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Trends in scientific research on climate change in agriculture and forestry subject areas (2005–2014)

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ABSTRACT

The term "Climate change" involves an alteration of the mean and variability of the climate properties. It implies unusual variations in the planet earth atmosphere, which causes related effect on other parts of the planet. The reduction in the land crops annual yield is derived from those alterations. The objective of this paper was to contribute to a better understanding of the scientific knowledge of climate change and its effect concerning agriculture and investigate its evolution through published papers. The items under study were obtained from the Web of Science (WOS) platform from Thomson Reuters. A bibliometric and social network analysis was performed to determine the indicators of scientific productivity, impact and collaboration between authors, institutions and countries. A subject analysis taking into account the key words assigned to papers and subject areas of journals was also carried out. A total of 1471 articles were included in the selected subject categories in WOS from 2005 until 2014. More than 50% of the papers were published in the last three years. The papers were published in 302 different journals. The United States Department of Agriculture (USDA) is the most productive institution ($n = 70$), followed by the Chinese Academy of Sciences ($n = 58$) and the Institut National de la Recherche Agronomique (INRA, France) ($n = 47$). The Canadian Forest Service has the most citations ($n = 1456$). The most frequent keywords were CO2, adaptation, model, temperature and impact. The network of collaboration between institutions and countries involve both centres from developed and developing countries and the central position of the United States, together with other leading countries, such as China, Canada, Australia, Germany, and the United Kingdom. Twenty papers received more than 100 citations, most of them concerned with emerging risks that climate change causes on forests, the impact on the forest ecosystems, the effect on plant diseases and adaptation options.

1. Introduction

Climate change caused by human activities is having a massive impact on the Earth's ecosystem, influencing both physical and social activities. The negative environmental associated impacts are compromising the sustainable development of humans and therefore of human society. Climate change has been defined as the alteration of the state of the climate where changes in the mean and the variation of its properties can be easily identified (IPCC, 2007). It reflects abnormal variations that cause a noticeable impact on other parts of the planet. An example of the mentioned effects concerns the alteration of normal crops cycles and yields (Challinor et al., 2007).

Scientific publications that analysed the effects of climate change as a main theme have rapidly increased in the past several decades. Renowned scientific journals, such as Nature (Walther et al., 2002; Harte et al., 2004; Thomas et al., 2004) and Science (Crowley, 2000; Watson, 2003; Lobell et al., 2008), have been steadily publishing the latest research achievements in the field.

Analyses of agriculture and climate change have been combined in a large number of publications on topics, such as the drought impact in Sonora and Puebla (Mexico) (Liverman, 1990), sea level increases in the Vietnamese Mekong delta and its implications on rice production (Wassmann et al., 2004), food security and the needs adaptation to a climate change scenario (Lobell et al., 2008), influences of climate change on soil fauna (Briones et al., 1997),

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global precipitation extremes that are dependent on temperature (Liu et al., 2009), diurnally asymmetric trends of climatic conditions in Taiwan (Shiu et al., 2009), and the effect of climate change on air quality (Jacob and Winner, 2009).

In the field of fruit production, especially in viticulture, climate change is profoundly influencing plant phenology and fruit composition — for example, on vines and grapes, which influence winemaking, wine microbiology and chemistry, and sensory aspects (Mira de Orduña, 2010). Hall and Jones (2009) indicated that within the current century, some Australian wine regions will not be suitable for the production of premium wines. Moreover, in several European wine-producing regions, an important effort must be made in terms of cultivar selection and winemaking practices and technology to cope with abnormal climate alterations associated with climate change phenomena (Seguin and García de Cortazar, 2005; White et al., 2009). A comparative study on the antioxidant properties and phenolic composition of different grape-growing regions and vintages has been recently reported (Stockham et al., 2013), which is the main aim of the research on the identification of chemical markers for climate change.

One major impact of climate change on agriculture is variations of evapotranspiration, which have a significant role in irrigation scheduling and water resource management (Valipour, 2015a). Several models are available to estimate evapotranspiration, including mass transfer, radiation, temperature and pan evaporation methods can be nowadays modelled (Valipour, 2014, 2015b, 2015c; Valipour and Eslamian, 2014). Efficient water management using mathematical models for the simulation of surface irrigation are necessary for cost effectiveness and consumption reduction (Valipour, 2012a, 2012b; Khasraghi et al., 2015; Valipour et al., 2015, 2017).

Political agendas have targeted global warming, greenhouse gases and the limitation of CO_2 emissions as top priorities. After the environmental Kyoto protocol (Bohringer, 2003), some countries have committed to reduce human greenhouse gas emissions by at least 5% during the 2008–2012 period. This would have placed the levels of greenhouse gases, which includes CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride, below those present in 1990.

Bibliometric studies analysing trends in research through published studies have recently gained importance because they provide valuable indicators of scientific research and its progression (Vain, 2007). Despite the increasing public importance of research on climate change, there have not been any scientometric studies on the climate change effects on agriculture. The objective of this paper was to contribute to a better understanding of the scientific knowledge of climate change and its effect concerning agriculture and to investigate its evolution through the published papers included in the Web of Science database.

2. Methods

The papers under study were recorded from the Web of Science Core Collection (WOS) platform from Thomson Reuters. We searched for the following terms that were also used in a previous paper by Li et al. (2011): “climate change” OR “climate changes” OR “climatic change” OR “climatic changes”. With the aim to achieve greater accuracy in the results, the search was conducted in the title field of the registries in the WOS. The terms were included in quotation marks to guarantee more precision in the obtained records, e.g., all records containing one term after the other. To focus on agricultural areas, we limited the search to the following WOS subject categories: Food science technology, plant sciences, forestry, agricultural engineering, agronomy, horticulture, agriculture dairy animal science, agriculture multidisciplinary, and agricultural economics policy. We limited the search to the 2005–2014 period. The study was restricted to articles and reviews; therefore, abstracts from conferences, bibliographical articles, book reviews, editorials, letters, reprints and news were excluded.

As indicators of scientific production, we chose the annual evolution of published papers and distribution of papers for each of the journals, institutions and countries that developed the research, the key words assigned to papers and WOS subject categories. As indicators of impact, we mined the number of citations, ratio citations per article, impact factor, quartile in Journal Citation Reports and the most cited papers. The number of citations was obtained from the WOS database, and we took into account all those received by the articles and reviews during the analysed period. The ratio citations per article was calculated by dividing the number of citations that all the articles on the topic published in each journal had received, by the number of articles published by the journal (on the this topic). This ratio is more sensitive than the impact factor to measure the quality of a journal on a specific topic because it is calculated using only the collection of articles and citations on this topic, whereas in the calculation of the impact factor all the articles published in the journal and their citations are involved. Impact factor numbers were extracted from the 2014 edition of the Journal Citation Reports. To analyse and present the collaboration patterns, a social network analysis (SNA) was also performed to identify the number of co-occurrences between authors, institutions and countries. Co-occurrences refer to all combinations of pairs of authors, institutions or countries in each paper that may also appear in other papers.

We also included a subject analysis, taking into account the key words assigned to papers and the subject areas of journals in the Journal Citation Reports to identify the three most frequent key words assigned to papers and the three most productive journals in each identified area. An SNA was also investigated to identify the number of co-occurrences between key words (co-words). Co-occurrences refer to all combinations of key word pairs in each paper that are repeated in the set of papers that were reviewed. The SNA used a co-word analysis that let us draw network graphs that show the strongest associations between the concepts described in papers and represented by key words (Lanza and Svendsen, 2007). Similar approaches have been reported to map the knowledge in this field (Haunnschild et al., 2016; Pasgaard and Strange, 2013; Schwechheimer and Winterhager, 1999) and in other fields, such as environmental science (Ho, 2007), tsunamis (Chiu and Ho, 2007) and wine and health (Aleixandre et al., 2013), among others (Waltman et al., 2010).

To visualize the networks, we used Pajek and VOSViewer (Batagelj and Mrvar, 2002). A threshold or minimum of papers written in collaboration between authors, institutions or countries was applied to correctly visualize the networks. This threshold is specified when each Figure is mentioned.

