

# Science mapping approach to analyze the research evolution on precision agriculture: world, EU and Italian situation

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Published online: 17 March 2018

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**Abstract** The relevance of precision agriculture produced a growth of the related literature over the years. However, a structured analysis of the published material is still missing. Thus, this study attempts to analyze the global scientific output of precision agriculture researches published during the period 2000–2016. By using a science mapping approach, mainly based on the application of network analysis tools, it was possible to investigate pivotal aspects of this research field such as publication trends, research topics and their geographical distribution. Using the Scopus database 17,756 scientific publications were retrieved from the chosen period. The number of publications increased after 2006, highlighting the vibrancy of the field. By authoring 35% of the publications, U.S.A. and China were the most active knowledge producer countries. Moreover, the generation of time resolved maps allowed us to identify agriculture engineering, computer science and agriculture studies as three main research areas characterizing precision agriculture panorama. The paper discusses the distribution of these topics at global level, among European countries and in Italy. Overall, this analysis represents the first holistic view of precision agriculture research providing valuable information for farmers, policy makers and researchers.

**Keywords** Precision farming · Terms mapping · Scopus · Scientific publications · Bibliometrics

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## Introduction

Precision agriculture (PA) handles important issues related to a more sustainable agriculture. PA plays a crucial role in a sustainable intensification, being recognized as a contributor to farming efficiency and environmentally friendly practices (Lundström and Lindblom 2016). Briefly stated, PA is a management concept based on observing, measuring and responding to intra-field variability in crops. PA technology allows farmers to recognize variations in the fields and to apply variable rate treatments with a much finer degree of precision than earlier possible (Lindblom et al. 2016). The emergence of PA technology represents a paradigm shift in farming practices. Indeed, it permits the consideration of the field as a heterogeneous entity eligible for selective treatment instead of a homogenous one equally treated (Aubert et al. 2012). The global advent of PA represents a new agricultural revolution taking advantage of a combination of new available technologies, such as global positioning satellite systems, sensors and digital technologies, ICT (Information and Communication Technology) and Internet of Things. PA methods promise to increase the quantity and quality of agricultural outputs while using less inputs (water, energy, fertilizers, pesticides, etc.), to automate farm tasks, to simplify decision-making, to measure crop and animal performances and carry out several other tasks (Eastwood et al. 2017). The aims are to increase farm income, reduce costs, to minimize environmental impact while producing more and better food. PA technologies started to appear in late 1980s in both United States and Australia (Pierce and Nowak 1999; Cook and Bramley 1998; Stafford 2000) since then undergoing a constant growth till now. This, following the appearance on the market of newly developed technologies e.g. miniaturized sensors or positioning systems with increased accuracy and precision (Suprem et al. 2013). In May 2000, the American government discontinued the use of Selective GPS Availability (an intentional degradation of GPS signals was implemented for military reasons) making more precise its use for civilian applications e.g. for accurately locating a vehicle and navigate (Cox 2002). Therefore, a wide variety of activities were developed, such as electronic controllers for variable rate applications (VRA) to manage the positioning information and crop yield monitoring (Bora et al. 2015). For some observers, the moment in which yield variability data were linked to soil maps, regarding spatial and temporal nutrient changes, determined the true beginning of PA, firstly in open field crops (mainly cereals) (Casa and Castrignanò 2008; Basso et al. 2011; Hedley 2015). Currently, PA is studied and applied in many countries in the world, including Italy, even if Italian agriculture appears to be a fragmented reality with an extremely rich and diverse territory (Pisante et al. 2016; Castaldi et al. 2017; Morari et al. 2018). At the present time several real practical benefits are coming from PA applications, including the overall maximization of the production efficiency, reduction of environmental impact and management of risks connected with the agricultural practices (Whelan 2007). In the meantime, PA has opened new socio-economic scenarios, and policy decisions and regulations are now demanded in order to face political issues (e.g., data management, data ownership and access to open data) (Lötscher and Didelot 2012). Presently, many research studies have been conducted to increase the implementation level of new technologies or with an effort to develop new ones able to improve the whole farm management in the name of an increased sustainability (Fountas et al. 2016). Often the research efforts aim at mainstream focuses while minor but important topics (e.g. the implementation of VRA in minor crops) might be left behind. Moreover, could be interesting to analyze the research trend during years

and compare the expertise and contributes of different actors (e.g., countries) to PA research, underlining crucial aspect with regards to specific places/time periods.

Bibliometrics applies quantitative methods to analyze scientific publications as an information process. Specifically, once the patterns and dynamics of scientific publications are identified, they are used as a proxy for the development of the investigated disciplines (Pritchard 1969; van Raan 2004). Therefore, it represents a powerful analytical tool to measure the scientific research production. These studies can facilitate scientific policy-making and planning. The bibliometric approach has already been applied to different research fields such as climate change (Li et al. 2011), geostatistics (Hengl et al. 2009) and solid waste research (Mesdaghinia et al. 2015). In recent years bibliometrics has been used in concert with terms analysis (i.e. words) that appear in the title, abstracts and keywords of published papers. Such approach, termed bibliometric mapping or science mapping, has been widely used to acquire a deeper understanding on the research structure itself. For example, it has been applied successfully to different research fields such as chemistry (Boyack et al. 2008), Mediterranean forests (Nardi et al. 2016), carbon isotopes (Di Matteo et al. 2016) or climate change (Haunschild et al. 2016). Science mapping offers the possibility of obtaining insights into the wide and complex amount of information contained in bibliographic databases, thus, allowing researchers to detect and visualize the main research topics investigated in the field of PA, which is becoming more attractive to researchers, science policy makers and research managers.

