Elsevier Editorial System(tm) for Journal of Cleaner Production

Manuscript Draft

Manuscript Number: JCLEPRO-D-16-02199

Title: Trends in scientific research on climate change in Agriculture and related areas (2005-2014)

Article Type: Original article

Keywords: Climate change, agriculture, research collaboration, bibliometrics, social network analyses.

Corresponding Author: Prof. José Luis Aleixandre, Ph. D. Agricultural Engineer

Corresponding Author's Institution: Politecnic University of Valencia (Spain)

First Author: Rafael Aleixandre-Benavent

Order of Authors: Rafael Aleixandre-Benavent; José Luis Aleixandre-Tudó; Lourdes Castelló-Cogollos; José Luis Aleixandre, Ph. D. Agricultural Engineer

Abstract: Climate change refers to an alteration in the state of the climate that can be identified by changes in the mean and the variability of its properties. Climate change reflects abnormal variations in the Earth's atmosphere and subsequent effects on other parts of the planet, such as on crop lands, reducing the annual yield. The objective of this paper was to contribute to a better understanding of the scientific knowledge in climate change and his effect concerning agriculture, as well as to investigate its evolution through the published papers.
Items under study were obtained from Web of Science (WOS) platform from Thomson Reuters. A bibliometric and social network analyses was performed to determine 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 1,471 articles were included in the selected subject categories in WOS
since 2005 until 2014. The most productive journals were Agricultural and forest Meteorology, Forest Ecology and Management, and Agriculture Ecosystems & Environment. Excluding climate or climatic change, the most frequent keywords have been CO2, Adaptation, Model, Temperature and Impact. The network of collaboration between countries shows the central position of the United States, together with other leading countries such as China, Canada, Australia, Germany, and United Kingdom.
This work has provided helpful insights into the climate change research in Agricultural subject areas, wich had grown steadily during the last decade. The network of collaboration between institutions and countries involve both centres from developed and developing countries, and it is noteworthy the cooperation between US and China. Highly cited papers reveal the concern on emerging climate change risks for forest, the impact on forest ecosystems, the effect on plant diseases and adaptation options.

Suggested Reviewers: Juan Carlos Valderrama
juan.valderrama@uv.es

Adolfo Alonso
adolfo.alonso@uv.es

Edmundo Bordeu
ebordeu@puc.cl

Fernanda Peset
mpesetm@upv.es

COVER LETTER

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Authors:
1. José Luis Aleixandre (corresponding author)
   - Professor of Universidad Politécnica of Valencia
   - Camino de Vera, s/n 46022 Valencia (Spain)
   - e-mail: jaleixan@tal.upv.es
   - Cell phone: +34 625978549
2. José Luis Aleixandre Tudó
   - Postdoctoral Fellow Research Universidad Politécnica of Valencia
   - Camino de Vera, s/n 46022 Valencia (Spain)
   - e-mail: joaltu@upvnet.upv.es
   - Cell phone: +34 695462285
3. Lourdes Castelló Cogollos
   - Assistant Professor of Universidad de Valencia
   - Plaza Cisneros, 4 46003 Valencia (Spain)
   - e-mail: lourdes.castello@uv.es
   - Cell phone: +34 963926295
4. Rafael Aleixandre Benavent
   - Researcher of Spanish Research Council
   - Plaza Cisneros, 4 46003 Valencia (Spain)
   - e-mail: Rafael.Aleixandre@uv.es
   - Cell phone: +34 697881288

Authors contributions :

1. José Luis Aleixandre was the project leader

2. José Luis Aleixandre-Tudó was responsible of the climate change information.
3. Lourdes Castelló was responsible of the statistical treatment
4. Rafael Aleixandre-Benavent searched and reviewed the literature

Trends in scientific research on climate change in Agriculture and related areas (2005-2014)

R. Aleixandre-Benavent[1], J.L. Aleixandre-Tudó[2], L. Castelló-Cogollos[3], J.L. Aleixandre[2]

[1] Ingenio (CSIC-UPV). UISYS-Universidad de Valencia, Spain.

[2] Instituto de Ingeniería de Alimentos para el Desarrollo (IIAD). Universidad Politécnica de Valencia, Spain.

[3] Departamento de Sociologia y Antropología Social. Universidad de Valencia. UISYS-Universidad de Valencia, Spain.

Corresponding author: José Luis Aleixandre (e-mail: jaleixan@tal.upv.es)

ABSTRACT

The definition of climate change includes changes in the climate properties that alters the behaviour of its normal state. Climate change thus causes abnormal variations at atmosphere levels which influences climate condition in different parts of the planet. A good example of this alteration is the modification of the annual yield reduction in certain crops

The objective of this paper was to contribute to a better understanding of the scientific knowledge in climate change and his effect concerning agriculture, as well as to investigate its evolution through the published papers.

Items under study were obtained from Web of Science (WOS) platform from Thomson Reuters. A bibliometric and social network analyses was performed to determine 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 1,471 articles were included in the selected subject categories in WOS since 2005 until 2014. The most productive journals were Agricultural and forest Meteorology, Forest Ecology and Management, and Agriculture Ecosystems & Environment. Excluding climate or climatic change, the most frequent keywords have been CO_2, Adaptation, Model, Temperature and Impact. The network of collaboration between countries shows the central position of the United States, together with other leading countries such as China, Canada, Australia, Germany, and United Kingdom.

This work has provided helpful insights into the climate change research in Agricultural subject areas, wich had grown steadily during the last decade. The network of collaboration between institutions and countries involve both centres from developed and developing countries, and it is noteworthy the cooperation between US and China. Highly cited papers reveal the concern on emerging climate change risks for forest, the impact on forest ecosystems, the effect on plant diseases and adaptation options.

Key words: Climate change, agriculture, research collaboration, bibliometrics, social network analyses.

INTRODUCTION

The climate change caused by human activities is having a massive impact on the Earth's ecosystem, influencing both physical and social activities. The environmental negative associated impacts are compromising the sustainable development of the human being 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 his 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 has to do with the alteration of the normal crops cycles and yields (Challinor et al. 2007).

Scientific publications that adopted the effects of climate change as main theme have rapidly increased in the past several decades. Renown 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.

Agriculture and climate change have been combined in a large number of publications such as drought impact in Sonora and Puebla (Mexico) (Liverman, 1990), see level rise in the Vietnamese Mekong delta and its implications on rice production (Wassman et al., 2004), food security and climate change adaptation needs (Lobell et al., 2008), influences of climate change on soil fauna (Briones et al., 1997), global precipitation extremes dependant on temperatures (Liu et al., 2009), diurnally asymmetric trends of temperature, humidity and precipitation in Taiwan (Shiu et al., 2009) or the effect of climate change on air quality (Jacob and Winner, 2009).

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

The political agenda has targeted global warming, greenhouse gases and the limitation on CO_2 emissions as top priorities. After the environmental Kyoto protocol (Bohringer, 2003) some countries have committed to reduce the human greenhouse emissions by at least 5% during the 2008-2012 period. This would have placed the levels of greenhouse gases (CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride) below those present in1990.