3. Results

3.1. Authors, institutions and countries

During the period of analysis, 1471 articles were included in the selected subject categories in WOS. As shown in Fig. 1, the number of published articles has grown exponentially since 2005 — in which 41 articles were published (2.78%) and was the year in which the first article was included in the WOS — until 2014, with 268 (18.22%) articles. The greatest growth has occurred in the last three years (2012–2014), when 50.65% of the papers were published.

The papers were published in 302 different journals. The 44 journals publishing 10 or more papers are shown in Table 1 with

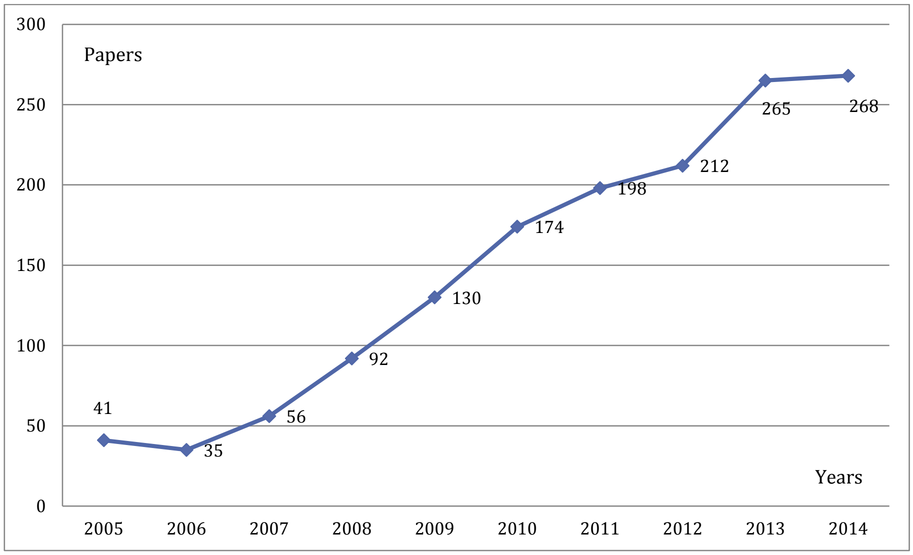

Fig. 1. Annual evolution of published papers.

other data, including the number of citations received, the ratio of citations per paper, the impact factor, the quartile and the ranking in the subject category. The most productive journals with more than 50 published articles were *Agricultural and Forest Meteorology* (n = 64), *Forest Ecology and Management* (n = 62) and *Agriculture, Ecosystems & Environment* (n = 57). In relation to the number of citations, the journal that ranks first is *Forest Ecology and Management* (n = 2441), followed by *Agricultural and Forest Meteorology* (n = 1839) and *Agriculture Ecosystems & Environment* (n = 1358). The ratio of citations per article is also higher in *Forest Ecology and Management* (C/A = 39.37), followed by *Agricultural and Forest Meteorology* (C/A = 28.73) and *Food Research International* (C/A = 27.94). *New Phytologist* has the highest impact factor (IF = 6.672), followed by the *Journal of Ecology* (IF = 5.521), *Agronomy for Sustainable Development* (IF = 3.992) and *Agricultural and Forest Meteorology* (IF = 3.762). Most of the mentioned journals rank in the first or second quartile in the Journal Citation Reports subject categories, with the exception of the *Journal of Agrometeorology, Forestry Chronicle, Fourrages, Journal of Food Agriculture & Environment,* and *Journal of Integrative Agriculture,* which rank in the third or fourth quartile.

Institutions publishing more than 10 papers are presented in Table 2. The United States Department of Agriculture (USDA) is the most productive (n = 70), followed by Chinese Academy of Science (n = 58) and the Institut National de la Recherche Agronomique (INRA, France) (n = 47). Canadian Forest Service has the most citations (n = 1456), followed by four institutions receiving near 1200 citations as follows: The University of Tasmania (Australia), Institut National de la Recherche Agronomique (INRA, France), the United States Department of Agriculture (USDA) and Oregon State University (US). In the ratio of citations per article, the following two institutions stand out: The Food and Agriculture Organization of the United Nations (FAO) and the Canadian Forest Service, both with more than 100 citations per paper.

Regarding the distribution of papers by country (Table 3), the country that has published the most has been the United States (n = 323), followed by Germany and the United Kingdom (n = 152)

Table 1
Most productive journals on climate change in agriculture and forestry subject areas (2005–2014) (>15 published articles).

Journals	Articles	Citations	Citations/Article	2014 Impact factor	Quartil
Agricultural and Forest Meteorology	64	1839	28.73	3.762	Q1
Forest Ecology and Management	62	2441	39.37	2.660	Q1
Agriculture Ecosystems & Environment	57	1358	23.82	3.402	Q1; Q2
Journal of Agrometeorology	31	47	1.52	0.145	Q4
Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere	30	599	19.97	1.683	Q2
Agricultural Systems	27	505	18.70	2.906	Q1
Forestry Chronicle	26	361	13.88	0.646	Q3
Journal of Ecology	25	607	24.28	5.521	Q1
Annals of Forest Science	23	190	8.26	1.981	Q2
Agricultural Water Management	23	248	10.78	2.286	Q1
Paddy And Water Environment	21	71	3.38	1.151	Q3; Q2
Journal of Agricultural Science	20	302	15.10	1.157	Q1
Fourrages	18	0	0.00	0.667	Q4
New Phytologist	17	419	24.65	7.672	Q1
Journal of Food Agriculture & Environment	17	15	0.88	0.435	Q4
European Journal of Agronomy	17	428	25,18	2.704	Q1
Plant Ecology	16	200	12.50	1.463	Q2; Q3
Journal of Integrative Agriculture	16	24	1.50	0.833	Q4
Food Research International	16	447	27.94	2.818	Q1
Agronomy for Sustainable Development	16	318	19.88	3.992	Q1

Table 2
Most productive institutions publishing on climate change in agriculture and forestry subject areas (2005–2014) (>10 published articles).

Institutions	Countries	Articles	Citations	Citations/Article
United States Department of Agriculture	United States	70	1236	17.66
Chinese Academy of Science	China	58	728	12.55
Institut National de la Recherche Agronomique	France	47	1241	26.40
Commonwealth Scientific and Industrial Research Organisation	Australia	39	828	21.23
Wageningen University	The Netherlands	37	682	18.43
Swedish Univ Agr Sci	Sweden	30	404	13.47
University of National Resources & Applied Life Science-BOKU	Austria	24	700	29.17
National Resources of Canada	Canada	20	347	17.35
University of Copenhagen	Denmark	19	194	10.21
University of British Columbia	Canada	17	310	18.24
Oregon State University	United States	17	1225	72.06
Indian Agricultural Research Institute	India	17	100	5.88
Centre National de la Recherche Scientifique	France	16	332	20.75
University of Reading	United Kingdom	16	354	22.13
Beijing Forestry University	China	15	182	12.13
University of Florida	United States	15	287	19.13
Rothamsted Research	United Kingdom	15	387	25.80
Aarhus University	Denmark	15	421	28.07
University of Queensland	Australia	14	447	31.93
Chinese Academy of Agricultural Science	China	14	285	20.36
Colorado State University	United States	13	132	10.15
University of Bonn	Germany	13	405	31.15
Canadian Forestry Service	Canada	13	1456	112.00
MTT Agrifood Research of Finland	Finland	13	227	17.46
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	India	13	213	16.38
Universidad Nacional Autonoma Mexico	Mexico	13	46	3.54
University of Illinois	United States	12	234	19.50
University of Freiburg	Germany	12	141	11.75
Universitat Autònoma de Barcelona	Spain	12	136	11.33
University of California Davis	United States	12	227	18.92
Centre de Recerca Ecològica i Aplicacions Forestals	Spain	11	122	11.09
University of Eastern Finland	Finland	11	75	6.82
Cranfield University	United Kingdom	11	217	19.73
Kansas State University	United States	11	360	32.73
University of Tasmania	Australia	11	491	44.64
Food and Agriculture Organization	Italy	11	1285	116.82
Technical University of Munchen	Germany	11	135	12.27
INRES	Germany	11	361	32.82

and the following three countries with more than 100 papers: Australia, Canada and China. For citations, the United States is in first position (n = 6530) followed by three countries with approximately 3000 citations as follows: Canada, United Kingdom and Australia. The ratio of citations per article is higher for South Korea, Switzerland, Italy and Austria.

