1990 and 2021, total link strength, number of citations, average number of citations, and country. These organizations are located mainly in the U.S., 13 and PRC, 6. USDA ARS, Texas A&M Univ., North Carolina State Univ., Univ. Georgia, and Cotton Inc. are the five most prolific producers of scientific papers dealing with *Gossypium*. The organizations of Nanjing Agricultural Univ., Louisiana State Univ., Chinese Acad. Sci., Mississippi State Univ., and USDA ARS show the higher average number of citations.

Table 6. Top 20 organizations cotton research from Agronomy WoS category

Rank	Organizations	No. Cluster	No. Records	TLS[z]	No. Citations	Avg. No. citations	Country
1	USDA ARS	12	418	476	9368	22.4	USA
2	Texas A&M Univ	9	197	316	3900	19.8	USA
3	North Carolina State Univ	8	158	232	2870	18.2	USA
4	Univ Georgia	13	156	298	2872	18.4	USA
5	Cotton Inc	12	153	312	1614	10.5	USA
6	Mississippi State Univ	14	150	264	3370	22.5	USA
7	Univ Arkansas	11	133	176	2396	18.0	USA
8	Texas Tech Univ	9	130	193	1485	11.4	USA
9	Chinese Acad Agr Sci	1	118	120	1738	14.7	China
10	Nanjing Agr Univ	1	103	64	2633	25.6	China
11	New Mexico State Univ	12	92	141	1589	17.3	USA
12	CIRAD	5	69	61	1145	16.6	France
13	Louisiana State Univ	11	63	98	1582	25.1	USA
14	Univ Tennessee	11	62	94	803	13.0	USA
15	Chinese Acad Sci	2	60	38	1480	24.7	China
16	Shihezi Univ	1	55	34	614	11.2	China
17	Huazhong Agr Univ	2	54	37	978	18.1	China
18	Auburn Univ	8	53	104	974	18.4	USA
19	China Agr Univ	1	48	70	1001	20.9	China
20	Clemson Univ	8	47	103	885	18.8	USA

[z] TLS: Total link strength

Of the 1,660 organizations, 200 organizations met the minimum threshold of five records for VOSviewer analysis, of which 190 organizations were connected to each other (Fig. 4). The VOSviewer software divided these 190 institutions into 16 color-coded clusters. Within the context of network formation, organizations tend to form bonds with other institutions in the same region, or rather, network agents do not necessarily connect with the most central agents but with those geographically closest. Geographical localization is an important factor for partnership and joint venture. Perhaps this is why there is a heavy presence of intra-institutional relationships within the scientific network on publications.

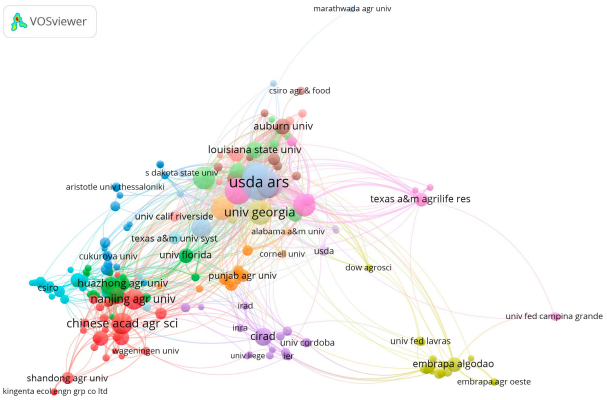

Figure 4. The organization coauthorship network in cotton research from WoS agronomy category during 1990 to 2021.

All Keywords Co-occurrence Analysis. Figure 5 shows the network map that links all of the keywords to the entire sample of the articles analyzed. Of 9,401 keywords, only 1,074 keywords met our threshold of occurring in five or more articles and therefore included in the map. The top 20 keywords were cotton, yield, growth, *gossypium hirsutum,* upland, cotton, management, *gossypium-hirsutum,* resistance, soil, lint yield, nitrogen, cultivars, quality, fiber quality, plants, wheat, photosynthesis, registration, identification, stress, each more than 95 occurrence times. Keywords analysis produced six main clusters that represent different areas of cotton research from the WoS agronomy category.