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

METHODS

Papers under study were obtained from the Web of Science Core Collection (WOS) platform from Thomson Reuters. We run the same terms used in the previous paper of Li et al (2011): “climate change” OR “climate changes” OR “climatic change” OR climatic changes”. 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 into quotation marks to guaranty more precision in the obtained records, e.g., all records containing one term after the other. To focus this topic in 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, Agricultural Economics Policy. We limited the search to the 2005-2014 period. The study was restricted to articles and reviews and, therefore, abstract of conferences, bibliographical articles, book reviews, editorials, letters, reprints and news were excluded.

As indicators of scientific production we determined: annual evolution of published papers and distribution of papers per journals, institutions and countries that developed the research, 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 most cited papers. The number of citations was obtained from WOS database and we took into account all those received by the articles and reviews during the analysed period. Impact factor numbers were extracted from the 2014 edition of the Journal Citation Reports. To analyse and drawn the collaboration patterns, a social network analysis (SNA) was also carried out 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, which might also appear in other papers.

We also performed a subject analysis taking into account on the one hand, the key words assigned to papers, and on the other, subject areas of journals in the Journal Citation Reports joint to three most frequent key words assigned to papers and to three most productive journals in each identified area. SNA was also carried out to identify the number of co-occurrences between key words (co-words). Co-occurrences refer to all combinations of key word pairs on each paper and that are repeated in the set of papers revised. SNA applied to co-word analysis 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 constructed to map knowledge in other fields, such as environmental science (Ho 2007), tsunamis (Chiu and Ho 2007) and wine and health (Aleixandre et al. 2013), among others.

To visualize the networks we used the softwares Pajek and VOSViewer (Batagelj and Mrvar 2001). A threshold or minimum of relations was applied in order visualize correctly the networks. This threshold is specified when each figure is mentioned.

RESULTS

1. Authors, institutions and countries

During the period of analysis, 1,471 articles were included in the selected subject categories in WOS. As shown in Figure 1, the number of published articles has grown exponentially since 2005, when 41 articles were published (2.78%) the year in which the first article was included in WOS, until 2014, with 268 (18.22%) articles. The greatest growth has occurred in the last three years, since 50.65% of the papers was published.

Papers have been published in 302 different journals. The 44 journals publishing 10 or more papers are shown in Table 1, along with other data as the number of citations received, the ratio citations per paper, the impact factor, 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=2,441), followed by *Agricultural and Forest Meteorology* (n=1,839), and *Agriculture Ecosystems & Environment* (n=1,358). The ratio 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* is he journal with the higher impact factor (IF=6.672), followed by *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 first or second quartile in Journal Citation Reports subject categories, with the exception of *Journal of Agrometeorology, Forestry Chronicle,* *Fourrages, Journal of Food Agriculture & Environment,* and *Journal of Integrative Agriculture* that ranks in 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 is the institution with most citations (n=1,456), followed by four institutions receiving near 1,200 citations: University of Tasmania (Australia), Institut National de la Recherche Agronomique (INRA, France), United States Department of Agriculture (USDA) and Oregon State University (US). In the ratio citations per article, two institutions stand out: Food and Agriculture Organization of the United Nations (FAO) and Canadian Forest Service, both with more than 100 citations per paper.

Regarding the distribution of papers by country (Table 3), the country publishing more papers has been United States (n=323), followed by Germany and United Kingdom (n=152, respectively) and other three countries with more than 100 papers: Australia, Canada and China. By citations highlights United States in first position (n=6,530) and then three countries with about 3,000 citations: Canada, United Kingdom and Australia. The ratio citations per article is higher for South Korea, Switzerland, Italy and Austria.

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

The most common keywords can be seen in Table 4, as well as annual evolution. Excluding climate or climatic change, the most frequent keywords have been CO_2 (n=406) and four key words with more than 200 papers: 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: 72% of papers related with CO_2; 84% of papers related with Adaptation; near 75% of papers related with Model, Temperature, Impact and Simulation, respectively; 89% related with Management; 79% with Drought; 83% with 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 Categories are detailed in Table 5. In first place stands the subject categorie Forestry (n=419), where the most common key words have been adaptation (n=94), model (n=80) and CO_2 (n=78). Journals belonging to this subject category that published more articles have been *Agricultural and Forest Meteorology* (n=64), *Forest Ecology and Management* (n=62) and *Canadian Journal of Forest Research* (n=30). The subject category positioned in second place was Plant Sciences (n=351), whose most frequent key words have been CO_2 (n=133), Temperature (n=54) and responses (n=42). Journals belonging to this subject category that published more articles were *Journal of Ecology* (n=25), *New Phytologist* (n=17) and *Plant Ecology* (n=16). Other three subject category including more than 100 articles were: Agronomy (n=319), with the most frequent key words being CO_2, Model and Agriculture; Agriculture, Multidisciplinary (n=243), with the key words CO_2, Adaptation and Agriculture; Ecology (n=125), with the key words CO_2, Temperature and Model; and Food Science and Technology (n=101), with the key words Temperature, Adaptation and Food security.

Figure 8 shows the network of co-words. The size of the spheres in the graphs is proportional to the number of articles including each key word, and the thickness of lines connecting the spheres is proportional to the number of papers including simultaneously two key words. 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, as 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 performed 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).

3. Most cited papers

The 20 research articles receiving more than 100 citations are presented in Table 6. The most cited article has been the review entitled "A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests" was published in the journal *Forest Ecology and Management* in 2010 by Allen et al., a research team conformed by 20 researcher 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. It highlights the need of a globally coordinated observation system to provide key information on the most important gaps and uncertainties that difficulty the ability to predict tree mortality. These results were first presented at the Conference on Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health Location, 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 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 in order to cover all levels of decision making. In addition to this an appropriate strategy includes the use of integrated monitoring networks and projection models applied from policy development to management unit. 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), and reviews the climate change effects on plant disease. The interesting conclusion reveals that one of the most important predictor to quantify the magnitude of the climate change effects has to see with the adaptive potential of plant and pathogen populations.

4. Network of collaboration between authors, institutions and countries

Figures 2, 3 and 4 show the network of collaboration between authors. To drawn this network, we have applied a threshold of almost 2 papers written in collaboration. The size of the spheres is proportional to the number of published papers by each author, and the size of the lines connecting two authors is proportional to the number of papers published in collaboration. A team of 29 researchers integrate the first group (Figure 2) and researchers from 14 different institutions from 9 countries comprise it. The authors with more connections with others have been de following: Peltonen Sainio, from MTT Agrifood Research Finland, with 11 collaborators; Olensen, from Aarhus University, Denmark, with 10 collaborators; and Eitzinger, from Norwegian University of Life Sciences, Norway, with 9 collaborators. The other researchers belong to centres from Czech Republic, Germany, USA, Netherlands, Sweden and Austria.