3.2. Key words, subject areas of research and network of co-words

The most common keywords and their annual evolution are provided in Table 4. Excluding climate or climatic change, the most frequent keyword was CO_2 (n = 406) and four key words in more than 200 papers were adaptation (n = 259), model (n = 225), temperature (n = 222) and impact (n = 209). Most of the key words increase in frequency, especially from the 2010s as follows: 72% were related to CO_2; 84% were related to adaptation; almost 75% were related to model, temperature, impact and simulation; 89% were related to management; 79% to drought; and 83% were related to food Security.

The most productive subject categories, three most common assigned key words to the articles, and three journals publishing more articles in each subject category are detailed in Table 5. Forestry (n = 419) is in first place, where the most common key words were adaptation (n = 94), model (n = 80) and CO_2 (n = 78). The journals belonging to this subject category that published more articles include *Agricultural and Forest Meteorology* (n = 64), *Forest Ecology and Management* (n = 62) and the *Canadian Journal of Forest Research* (n = 30). The subject category in second place was Plant Sciences (n = 351), whose most frequent key words were CO_2 (n = 133), temperature (n = 54) and responses (n = 42). The journals belonging to this subject category that published more articles were the *Journal of Ecology* (n = 25), *New Phytologist* (n = 17) and *Plant Ecology* (n = 16). Three subject categories with more than 100 articles were agronomy (n = 319), with the most frequent key words being CO_2, model and agriculture; multidisciplinary agriculture (n = 243), with the key words being CO_2, adaptation and agriculture; ecology (n = 125), with the key words being CO_2, temperature and model; and food science and technology (n = 101), with the key words being temperature, adaptation and food security.

Fig. 8 shows the network of co-words with a proportional relationship between the sizes of the spheres in the graphs and the number of articles including each key word. Moreover it is also proportional the thickness of the lines connecting the spheres and the number of papers that include two key words simultaneously. A threshold of almost 15 co-occurrences has been applied; the network drawn consisted of 75 key words. Not surprisingly, the key word climate change occupies a more central position and intermediation because it is strongly associated with the following key words: CO_2 (n = 179), adaptation (n = 168), model (n = 127), impact (n = 118), agriculture (n = 111), temperature (n = 105), simulation (n = 77), management (n = 66), yield (n = 62) and growth (n = 60). Other strong associations are observed between CO_2 and temperature (n = 100), model (n = 69) and growth (n = 63); and between adaptation with impact (n = 64) and agriculture (n = 64).

Table 3
Most productive countries publishing on climate change in agricultural and forestry subject areas (2005–2014) (>10 published articles).

Countries	Articles	Citations	Citations/Article
United States	323	6530	20.22
Germany	152	2152	14.16
United Kingdom	152	3101	20.40
Australia	130	3054	23.49
Canada	127	3267	25.72
China	114	2411	21.15
France	97	2877	29.66
India	92	612	6.65
Spain	80	2057	25.71
Italy	73	2827	38.73
The Netherlands	55	1028	18.69
Brazil	54	443	8.20
Japan	45	625	13.89
Finland	42	1134	27.00
Sweden	42	694	16.52
Switzerland	42	1679	39.98
Denmark	38	776	20.42
Austria	35	1067	30.49
Mexico	33	316	9.58
Norway	31	620	20.00
South Africa	27	241	8.93
South Korea	22	1256	57.09
Portugal	18	209	11.61
Kenya	17	459	27.00
Czech Republic	16	304	19.00
New Zealand	15	214	14.27
Belgium	15	304	20.27
Colombia	14	145	10.36
Pakistan	14	41	2.93
Taiwan	14	47	3.36
Iran	13	79	6.08
Hungary	12	36	3.00
Chile	12	74	6.17
Turkey	12	1091	90.92
Russia	11	1114	101.27

3.3. Most cited papers

The 20 research articles receiving more than 100 citations are presented in Table 6. The most cited article is a review entitled "A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests," which was published in the journal *Forest Ecology and Management* in 2010 by Allen et al., a research team comprising 20 researchers from 13 countries (USA, Algeria, France, Argentina, Switzerland, Canada, Australia, China, Spain, Russia, South Korea, Italy and Turkey). This research presents the current effect and future potential of drought and heat stress on tree mortality and highlights the need for a globally coordinated observation system to provide key information on the most important gaps and uncertainties that cause difficulties in the ability to predict tree mortality. These results were first presented at the Conference on the Adaptation of Forests and Forest Management to Changing Climate with an Emphasis on Forest Health Location, which was held in Umea, Sweden, in 2008.

The second most cited paper ($n = 298$) was "Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems", which was also published in 2010 in *Forest Ecology and Management* and was presented at the same conference by Linder et al. In the published research, current knowledge on the observed and projected impacts of climate change on European forests is discussed. The authors highlighted the importance of an interdisciplinary research agenda to cover all levels of decision making. In addition to this, an appropriate strategy includes the use of integrated monitoring networks and projection models that would be applied from policy development to management units. The third most cited paper, with 238 citations, was published in 2006 in *Annual Review of Phytopathology* by Garret et al. from the Kansas State University (USA), which reviews the effects of climate change on plant disease. The interesting conclusion reveals that one of the most important predictors for quantifying the magnitude of the climate change effects is related to the adaptive potential of plant and pathogen populations.

3.4. Network of collaboration between authors, institutions and countries

Figs. 2–4 show the collaboration network between authors. To create this network, we applied a threshold of almost 2 papers written in collaboration. Both the size of the spheres and the number of published papers by each author, and the size of the lines connecting the two authors and the number of papers published in collaboration follow a proportional relationship. A team of 29 researchers from 14 different institutions from 9 countries comprise the first group (Fig. 2). The authors with the most connections to others include Peltonen Sainio from MTT Agrifood Research Finland, with 11 collaborators; Olensen from Aarhus University, Denmark, with 10 collaborators; and Eitzinger, from the Norwegian University of Life Sciences, Norway, with 9 collaborators. The other researchers are from centres in the Czech Republic, Germany, USA, Netherlands, Sweden and Austria.

As shown in Fig. 3, we describe the other group of 23 researchers from 5 countries — Italy, France, Portugal, Austria and Finland — which are the countries with the most authors. The institutions of these researchers are the University of Natural Resources and Applied Life Sciences-BOKU (Vienna, Austria); the University of Lisbon (Portugal); Institut National de la Recherche Agronomique (INRA, France); the Italian Academy of Forestry Science; and six additional universities and research institutes from Finland. As shown in Fig. 4, the following 6 other groups are identified: one with 14 researchers, one with 11 researchers and four with 10 researchers from France (Institut National de la Recherche Agronomique-INRA), India (two groups from the Indian Agricultural Research Institute and National Dairy Research Institute), South Korea (Konku University), USA (Kansas State University and North Dakota State University), and Spain (Centre de Recerca Ecologica i Aplicacions Forestals-CREAF, Spanish National Research Council and Universitat Autònoma of Barcelona).

Regarding the network of collaboration between institutions (Fig. 5), when applying a threshold of almost 2 papers published in cooperation, the main network includes 32 institutions, some of which have more central positions and have connections with others. Here again, the number of published papers by each institution is proportional to the size of the spheres, and the number of papers published in collaboration is proportional to the size of the lines connecting the two institutions. This applies to organizations, such as the INRA, BOKU and USDA, the last of which is located in a central position relative to other US institutions. As shown in Fig. 6, 9 other groups of institutions are not connected with the previous group and integrate organizations from China and Australia; the United States; the United Kingdom and Denmark; Germany; Australia; Spain; Canada; China; and Finland. The strongest collaboration in the network of institutions appears between the Institute of Crop Science and Resource Conservation (INRES) and the University of Bonn ($n = 11$); the Chinese Academy of Sciences and Grad University ($n = 10$); Beijing Forestry University and the Chinese Academy of Sciences ($n = 9$); and Universitat Autònoma de Barcelona and Centre de Recerca Ecologica i Aplicacions Forestals-CREAF ($n = 9$).