The same data were then arranged by period of cotton research from the WoS agronomy category on the overlay map in Fig, 6. Blue colors indicate earlier research topics within the 1990 to 2021 study period, whereas green and yellow colored circles indicate more recent topics of interest. Obviously, if a topic is presented in blue, it does not mean that there is no longer any research in this area but does indicate that, on average, this topic was intensely investigated earlier and attention has shifted towards other topics. For example, the circle for fluometuron in the lower left is represented by dark blue. Perhaps this term is now so general that it is not used extensively as a keyword.

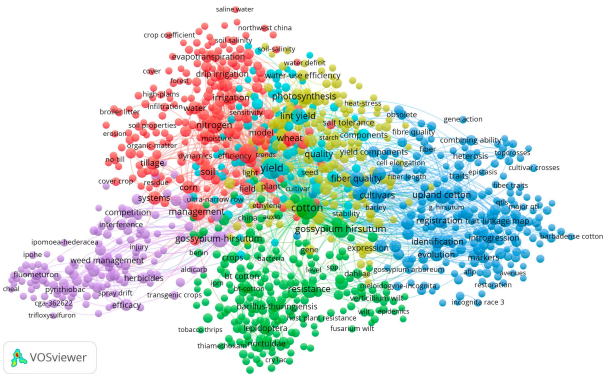

Figure 5. VOSviewer co-occurrence network visualization mapping of most frequent keywords (minimum of 5 occurrences) in cotton research from WoS agronomy category during 1990 to 2021.

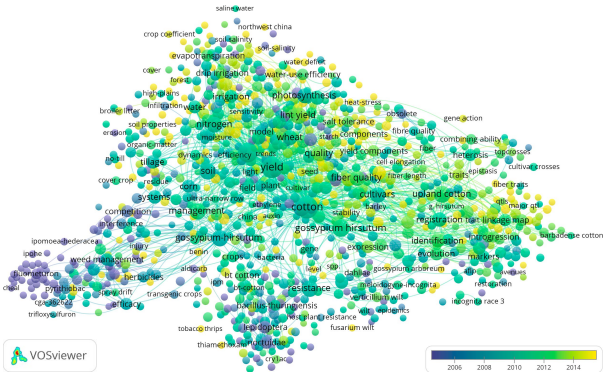

Figure 6. VOSviewer co-occurrence overlay visualization mapping of most frequent keywords (minimum of 5 occurrences) in cotton research from WoS agronomy category during 1990 to 2021.

Visualizations conducted on large datasets offer exploratory information on the current state in a scientific field or discipline as well as indicate possible developments in the future. The clusters in Fig. 5 were developed using the top 20 keywords for each research area and is presented as an example of the power of visualization analyses. The first cluster (red) is focused on cotton growth management, including keyword terms such as growth, management, soil, nitrogen, wheat, systems, tillage, temperature, corn, irrigation, water, use efficiency, plant, maize, field, fertilization, drip irrigation, evapotranspiration, model, and crop. The second cluster (green) represents Bt transgenic cotton research publications with keyword terms ranked as cotton, *Gossypium*

hirsutum, resistance, populations, Bt cotton, noctuidae, Lepidoptera, transgenic cotton, crops, bacillus-thuringiensis, helicoverpa armigera, impact, China, homoptera, tomato, dahlia, insecticide resistance, Australia, protein, and verticillium wilt. The third cluster (blue) is focused on upland cotton cultivars and fiber quality, including keywords: upland cotton, cultivars, fiber quality, registration, identification, *Gossypium hirsutum*, evolution, germplasm, population, rice, genetic diversity, linkage map, diversity, markers, inheritance, QTL analysis, gossypium, traits, heterosis, and quantitative trait loci. The fourth cluster (yellow) represents plant responses to stress with keyword terms of plants, photosynthesis, stress, responses, leaves, L., tolerance, expression, accumulation, *Gossypium hirsutum*, drought, water-use efficiency, salt tolerance, potassium, salinity, metabolism, germination, stomatal conductance, and variability. The fifth cluster (violet) is focused on weed management and weed control. Keywords include *Gossypium hirsutum*, weed management, glyphosate, competition, efficacy, density, herbicides, emergence, amaranth, amaranthus palmeri, pyrithiobac, interference, translocation, cotton yield, fluometuron, glufosinate, herbicide-resistant crops, resistant, herbicide, absorption, and weed control. The sixth cluster (light blue) is focused on cotton yield and quality with keyword terms ranked as yield, lint yield, quality, components, genotypes, performance, dry-matter, environment, mepiquat chloride, maturity, fiber properties, leaf senescence, stability, canopy photosynthesis, patterns, plant density, cultivar, earliness, leaf nitrogen, and light interception.