In Figure 3 we represents other group with 23 researchers from 5 countries: Italy, France, Portugal, Austria and Finland, the country with most authors. The institutions of these researchers are: University of Natural Resources and Applied Life Sciences-BOKU (Vienna, Austria); University of Lisbon (Portugal); Institut National de la Recherche Agronomique (INRA, France); Italian Academmy of Forestry Science; and six more universities and research institutes from Finland. In figure 4 are identified other 6 groups, one with 14 researchers, one with 11 and four with 10 researchers from France (Institut National de la Recherche Agronomique-INRA); India (two groups from 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 (Figure 5), applying a threshold of almost 2 papers published in cooperation, the main network includes 32 institutions, some of them reaching more central position and providing connection with others. Here again, the size of the spheres is proportional to the number of published papers by each institution, and the size of the lines connecting two institutions is proportional to the number of papers published in collaboration. This applies to organizations such as INRA, BOKU and USDA, the last one located in a central position relative to other US institutions. In figure 6 it can be observed other 9 groups of institutions not connected with the previous one that integrates organizations from China and Australia; United States; United Kingdom and Denmark; Germany; Australia; Spain; Canada; China; and Finland. The strongest collaboration in the network of institutions appears between Institute of Crop Science and Resource Conservation (INRES) and University of Bonn (n=11); Chinese Academy of Science and Grad University (n=10); Beijing Forestry University and Chinese Academy of Science (n=9); Universitat Autònoma de Barcelona and Centre de Recerca Ecologica i Aplicacions Forestals-CREAF (n=9).

Figure 7 shows the network of collaboration between countries. It can be appreciate the central position of the United States, together with other leading countries such as China (n=32), Canada (n=25), Australia (n=20), Germany (n=17), United Kingdom (n=15), and Italy (n=14). Other important relationships are established between Germany and United Kingdom (n=12), Austria (n=10) and Denmark (n=10); and France with Italy (n=10).

DISCUSSION

This work has identified the annual evolution of scientific articles on climate change in agricultural areas, as well as the most productive and cited papers and journals, subject categories, research groups, institutions and their international collaboration. It has also been shown the main topics discussed on this subject through the most assigned key words and the Social Network Analyses of co-words. The diffusion of knowledge and information regarding climate change might contribute to promote a higher level of cooperation within the climate change community and to create a favourable environment for debate. Policy discussions to suggest future research directions would be of high interest, acting as a starting point to monitor future developments in the area (Husain and Mushtaq, 2014)

Climate change is now evidence and proof of its importance is that many institutions at global and national level are funding or conducting research on the causes, consequences and how to combat them. For example, at international level. In 2014 the World Bank Group sponsored 224 climate projects in 77 countries with a $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, FAO's Programme work contributes to implement the policy frame works and institutional arrangements by supporting countries to create an environment suitable for the development of the agriculture under the climate change conditions. The improved decision making as well as the implementation of adaptive measures is 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). Other international institution involved is WHO. Four main objectives within its climate change and health work plan have been defined by the organization in 2009. These include enhance scientific evidence, advocate and raise awareness, strengthen 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 to health protection

Looking at national level, in United States, the Climate Change Program Office (CCPO) coordinates United States Department of Agriculture responses to climate change, focusing on implications of climate change on agriculture, forests, grazing lands, and rural communities. The climate change response strategies focus on the analysis, planning and research aims coordination (Climate Change Program Office, 2016). In France, the Institut National de la Recherche Agronomique (INRA) support the program "Adaptation of agriculture and forests to climate change" (AAFCC), that studies to possible adaptation strategies to understand the combined effects cause by climate change on agriculture and natural environments as well as their environmental and socio-economic consequences (INRA, 2016).

And there are also individual projects, as *Climate Reality Project*, established and chaired by Al Gore, founder and chair of the Alliance for Climate Protection, with the mission of to catalyse a global solution to the climate crisis by making urgent action a necessity across every level of society. We cannot forget that Gore received in 2007 the Nobel Peace Prize, jointly with the Intergovernmental Panel on Climate Change, established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 with the aim to provide 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 lied in convincing the U.S. and China, by far the two largest national emitters, to the adoption of 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 are: soil contamination (Guo et al. 2014); the effects of wine on health (Aleixandre et al. 2013); production of bioenergy from biomass (Konur 2012); environmental marketing (Leonidou and Leonidou 2011); food and feed safety (Vain 2007), biotechnology (Dalpe 2002; Vain 2005), plant genetic resources (Dudnik et al. 2001). However, only fewer papers use bibliometric and social network analysis to measure and map the scientific knowledge in climate change (Li et al, 2011; Wang et al, 2014; Bjurström and Polk, 2011; Husain and Mushtaq, 2014).

An earlier scientometric study shows that climate change research has grown rapidly, specially since the 1970's (Stanhill, 2011). Li et al (2011), in a work that analysed the trends in research on global climate change from 1992 to 2009, also found an increase in the number of published papers, although we can not 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 analyses only research articles in strict sense. The overall increase in the number of articles published during the decade is a convincing evidence of the leap in productivity on research on the climate change field. This growth has also been observed in other related areas such as agro-ecology (Ferguson and Lovell 2014) and soil contamination (Guo et al. 2014). But It is not surprising that our results differ of those of found by Wang et al (2014) due to our specific scope to 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, Forest, Meteorology, Ecology, Environment, Water management and Phytology, among others, publishing articles about climate change. The fact that 15 of the 19 most productive journals are in first or second quartile reveals the importance of the topic for journals editors and scientific community.

The key words frequency analysis has revealed that the main issues addressed focus on “CO_2”, “Adaptation”, “Models”, “Temperature”, “Responses” and “Impact”. The analysis on the topics published in most cited papers also confirm that the climate change effects on plants, the impact on forest and ecosystems, the adaptive capacity of plants and agricultural production, are the most concerns. 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 other study by Li et al (2011) the items “temperature”, “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 leading research methods. It was also reported a novel method “phylogeaography” might have and important application in the near future.

Looking at the areas of research, in accordance with the previous rationale about key words, it was observed that articles have been published in a vast variety of areas that involves 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, and also suggests that Climate Change is an area that strongly needs for its development the contributions of other numerous scientific areas. In the subject area of Food Science and Technology it is also be mentioned the topic “Food security”.

The analysis of research groups identified and most productive institutions shows the leadership in research on the subject of major national institutions in developed countries, even ahead of universities. According to Bullock et al. (2007), multidisciplinary teams are a necessity for this work, and it is very important that the existing research community recognize this need and provide rewards for participation in interdisciplinary research. The ranking of countries shows that the research originates mainly from developed countries such as US, Germany, United Kingdom, Australia, Canada, France, Spain and Italy. Beside these leaders developed countries, highlights the presence of the BRICS Countries China, India, Brazil, South Africa and, more moderate, Russia (Aleixandre et al, 2015). In terms of collaboration, it is noteworthy the strong cooperation between US and China, and the involvement of Developing Countries such as South and Central American (Mexico, Argentina, Brazil, Chile, Peru, etc.), Asian countries (Bangladesh, Nepal, Vietnam, South Korea, Iran, etc.) and African countries (South Africa, Kenya, Algeria). The cooperation with China it is not estrange, because 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 developments. This geographical distribution has also been observed in other areas of research as agro-ecology (Ferguson and Lovel 2014), soil contamination (Guo et al. 2014) and 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 emphasised. First of all, a good portion of them deal with several aspects of the impact of climate change on plants (risk for forest ecosystems, plant stress and diseases, impact on field crops), impact on oceans, food safety, rain-fed farming and water crisis as response to this phenomenon. Secondly, the thematic of the journals where the articles have been published showed the multidisciplinary of the concerned subject. Finally, the importance stirs up issues related to the ecology, phytopathology, agriculture and agronomy, phycology, meteorology and food policy, among others.