Fig. 7 shows the network of collaboration between countries. The central position of the United States can be observed, together with other leading countries, such as China ($n = 32$), Canada

Table 4
Annual evolution of most frequently key words on climate change in agriculture and forestry subject areas (2005–2014).

Key words	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
CO_2	10	30	13	22	40	47	45	55	74	70	406
Adaptation	8	2	8	9	14	33	35	40	46	64	259
Model	14	4	11	16	17	25	32	29	41	36	225
Temperature	5	4	10	13	24	25	25	43	43	30	222
Impact	8	4	6	12	17	36	16	34	39	37	209
Agriculture	3	5	1	12	13	15	11	23	42	46	171
Simulation	3	6	9	7	10	14	18	15	34	23	139
Growth	7	3	6	6	5	24	9	19	24	24	127
Responses	9	5	5	4	11	17	18	14	20	19	122
Management	1	1	3	1	7	20	16	20	19	26	114
Yield	2	1	2	7	17	14	4	16	19	28	110
Drought	2	1	5	7	10	13	15	15	20	20	108
Variability	6	2	6	9	4	13	8	19	20	18	105
Global Warming	3	5	3	8	17	11	10	12	15	18	102
Productivity	1	1	3	4	10	11	10	12	23	14	89
United States	3	3	5	6	14	7	7	12	14	14	85
Plants	2	3	2	4	7	11	9	10	11	17	76
Wheat	3	2	4	3	7	5	11	16	10	12	73
Carbon	2	–	–	7	9	10	8	4	16	14	70
Food Security	–	1	–	4	7	13	4	9	14	18	70
Global Change	1	1	3	6	7	8	12	12	6	14	70
Land Use	1	–	2	3	5	9	9	15	8	16	68
Systems	4	2	1	4	7	8	6	3	16	17	68
Crop	1	2	3	3	3	10	7	11	10	14	64
Ecosystems	5	2	6	6	–	5	11	10	10	8	63
Phenology	1	3	2	8	5	5	6	12	9	12	63
Precipitation	4	–	1	6	7	8	7	12	7	10	62
Vegetation	4	–	4	8	4	8	8	5	15	6	62
Change Impacts		1	2	1	3	8	10	9	5	20	59
Forest	8	2	2	1	4	6	9	10	6	11	59
Trends	–	2	1	2	3	3	6	14	10	18	59
Climate	3	3	2	1	5	3	8	7	10	16	58
Conservation	2	2	1	3	6	3	6	11	10	13	57
Vulnerability	2	1	3	3	5	8	8	8	10	7	55
Scenarios	3	1	3	3	5	3	9	9	9	9	54
Modelling	–	1	2	5	5	4	9	6	9	11	52

($n = 25$), Australia ($n = 20$), Germany ($n = 17$), the United Kingdom ($n = 15$), and Italy ($n = 14$). Other important relationships are established between Germany and the United Kingdom ($n = 12$), Austria ($n = 10$) and Denmark ($n = 10$); and France and Italy ($n = 10$).

4. Discussion

This work has identified the annual evolution of scientific articles on climate change in agricultural areas and the most productive and cited papers and journals, subject categories, research groups, institutions and their international collaboration. The main topics discussed on this subject through the most assigned key words and the Social Network Analyses of co-words has also been shown. The diffusion of knowledge and information regarding climate change may contribute to promoting a higher level of cooperation within the climate change community and to create a favourable environment for debate. Policy discussions for future research directions would be of significant interest and would act as a starting point to monitor future developments in this relevant field (Husain and Mushtaq, 2015).

Climate change is now evident, and proof of its importance is that many institutions at the global and national level are funding or conducting research on the causes, consequences and methods of combatting its effects. For example, at international level, in 2014, the World Bank Group sponsored 224 climate projects in 77 countries with an $11.9 billion budget, including $8.79 billion from the World Bank (International Bank for Reconstruction-IBRD and Development and International Development Association-DIDA), $2.48 billion from International Finance Corporation-IFC, and $603 million from Multilateral Investment Guarantee Agency-MIGA (World Bank, 2016). Meanwhile, the work of FAO contributes to implementing the policy frameworks and institutional arrangements by helping countries create an environment that is suitable for the development of agriculture under the climate change conditions. Improved decision making and the implementation of adaptive measures are enhanced by the FAO with the transfer of technical guidance, data and tools. FAO has also embedded these tools and approaches in broader frameworks, such as FAO-Adapt, Climate-Smart Agriculture and the Disaster Risk Reduction for Food and Nutrition Security Framework (FAO, 2016). The other international institution involved is the World health organization WHO. Four main objectives within its climate change and health work plan have been defined by the organization in 2009. These include enhancing scientific evidence, advocating and raising awareness, and strengthening partnerships and the health systems. All these contributions are then used to improve health protection in international health and climate change negotiation agreements (WHO, 2016). Effective climate and health policies are encouraged by the publication of discussion papers, guidance documents and recommendations with the aim of health protection.

Looking at the national level, in the United States, the Climate Change Program Office (CCPO) coordinates with the United States Department of Agriculture responses to climate change on forests, agriculture, rural communities and grazing lands. Climate change response strategies focus on the coordination of analysis, planning and research aims (Climate Change Program Office, 2016). In France, the Institut National de la Recherche Agronomique (INRA) supports a programme known as “Adaptation of agriculture and

Table 5
Subject areas, most frequently used key words and most productive journals on climate change (2005–2014).

Subject areas	Articles	Most frequently used key words						Most productive journals
		Kw 1	n	Kw 2	n	Kw 3	n	
Forestry	419	Adaptation	94	Model	80	CO_2	78	• Agricultural and Forest Meteorology (64) • Forest Ecology and Management (62) • Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere (30)
Plant Sciences	351	CO_2	133	Temperature	54	Responses	42	• Journal of Ecology (25) • New Phytologist (17) • Plant Ecology (16)
Agronomy	319	CO_2	129	Model	66	Agriculture	57	• Agricultural and Forest Meteorology (64) • Journal of Agrometeorology (31) • Agricultural Water Management (23)
Agriculture, Multidisciplinary	243	CO_2	87	Adaptation	68	Agriculture	57	• Agriculture Ecosystems & Environment (57) • Agricultural Systems (27) • Journal of Agricultural Science (20)
Ecology	125	CO_2	38	Temperature	24	Model	19	• Agriculture Ecosystems & Environment (57) • Journal of Ecology (27) • Plant Ecology (16)
Food Science & Technology	101	Temperature	24	Adaptation	16	Food security	16	• Journal of Food Agriculture & Environment (17) • Food Research International (16) • Food Security (12)
Meteorology & Atmospheric Sciences	95	CO_2	34	Temperature	23	Impact	23	• Agricultural and Forest Meteorology (64) • Journal of Agrometeorology (31)
Environmental Sciences	73	CO_2	29	Adaptation	17	Agriculture	16	• Agriculture Ecosystems & Environment (57) • Journal of Agricultural & Environmental Ethics (2) • Environmental and Experimental Botany (7)
Agricultural Economics & Policy	56	Agriculture	18	Impact	16	Adaptation	14	• Australian Journal of Agricultural and Resource Economics (14) • Food Policy (10) • American Journal of Agricultural Economics (8)
Agriculture, Dairy & Animal Science	50	Climate factors	12	Agriculture	12	Livestock	11	• Fourrages (18) • Animal (8) • Indian Journal of Animal Sciences (4)
Agricultural Engineering	49	Model	18	Simulation	9	SWAT	9	• Paddy and Water Environment (21) • Transactions of The ASABE (12) • Journal of Irrigation And Drainage Engineering-Asce (6)
Water Resources	36	Model	15	Irrigation	14	Simulation	12	• Agricultural Water Management (23) • Irrigation and Drainage (7) • Journal of Irrigation And Drainage Engineering-Asce (6)

forests to climate change" (AAFCC), which studies possible adaptation strategies to understand the combined effects caused by climate change on agriculture and natural environments as well as their environmental and socio-economic consequences (INRA, 2016).