Top Papers Based on Essential Science Indicators. The most influential publications are those dealing with subjects of current intense interest that are highly cited, based on Clarivate Analytics' Essential Science Indicators (ESI). A highly cited paper is a paper that belongs to the top 1% of papers in a research field published in a specified year. A paper dealing with a subject of intense interest, sometimes termed a "hot paper," is a paper published in the past two years that received enough citations in the most recent two-month period to place it in the top 0.1% of papers in the same field. The ESI database, as of 21 January 2021, covers a 10-year, 10-month period: 1 January 2010 to 31 October 2020. Based on ESI data, there was only one highly cited paper, written by Abdelraheem et al. titled "Progress and perspective on drought and salt stress tolerance in cotton" published in *Industrial Crops and Products* 2019, 130:118-129 (Abdelraheem et al., 2019). Total citations of the paper was 32, with the average per year of 10.67.

Most Frequently Cited Articles. Citation analysis has been employed as a supplementary index to determine the impact of scientific studies and to identify studies, researchers, and the most renowned institutions dealing with the topic. Although many articles have been published, a relatively small number of individuals account for a large proportion of the citations within the period. Here, the total citations for the seven most frequently cited articles is more than 225 times (Fig. 7). The seven most cited papers were written by Gossett et al (1994), Zwart and Bastiaanssen (2004), Wendel and Cronn (2003), Corwin et al (2003), Mcinroy and Kloepper (1995), Kranthi et al (2002) and Cronn et al (2002), the total citations were 510, 499, 455, 440, 260, 249 and 225 times, respectively; the average per year were 18.21, 27.72, 23.95, 23.16, 9.63, 12.45 and 11.25 times, respectively. The annual citations of the seven papers showed a trend to increase during their citation history after the published year. The time dependence of a single paper is called its history. In the beginning year (zero year here), this was lower because all papers appeared in that published year. The annual number of citations of the seven most cited papers in this study increased during their citation history from year of publication until 2020, but the increase rate varied among papers. The citations per year was sharply increased for the paper (red) published in *Agricultural Water Management* and written by Zwart and Bastiaanssen (2004), which the average citations per year was the highest value as 27.72 in the seven papers. An increase in the number of cited references indicates that there are more citing and/or cited publications. The number of citations of a paper is considered a good quantitative measure of a paper's impact.

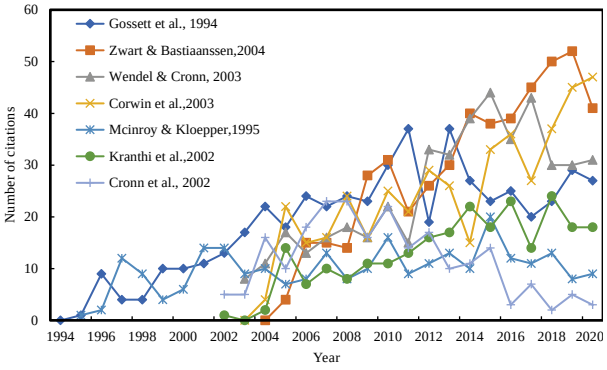

Figure 7. Comparison of the number of citations per year of the top seven papers from initial publications to 2 February 2021.

CONCLUSIONS

This study analyzed 3,487 papers of cotton research from the WoS agronomy category published during 1990 to 2021. These articles were mainly written in English (96.329%), from 8,860 authors, 87 countries/territories, 1,660 organizations, and published in 107 journals and book series. The top five core journals in order were *Crop Science, Agronomy Journal, Weed Technology, Field Crops Research,* and *Euphytica*. The top five countries/ regions were U.S., PRC, India, Brazil, and Australia. The top five organizations were USDA ARS, Texas A&M Univ., North Carolina State Univ., Univ. Georgia, and Cotton Inc. The top five authors were Johnie N. Jenkins, Don C. Jones, Jack C. McCarty, Jr., Jinfa Zhang, and C. Wayne Smith, with each publishing 72 or more papers. Based on the analysis of network map of VOSviewer, there is considerable cooperation among authors, organizations, and countries/regions. All keywords of the cotton research from the WoS agronomy category separated into six clusters of unique research topic. The analyses and visualizations reported herein offer exploratory information on the current state of research in a scientific field or discipline as well as indicate possible developments in the future.

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