Conclusions

This work has provided helpful insights into the climate change research in Agricultural subject areas. Many fronts including the most publishing journals, institutions, countries, subject areas and topics, as well as collaboration between researchers, institutions and countries have been discussed. On the basis of the research findings some conclusions could be drawn. The research on climate change in Agricultural subject areas had 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 both centres from developed and developing countries, and it is noteworthy the cooperation between US and China. This information would be useful both to strengthen the ties of collaboration between the groups working on similar or related topics, so that neophytes can contact and integrated into these groups. The most treated topics have been those related to Adaptation, Model, Impact, CO_2 and Temperature. Highly cited papers reveal the concern on emerging climate change risks for forest, the impact on forest ecosystems, the effect on plant diseases and adaptation options.

Limitations

Scientometric analysis was performed based on articles indexed in Web of Science to analyse how significant this topic already is in the scientific literature. Other databases as Scopus could provide other publications that complement the study. The conference proceedings were not included because the ideas presented in conference papers are often republished in journals at a later stage.

Future research

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

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<u>Title:</u> **Trends in scientific research on climate change in Agriculture and related areas (2005-2014).**

HIGHLIGHTS

1. Climate change reflects abnormal variations on crops lands, reducing the annual yields. Highly cited papers reveal the risk on forest ecosystems.

2. This study contribute to a better understanding of the scientific knowledge in climate change and his effect concerning agriculture.

3. The network of collaboration between countries shows the central position of the United States, together with other leading countries such as China. .

4. This work has provided helpful insights into the climate change research in Agricultural subject areas that had grown steadily during the last decade.

Figure

Figure 1. Annual evolution of published papers

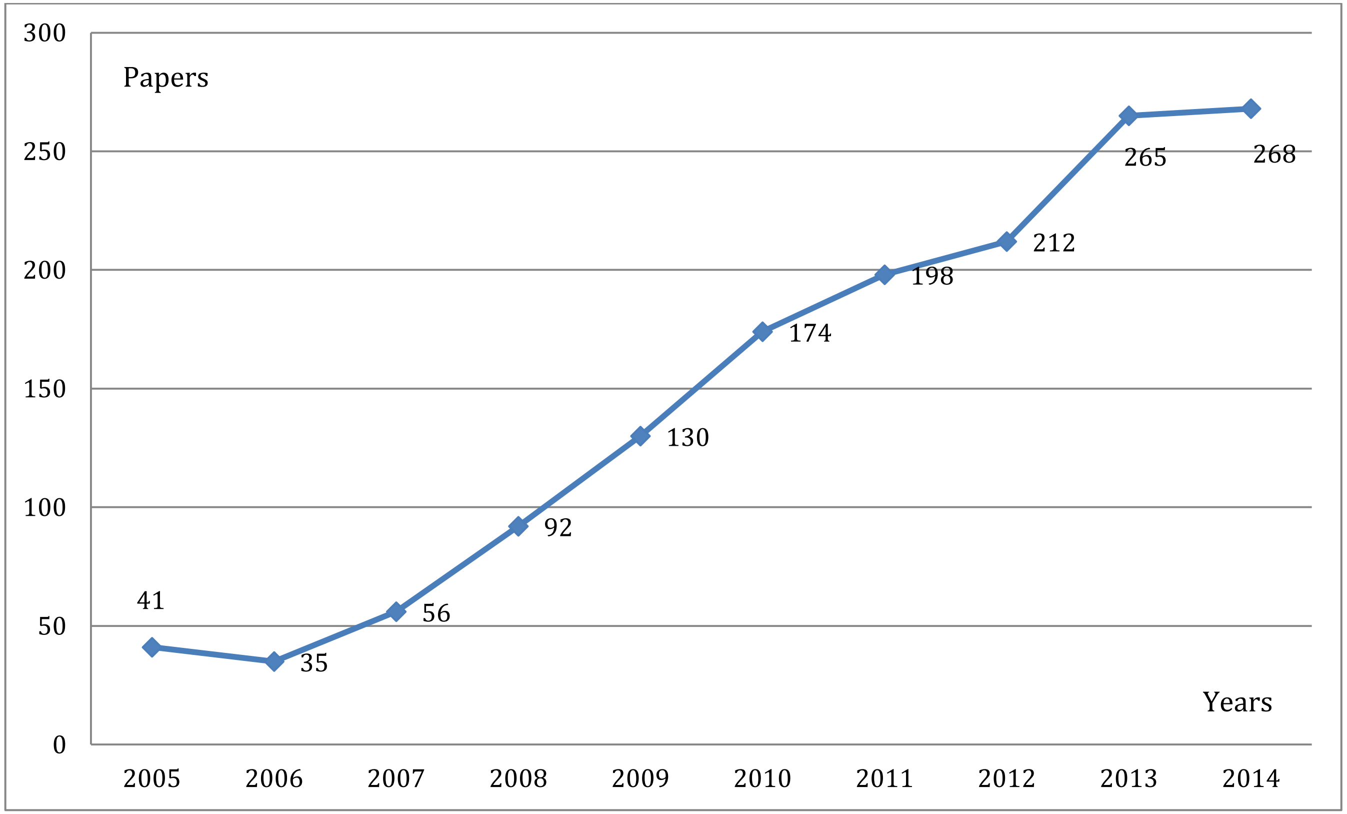


Figure 2. Main group of authors (n=29)