There are also individual projects, such as the *Climate Reality Project*, which is established and chaired by Al Gore, the founder and chair of the Alliance for Climate Protection, who states the need of a global solution to the climate crisis by making urgent actions across every level of society. In 2007, Gore received the Nobel Peace Prize jointly with the Intergovernmental Panel on Climate Change, which was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 with the aim of providing scientific information on the current knowledge on the effects of climate change and its future environmental and socio-economic impacts. Interestingly, think tanks in the 2015 United Nations Climate Change Conference, held in Paris, France in December 2015, argued that the keys to success lay in convincing the U.S. and China, by far the two largest national emitters, to adopt ambitious carbon emission capping targets (United Nations Climate Change Conference, 2015).

Several reports have been published employing scientometric techniques to assess a particular subject area or topic of scientific research. Some examples include soil contamination (Guo et al., 2014); the effects of wine on health (Aleixandre et al., 2013); the production of bioenergy from biomass (Konur, 2012); environmental marketing (Leonidou and Leonidou, 2011); food and feed safety (Vain, 2007); biotechnology (Dalpe, 2002; Vain, 2007); and plant genetic resources (Dudnik et al., 2001). However, fewer papers use bibliometric and social network analyses to measure and map the scientific knowledge in climate change (Li et al., 2011; Wang et al., 2014; Bjurstrom and Polk, 2011; Husain and Mushtaq, 2015).

An earlier scientometric study reported a rapidly growth on climate change research, especially since the 1970s (Stanhill, 2001). Li et al. (2011), in a work that analysed the research trends on global climate change from 1992 to 2009, also found an increase in the number of published papers, although we cannot compare our numbers with those because they took into account all types of publications included in Web of Science (including proceedings, meeting abstracts, letters and others), and we only analysed research articles in a strict sense. The overall increase in the number publications during the decade is convincing evidence of the leap in productivity on the research field of climate change. This growth has also been observed in other related areas, such as agroecology (Ferguson and Lovell, 2014) and soil contamination (Guo et al., 2014). However, it is not surprising that our results differ from those found by Wang et al. (2014) due to our specific scope of agricultural subject areas versus the vulnerability scope of the climate change topics analysed by Wang.

The importance that research on climate change is having in recent decades has led to numerous journals on agriculture, forestry, meteorology, ecology, environment, water management and phytology, among others, to publish articles about climate

Table 6
Highly cited articles on climate change in agriculture and forestry subject areas (2005–2014) (n > 100 citations).

Authors	Title	Source	Citations
Allen, CD; Macalady, AK; Chenchouni, H; Bachelet, D; McDowell, N; Vennetier, M; et al.	A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests	Forest Ecology and Management 2010; 259(4): 660-684	1029
Lindner, M; Maroschek, M; Netherer, S; Kremer, A; Barbati, A; Garcia-Gonzalo, J; et al.	Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems	Forest Ecology and Management 2010; 259(4): 698-709	298
Garrett, KA; Dendy, SP; Frank, EE; Rouse, MN; Travers, SE	Climate change effects on plant disease: Genomes to ecosystems	Annual Review of Phytopathology (2006); 44(): 489-509	238
Gilman, EL; Ellison, J; Duke, NC; Field, C	Threats to mangroves from climate change and adaptation options: A review	Aquatic Botany 2008; 89(2): 237-250	177
Ahuja, I; de Vos, RCH; Bones, AM; Hall, RD	Plant molecular stress responses face climate change	Trends in Plant Science (2010); 15(12): 664-674	177
Olesen, JE; Trnka, M; Kersebaum, KC; Skjelvag, AO; Seguin, B; Peltonen-Sainio, P; et al.	Impacts and adaptation of European crop production systems to climate change	European Journal of Agronomy (2011); 34(2): 96-112	175
Tao, FL; Yokozawa, M; Xu, YL; Hayashi, Y; Zhang, Z	Climate changes and trends in phenology and yields of field crops in China, 1981–2000	Agricultural and Forest Meteorology 2006; 138(1–4): 82-92	169
Gehrig-Fasel, J; Guisan, A; Zimmermann, NE	Tree line shifts in the Swiss Alps: Climate change or land abandonment?	Journal of Vegetation Science (2007); 18(4): 571-582	165
Hallegraeff, GM	Ocean climate change, phytoplankton community responses, and harmful algal blooms: a formidable predictive challenge	Journal of Phycology (2010); 46(2): 220-235	148
Ortiz, R; Sayre, KD; Govaerts, B; Gupta, R; Subbarao, GV; Ban, T; et al.	Climate change: Can wheat beat the heat?	Agriculture Ecosystems and Environment 2008; 126(1–2): 46-58	139
Gregory, PJ; Johnson, SN; Newton, AC; Ingram, JSI	Integrating pests and pathogens into the climate change/food security debate	Journal Of Experimental Botany 2009; 60(10): 2827-2838	130
Miraglia, M; Marvin, HJP; Kleter, GA; Battilani, P; Brera, C; Coni, E; et al.	Climate change and food safety: An emerging issue with special focus on Europe	Food and Chemical Toxicology 2009; 47(5): 1009-1021	128
Cooper, PJMDimes, J; Rao, KPC; Shapiro, B; Shiferaw, B; Twomlow, S	Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change?	Agriculture Ecosystems and Environment 2008; 126(1–2): 24-35	123
Challinor, AJ; Ewert, F; Arnold, S; Simelton, E; Fraser, E	Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation	Journal of Experimental Botany (2009); 60(10): 2775-2789	120
Petit, RJ; Hampe, A; Cheddadi, R	Climate changes and tree phylogeography in the Mediterranean	Taxon 2005; 54(4): 877-885	118
Stat, M; Carter, D; Hoegh-Guldberg, O	The evolutionary history of Symbiodinium and scleractinian hosts - Symbiosis, diversity, and the effect of climate change	Perspectives in Plant Ecology Evolution and Systematics (2006); 8(1): 23-43	117
Richardson, AD; Keenan, TF; Migliavacca, M; Ryu, Y; Sonnentag, O; Toomey, M	Climate change, phenology, and phenological control of vegetation feedbacks to the climate system	Agricultural and Forest Meteorology 2013; 169(): 156-173	108
Dukes, JS; Pontius, J; Orwig, D; Garnas, JR; Rodgers, VL; Brazee, N; et al.	Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict?	Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere 2009; 39(2): 231-248	105
Kullman, L	Tree line population monitoring of Pinus sylvestris in the Swedish Scandes, 1973–2005: implications for tree line theory and climate change ecology	Journal of Ecology (2007); 95(1): 41-52	104
Hanjra, MA; Qureshi, ME	Global water crisis and future food security in an era of climate change	Food Policy 2010; 35(5): 365-377	104

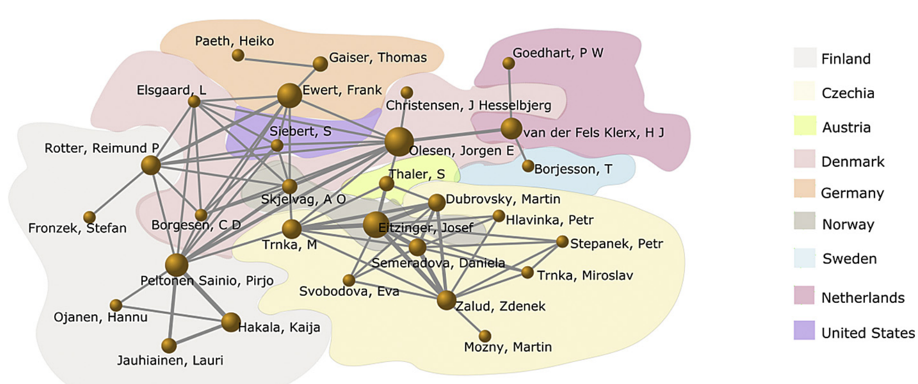

Fig. 2. Main group of authors (n = 29).

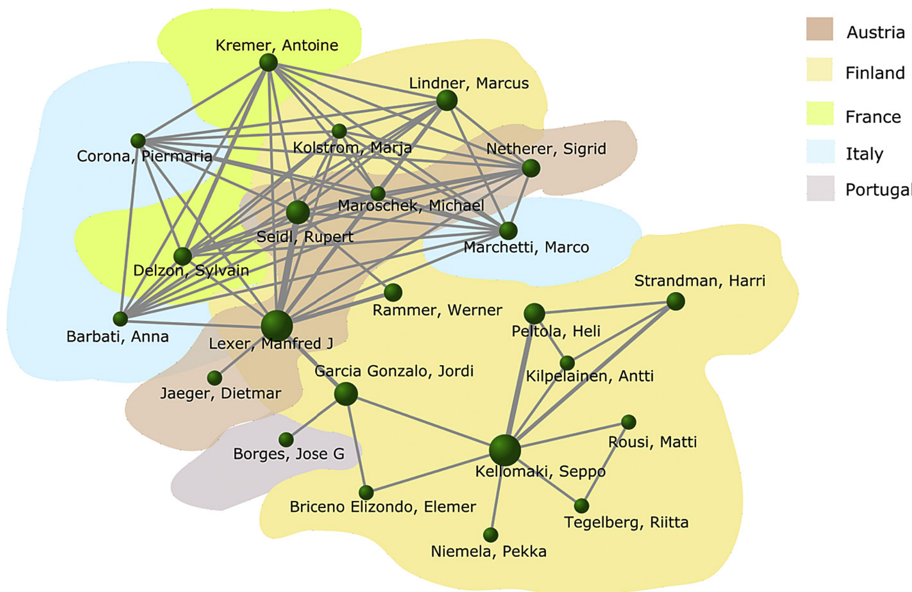

Fig. 3. Main group of authors (n = 23).

change. The fact that 15 of the 19 most productive journals are in first or second quartile reveals the importance of the topic for journal editors and the scientific community. It is striking that the *Journal of Agrometeorology*, which published 31 articles, has a low impact factor. One of the reasons may be that this journal does not have a famous publisher (such as Reed-Elsevier, Taylor & Francis, Wiley-Blackwell, Springer and Sage, which published more than half of the articles published in the Web of Science database between 1973 and 2013) but instead is published by the Association of Agrometeorologists.

The key word frequency analysis has revealed that the main issues focused on "CO_2", "Adaptation", "Models", "Temperature", "Responses" and "Impact". The analysis of the topics published in the most cited papers also confirm that the climate change effects on plants, the impact on forests and ecosystems, and the adaptive capacity of plants and agricultural production are the greatest concerns. We think that the topic of "adaptation" appears to be one of the most important topics because of the discussion of human-induced climate change that is moving towards clear fact-stimulated research on future pathways. The term "model" emerges as non-time dependant, indicating the strong relevance of climate modelling, which is also indicated by the subfield analysis. The term "impact" arises and points to research addressing the varying effects of climate change (Haunnschild et al., 2016). The

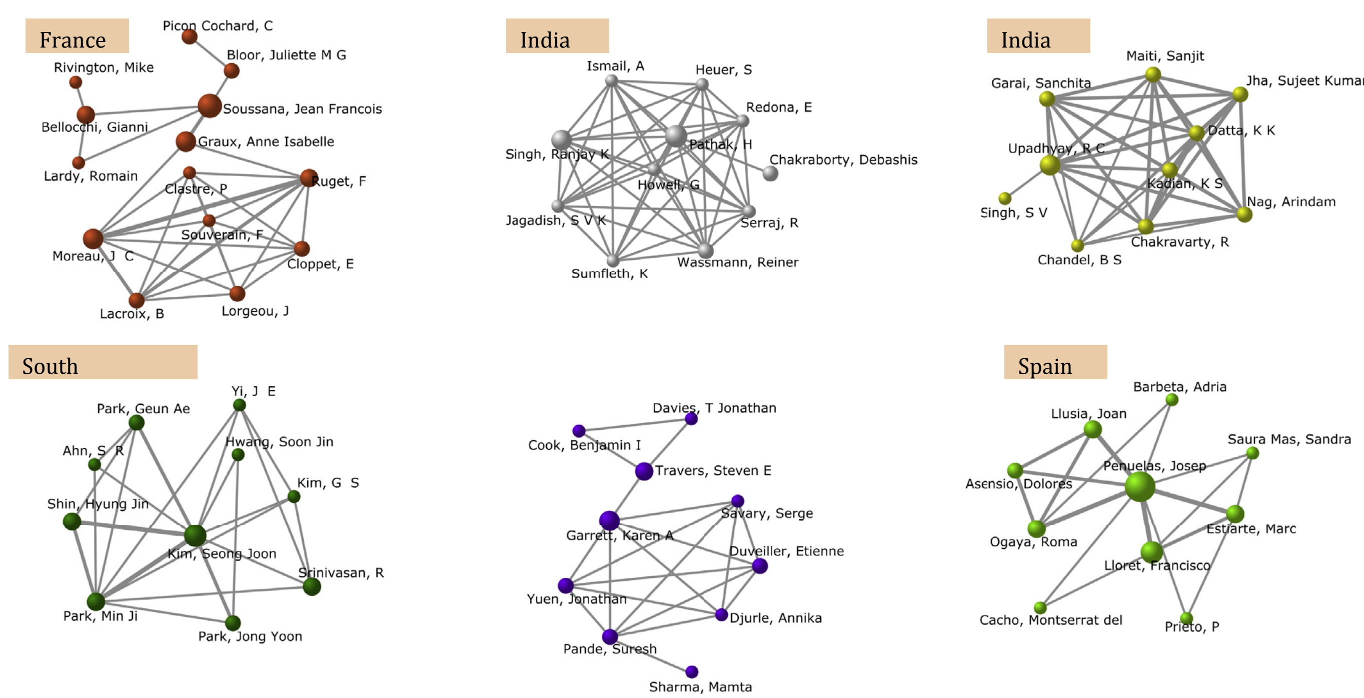

Fig. 4. Other groups of authors.

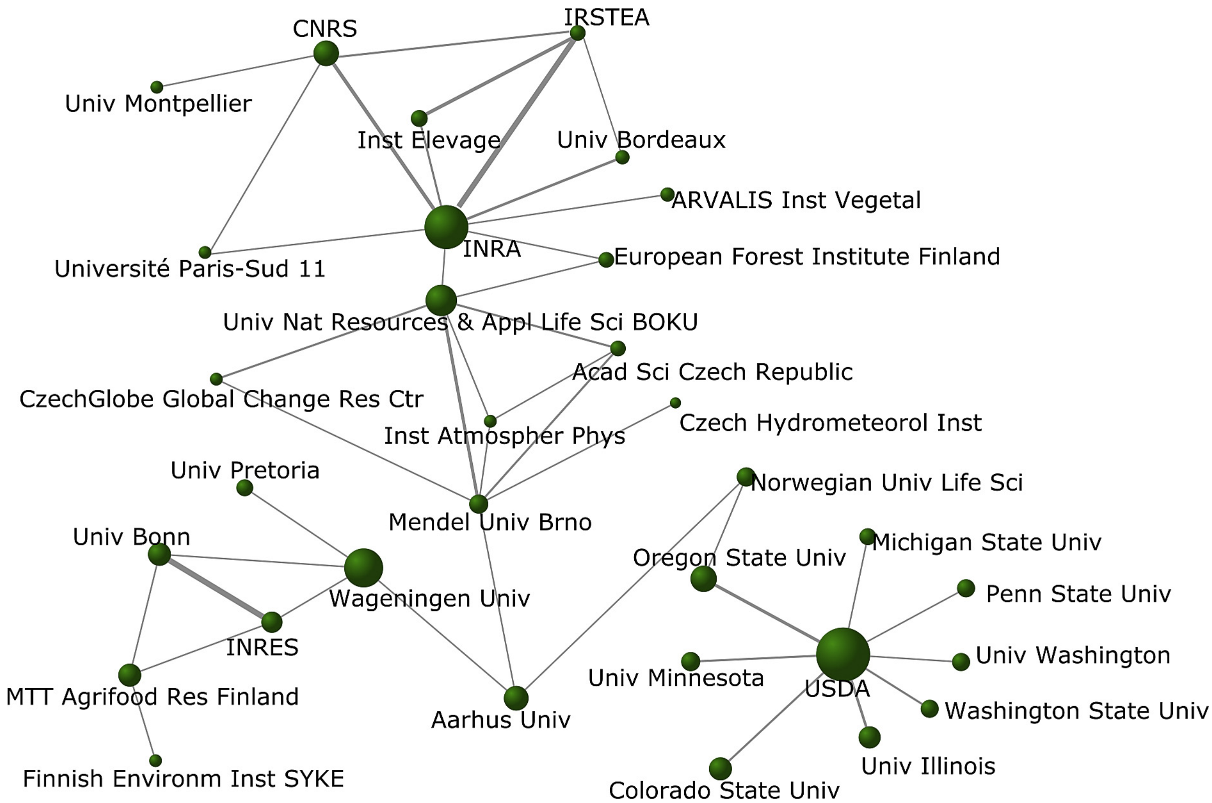

Fig. 5. Main network of institutions.