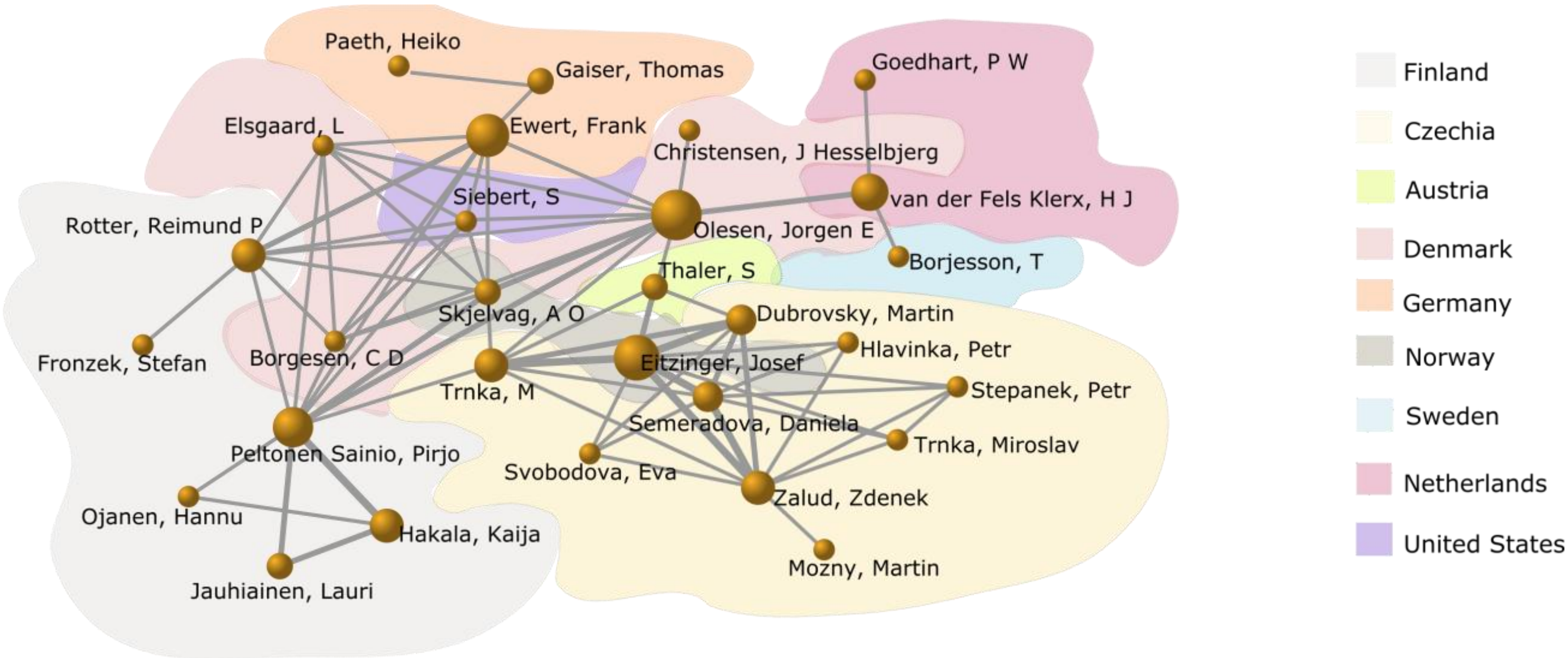


Figure 3. Main group of authors (n=23)