political agenda has targeted global warming, greenhouse gases and the limitation on “CO_2” emissions as top priorities. Global warming indicates an increase in average “global temperatures,” which are believed to be contributing to natural disasters and changes in human activity (IPCC, 2013). These topics are very similar to those identified in a previous publication from Wang et al. (2014), although it focuses on climate change vulnerability. In another study by Li et al. (2011), the items “temperature”,

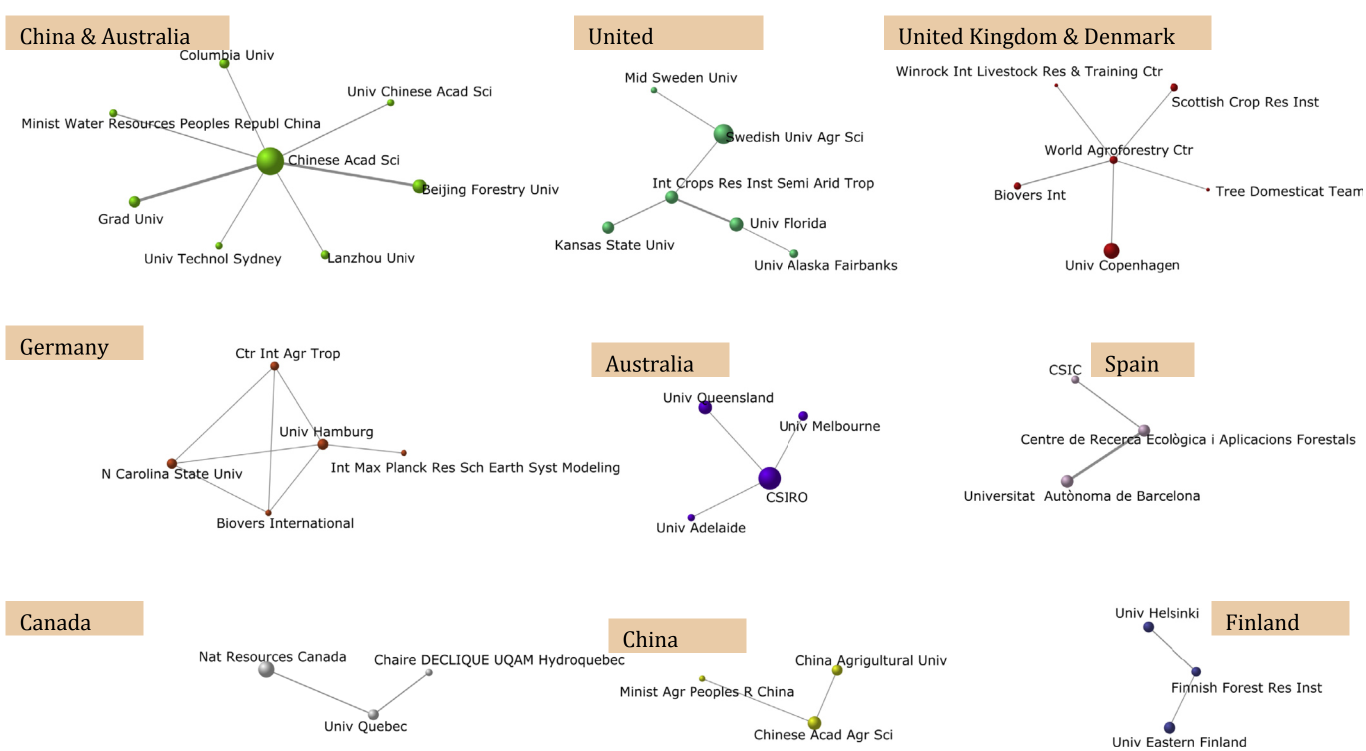

Fig. 6. Other groups of institutions.

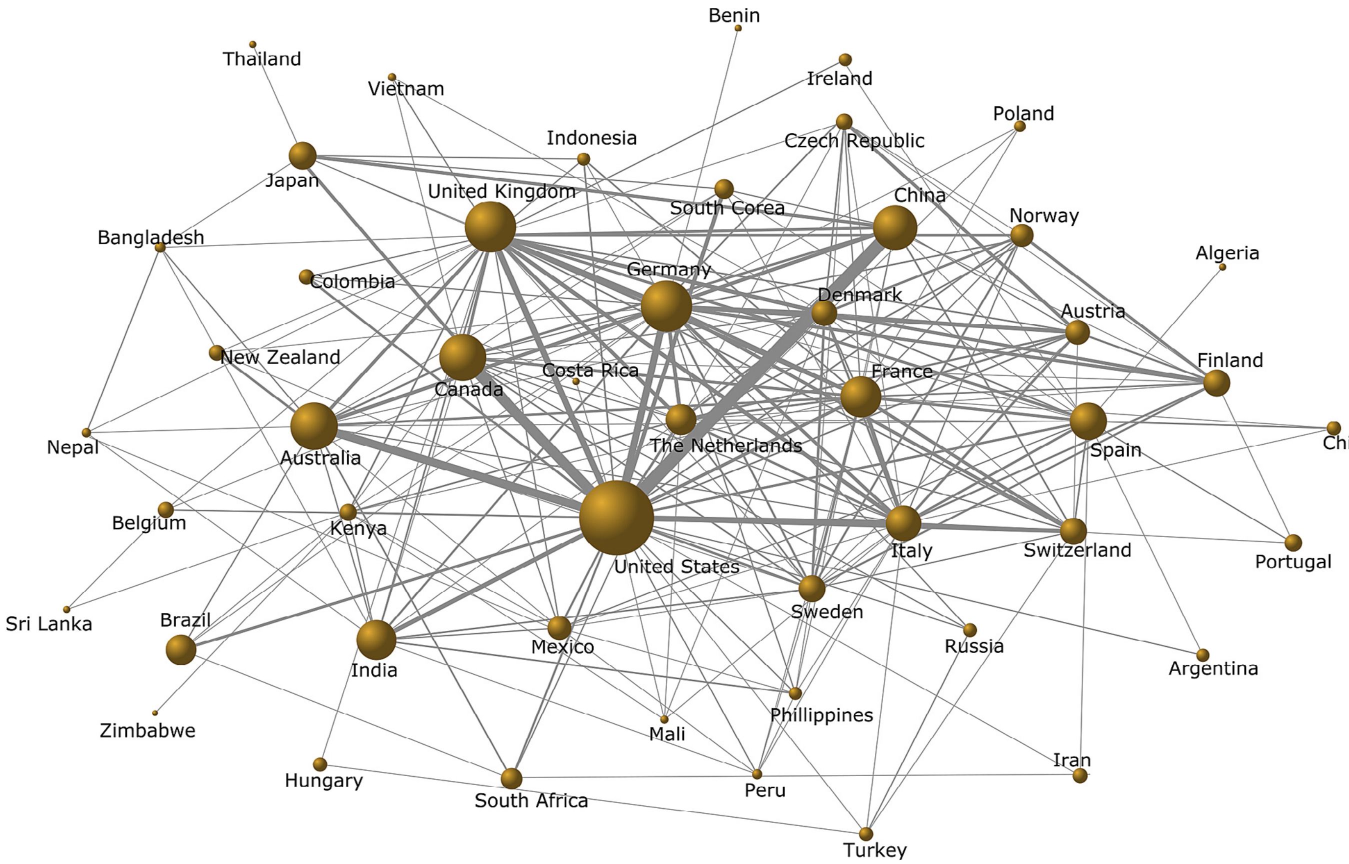

Fig. 7. Network of countries.

"environment", "precipitation", "greenhouse gas", "risk", and "biodiversity" were identified as the main foci of climate change research in the early 21st century, while "model", "monitoring", and "remote sensing" will continue as the leading research methods. It was also reported that the novel method "phylo-geaography" might have an important application in the near future.

Looking at the areas of research, in accordance with the previous rationale on key words, it was observed that articles have been published in a wide variety of areas, including forestry, plant sciences, agronomy, agriculture, ecology, food science and technology, meteorology, environmental sciences, economics and dairy resources, among others. This spread in subject publication is an exponent of the importance of this topic and its multidisciplinary nature and suggests that climate change is an area that strongly needs the contributions of other numerous scientific areas for its development. In the subject area of Food Science and Technology, the topic of Food security is also mentioned.

The analysis of the research groups and the most productive institutions shows the leadership in research on climate change at major national institutions in developed countries, even ahead of universities. According to Bullock et al. (2007), teams including several disciplines are a clear necessity, being also very important the recognition of these needs by the research community by for example providing rewards for the creation of interdisciplinary research groups. The ranking of countries shows that the research originates mainly from developed countries, such as the US, Germany, the United Kingdom, Australia, Canada, France, Spain and Italy. In addition to these leading developed countries, the presence of BRICS countries — China, India, Brazil, South Africa and, more moderately, Russia — has been highlighted (Aleixandre et al., 2015). In terms of collaboration, the strong cooperation between the US and China and the involvement of developing countries, such as South and Central America (Mexico, Argentina, Brazil, Chile, Peru, etc.), Asian countries (Bangladesh, Nepal, Vietnam, South Korea, Iran, etc.) and African countries (South Africa, Kenya, Algeria),i is noteworthy. The cooperation with China it is not unusual; since 2007, the Chinese government has changed its attitude towards climate change policy and has become one of the main drivers of low-carbon technology development. These results are consistent with those found by Haunnschild et al. (2016) in a set of papers published between 1980 and 2014, where the research on climate change was dominated by the USA, followed by the United Kingdom, Germany and Canada. China was ranked fifth, followed by France and Australia. This geographical distribution has also been observed in other areas of research, such as agro-ecology (Ferguson and Lovell, 2014), soil contamination (Guo et al., 2014) and the production of bioenergy from biomass (Konur, 2012).

Highly cited papers are an exponent of the importance given to some topics, and several aspects should be emphasized. First of all, a good portion of the papers address several aspects of the impact of climate change on plants (risk to forest ecosystems, plant stress and diseases, impact on field crops), the impact on oceans, food safety, rain-fed farming and water crises as responses to this phenomenon. Secondly, the themes of the journals where the articles were published showed the multidisciplinary nature of this topic. Finally, the importance of climate change involves issues related to ecology, phytopathology, agriculture and agronomy, phycology, meteorology and food policy, among others.

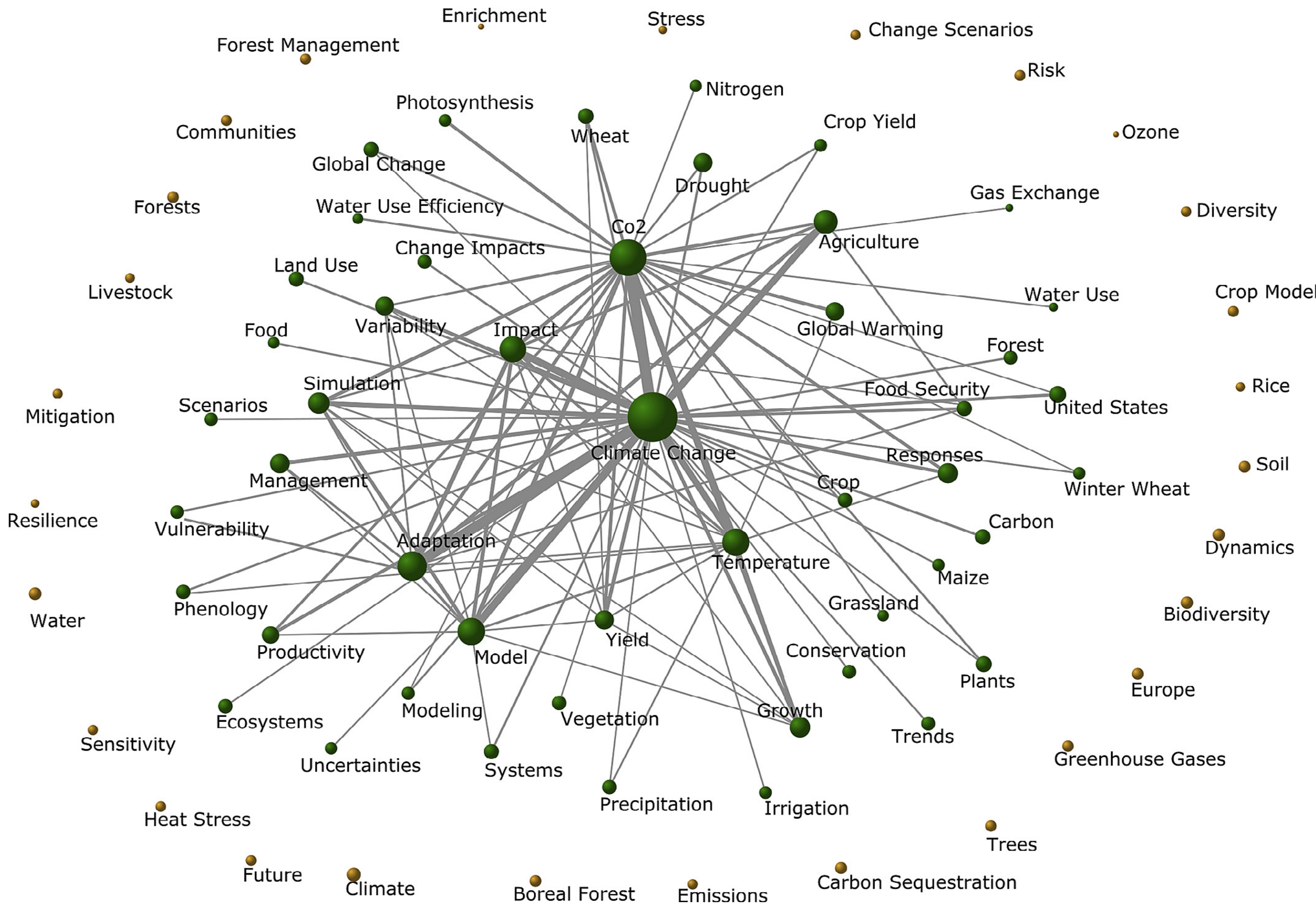

Fig. 8. Network of co-words.

5. Conclusions

This work has provided helpful insights into climate change research in agricultural subject areas. Many fronts including the most productive journals, institutions, countries, subject areas and topics, and collaboration between researchers, institutions and countries have been discussed. On the basis of the research findings, some conclusions can be drawn. The research on climate change in agricultural subject areas has grown steadily during the last decade. Research is usually led by major government institutions and universities devoted to agriculture. The network of collaboration between institutions and countries involve centres from developed and developing countries, and the cooperation between US and China is noteworthy. This information is useful both to strengthen the ties of collaboration between the groups working on similar or related topics so that newcomers can contact and become integrated into these groups. The most treated topics are those related to adaptation, model, impact, CO_2 and temperature. Highly cited papers reveal the concerns about the emerging climate change risks for forests, the impact on forest ecosystems, the effect on plant diseases and adaptation options.

6. Limitations

A scientometric analysis was conducted taking into account the articles indexed in the Web of Science to analyse how significant this topic already is in the scientific literature. At present, several well-curated bibliographic databases, such as Web of Science and Scopus, can be requested to conduct bibliometric analyses on various disciplines and topics. The Web of Science is one of the most used databases because it considers citations received by research papers and the impact factor of journals (Meho and Yang, 2007; Vandermeulen et al., 2011). The conference proceedings were not considered because the information presented in the conference papers are often published in scientific journals at a later stage. However, it is not appropriate to compare the citations received by articles published recently with those published years ago since not enough time has passed for recent papers to be cited.

7. Future research

Future research in this line could follow the evolution of research in this area and the progression of networks of collaborations between researchers, institutions and countries as well as their citations and impact. Another line of work could investigate whether interest in the current topics remains in the future or is replaced by others according to the evolution of climate change.

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