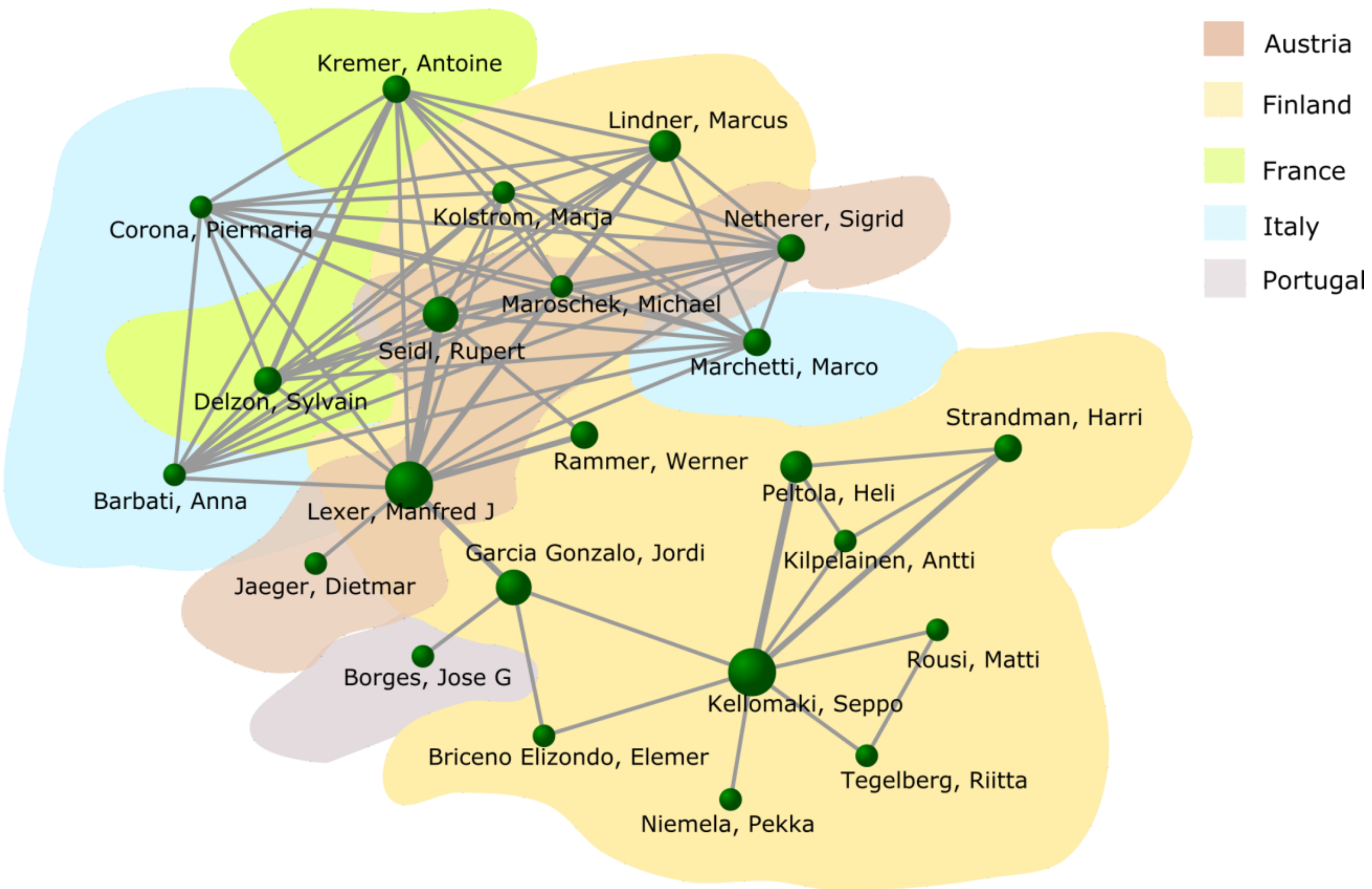


Figure 4. Other groups of authors

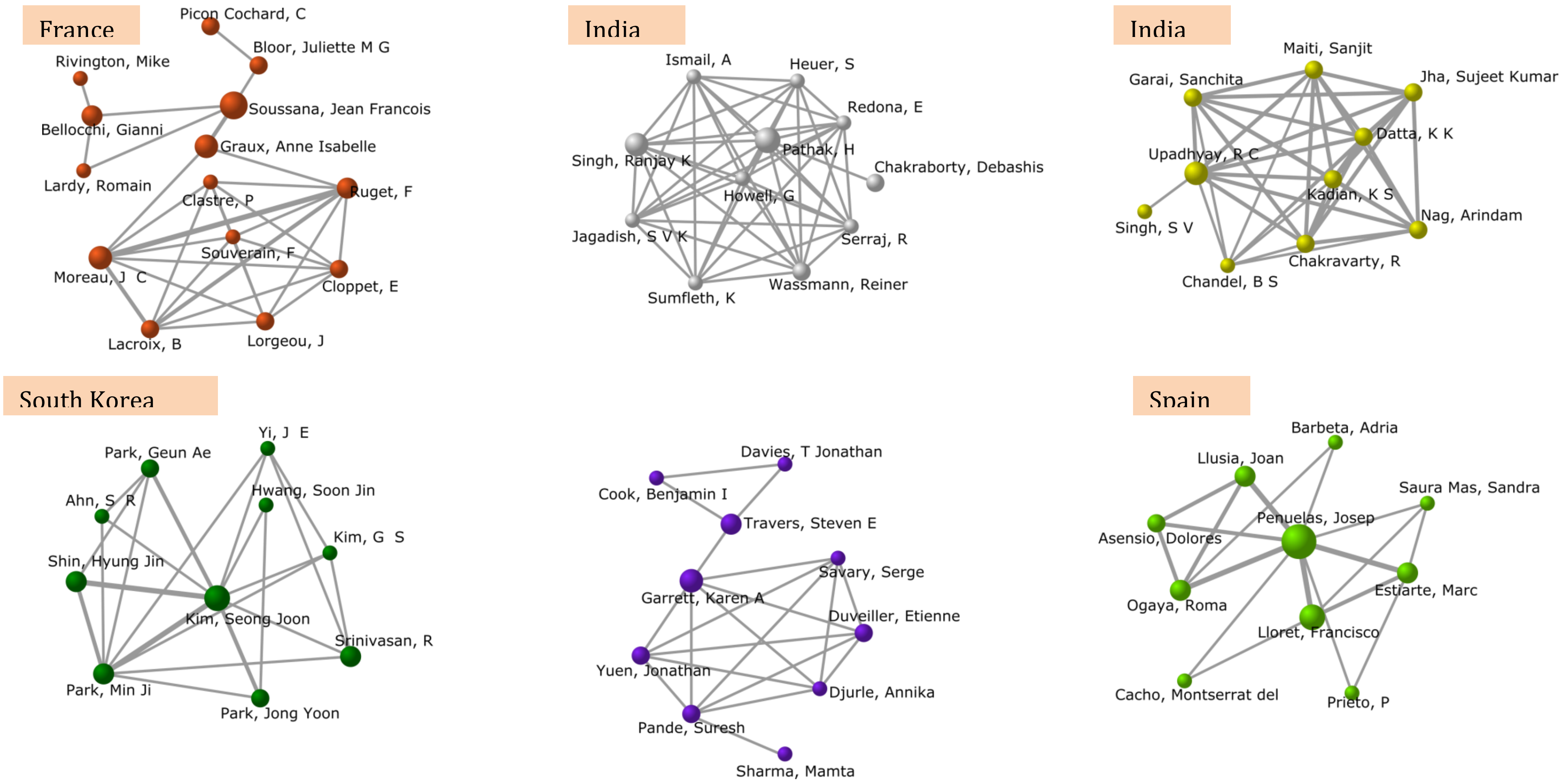


Figure 5. Main network of institutions

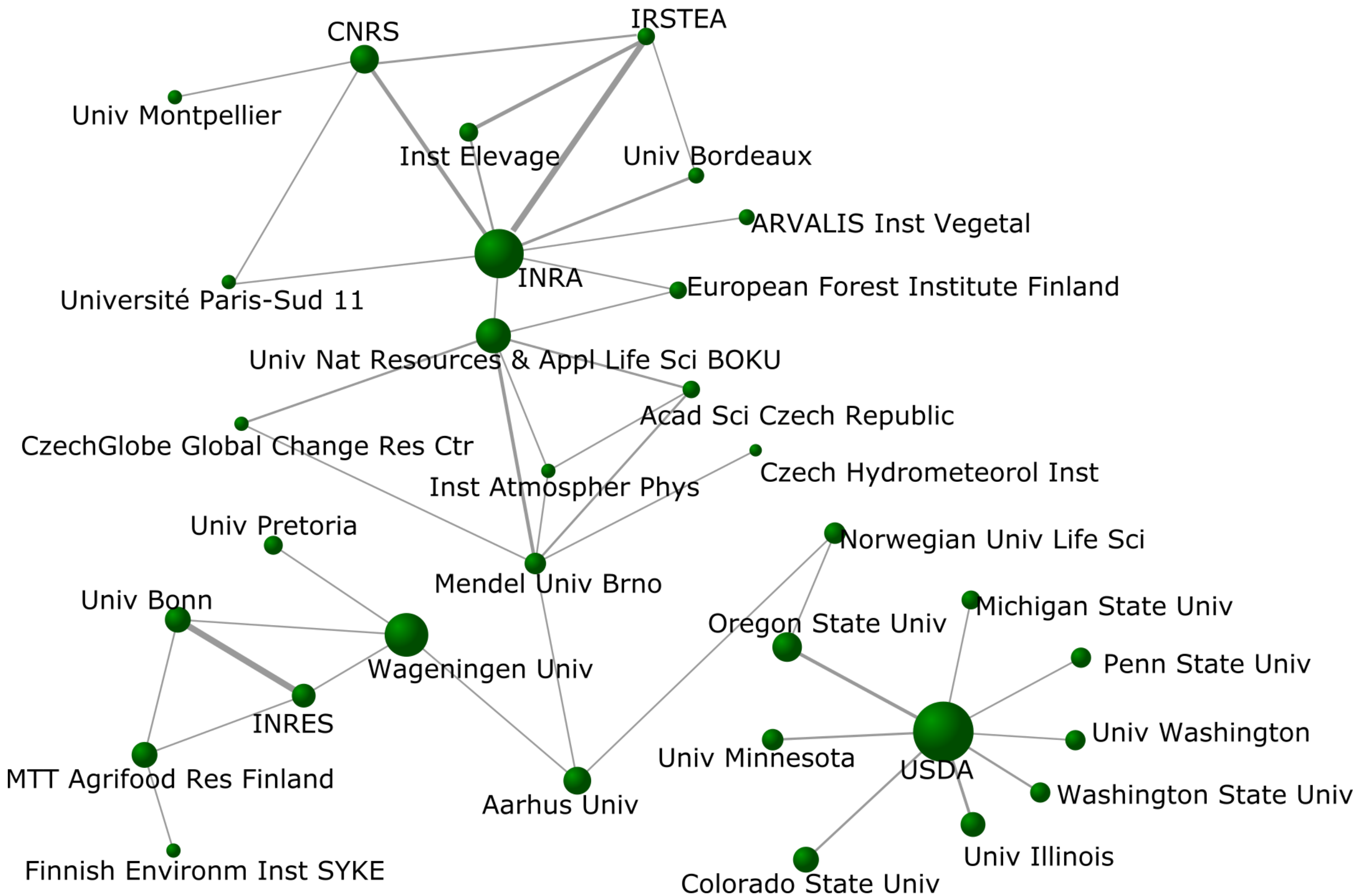


Figure 6. Other groups of institutions

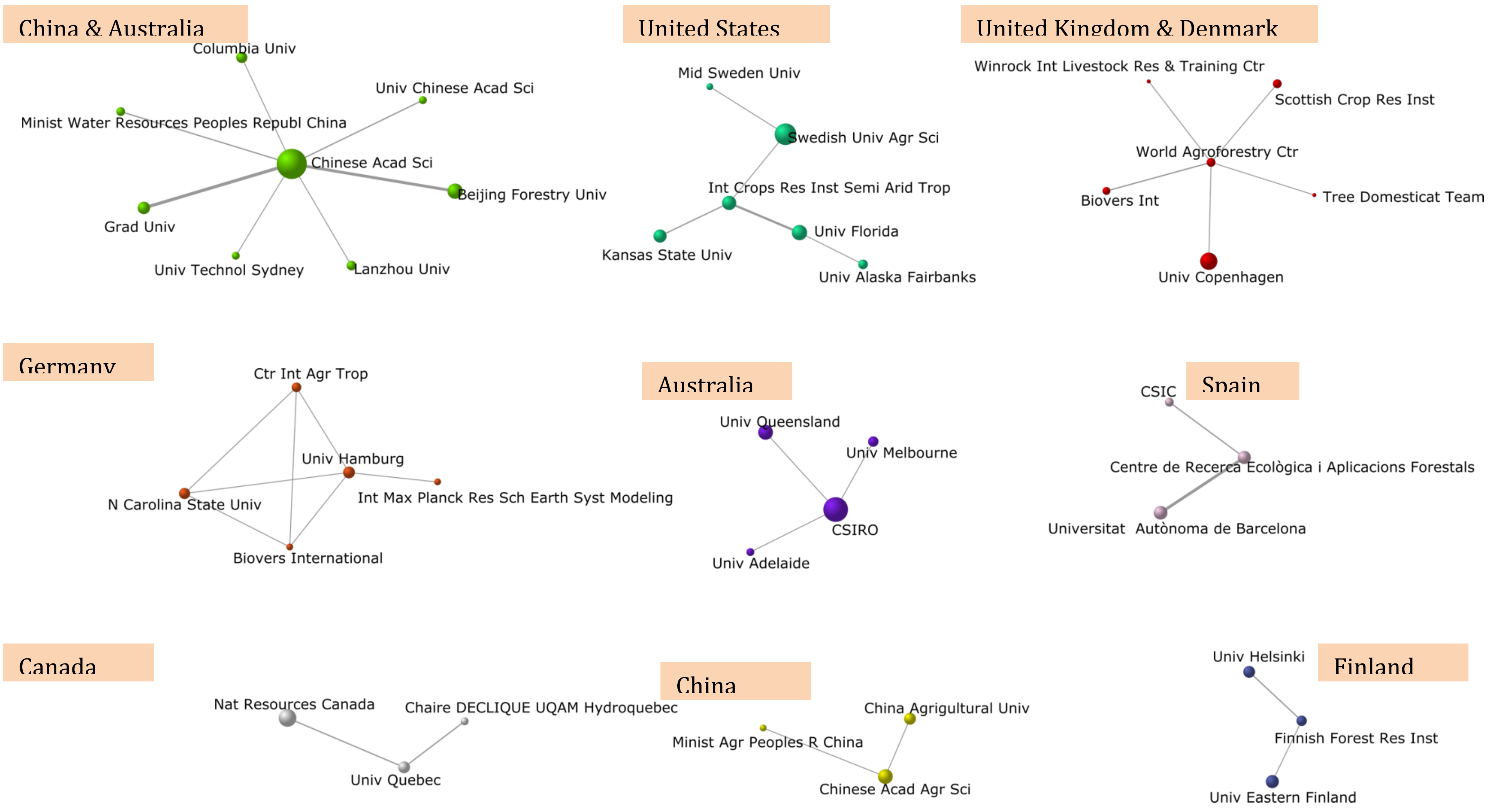


Figure 7. Network of countries

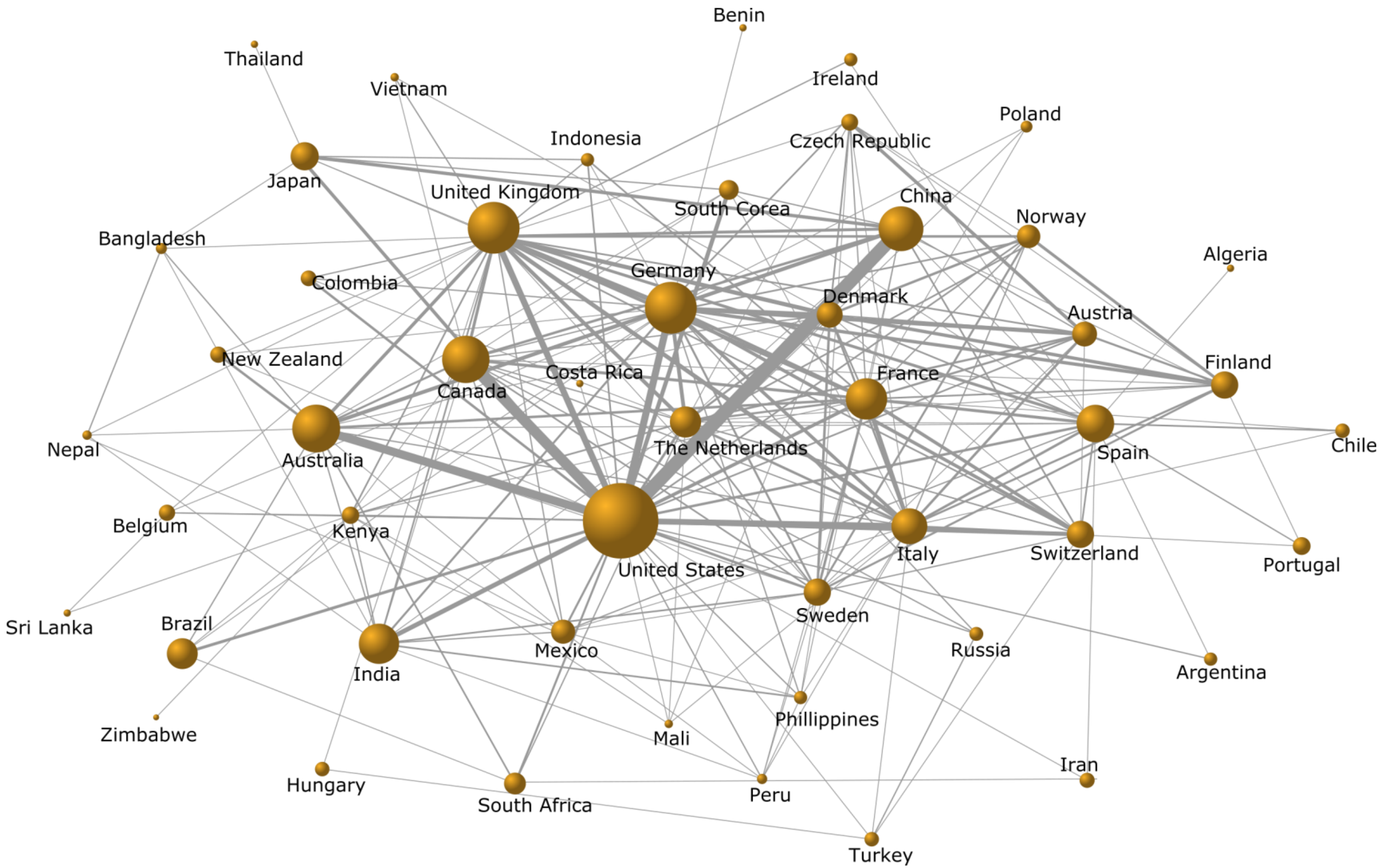
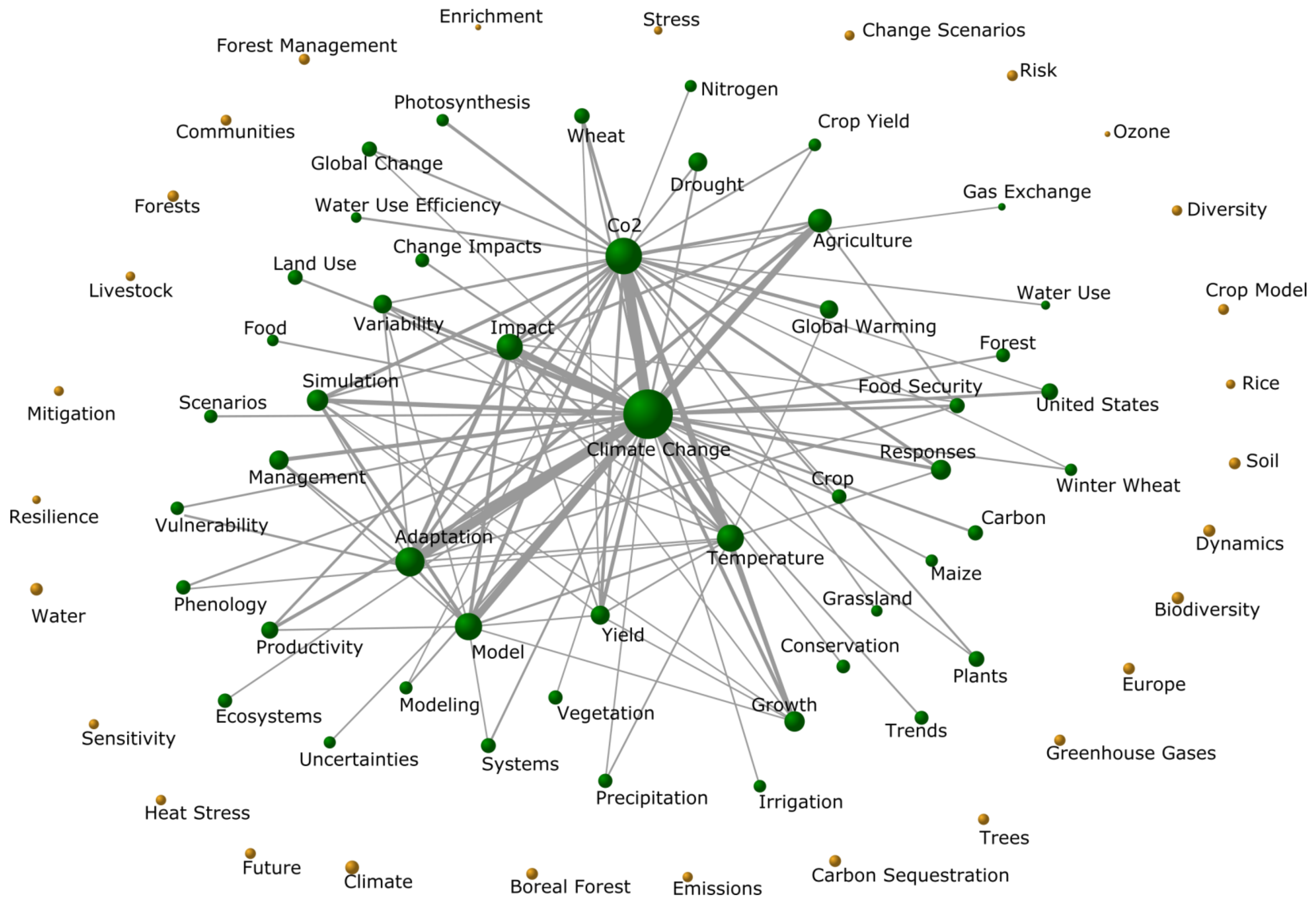


Figure 8. Network of co-words



Table

Table 1. Most productive journals (>15 articles)

Journals	Articles	Citations	Citations/Article	2014 Impact factor	Quartil
Agricultural and Forest Meteorology	64	1,839	28.73	3.762	Q1
Forest Ecology and Management	62	2,441	39.37	2.660	Q1
Agriculture Ecosystems & Environment	57	1,358	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 (>10 articles)

Institutions	Countries	Articles	Citations	Citations/Article
United States Department of Agriculture	United States	70	1,236	17.66
Chinese Academy of Science	China	58	728	12.55
Institut National de la Recherche Agronomique	France	47	1,241	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 Nattional 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	1,225	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	1,456	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	1,285	116.82
Technical University of Munchen	Germany	11	135	12.27
INRES	Germany	11	361	32.82

Table 3. Countries of publication (>10 articles)

Countries	Articles	Citations	Citations/Article
United States	323	6,530	20.22
Germany	152	2,152	14.16
United Kingdom	152	3,101	20.40
Australia	130	3,054	23.49
Canada	127	3,267	25.72
China	114	2,411	21.15
France	97	2,877	29.66
India	92	612	6.65
Spain	80	2,057	25.71
Italy	73	2,827	38.73
The Netherlands	55	1,028	18.69
Brazil	54	443	8.20
Japan	45	625	13.89
Finland	42	1,134	27.00
Sweden	42	694	16.52
Switzerland	42	1,679	39.98
Denmark	38	776	20.42
Austria	35	1,067	30.49
Mexico	33	316	9.58
Norway	31	620	20.00
South Africa	27	241	8.93
South Korea	22	1,256	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	1,091	90.92
Russia	11	1,114	101.27

Table 4. Annual evolution of most frequently key words

Key words	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
CO2	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
Modeling	-	1	2	5	5	4	9	6	9	11	52

Table 5. Subject areas. most frequently used key words and most productive journals

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)

Table 6. Highly cited articles (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 & Environment 2008; 126(1-2): 46-58	139
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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
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