Given the emergent importance of PA, the aim of this paper is to examine the interaction, distribution and scientific impact of research topics related to PA, using a science mapping approach. The analysis was carried out to show the evolution of research structure during the last 17 years and compare the research trajectories of different geographical areas, including Italy. The identification of the scientific knowledge structure of PA related researches can help learners to enter this field as well as to provide insights to policy decision makers and research managers.

## Materials and methods

### Scopus search

The Scopus database was used to retrieve bibliographic records related to precision agriculture research for the period 2000–2016. The research group decided to start from 2000 because prior that year the published papers were less than 50 *per* year. Web of Science was not used because not available to the research group, whereas Google Scholar offers results of inconsistent accuracy (Aguillo 2011; Nardi et al. 2016). To identify relevant precision agriculture publications, were used the following keywords in the combined field of title, abstract and keywords: precision PRE/3 agriculture OR precision PRE/3 forestry OR precision PRE/3 viticulture OR precision PRE/3 farming OR precision PRE/3 aquaculture. The proximity operator PRE/n specifies the proximity between two terms in an exact order. Specifically, PRE/n means “precedes by”, where the first term in the query must precede the second within a specified number of terms n. That is, the first word must be no more than (n) words apart from the second word. For instance, precision PRE/3 forestry will find documents in which precision appears before forestry by no more than three words. Those keywords were combined considering other 3 spatial and 2 temporal variables having a total of 6 different keywords combinations (3 spatial *per* 2 temporal). The 3 spatial

variables were: world (no additional keywords selected), 28 countries members of European Union (EU) (adding AFFILCOUNTRY before each of the 28 EU country names) and Italy (adding AFFILCOUNTRY Italy). The 2 temporal variables were: the period ranging from 2000 to 2009 (PUBYEAR > 1999 AND PUBYEAR < 2010) and the period ranging from 2010 to 2016 (PUBYEAR > 2009 AND PUBYEAR < 2017). The Scopus search was conducted on January 2017 and for this reason 2016 publications were not yet completely introduced in the Scopus data base by the Scopus staff and could result underestimated. However, it should be noted that due to Scopus limitations, some sources could be missing in the research. In fact, Scopus only analyzes the citations of the journals in its index and it has a bias in its coverage of European journals Elsevier titles. The search was restricted to publications written in English, therefore the study is biased in favor of studies published in this language and might exclude regionally important research published in other languages.

### **Bibliometric mapping and clustering**

Several bibliometric maps were created on retrieved publications, using the VOSviewer software version 1.6.5.0 (freely available at [www.vosviewer.com](http://www.vosviewer.com)). This software was specifically developed for creating, visualizing and exploring science's bibliometric maps (van Eck and Waltman 2010). Using VOSviewer the so-called term maps were produced. A term map, also called co-word map, is a two-dimensional representation of a research field, in which strongly related terms are located close to each other and less strongly related terms are located further away from each other. Thus, term maps provide overviews for identifying the structure of a topic. Thanks to natural language processing techniques and a linguistic filter employed by the software, terms occurring in titles, abstracts and keywords of publications were extracted and located in the map in form of circles (van Eck and Waltman 2011). Only terms occurring at least ten times were taken into consideration and extracted from the retrieved publications.

To display the elements on the maps, the software uses the VOS (*Visualization Of Similarities*) mapping technique, that is closely related to the well-known multidimensional scaling method (van Eck and Waltman 2010). The idea of VOS mapping technique is that of minimizing a weighted sum of squared Euclidean distances between all pairs of items through an optimization process. This mapping approach allows to lay out terms on the map following the distance between each pair of terms that represents their similarity as accurately as possible. In a term map, similarities among terms are calculated based on their number of co-occurrences in the title or abstract of the same publication (for further explanation regarding the method please see van Eck and Waltman 2010; Nardi et al. 2016). The larger the number of publications in which two terms co-occur, the stronger the terms are related to each other. Therefore, terms that often co-occur in the same publications are closely located to each other in a term map while less strongly related terms are (low co-occurrence) located far away from each other. Each term is represented by a circle, where its diameter and the size of its label indicate the number of publications that have the corresponding term in their title, abstract or keyword. Once terms are located in the map, the next step is to identify clusters of related terms. The software uses a weighted and parameterized variant of modularity-based clustering called VOS clustering technique (Waltman et al. 2010; Waltman and Van Eck 2013). The assignment of terms to the same cluster depends on their co-occurrences in the title or abstract of publications. More specifically, terms that often co-occur are strongly related to each other and are assigned

automatically to the same cluster. On the contrary, terms with a low co-occurrence or no-occurrences at all, are assigned into different clusters. A cluster that is made up of terms of the same colors can be understood as a research theme in which one or more research topics can be identified. Although VOSviewer offers the possibility to change the number of clusters by changing the resolution parameters, the default setting of one was used. In addition, the resulting cluster are automatically colored into the map, but if desired the colors of the clusters can be changed interactively. Hereafter, it will be referred to maps displaying clusters as term maps. In addition to the clusters maps, a term citation and a term year map was also produced. The former was constructed to analyze the scientific impact of specific topic, whereas the latter was constructed to perform a timeline analysis of the research topics.

In the term citation maps the color of a term is determined by the average citation impact of the publications in which the term occurs; specifically, colors reflect the average citation impact for the term rather than by cluster. To avoid bias related to the age of a publication, the number of citations it received is divided by the average number of citations of all publications appearing in the same year. This produces a publication's normalized citation score ranging from 0 to 2, where the colors are assigned according to these scores. The colors ranged from blue (average score of 0) to green (average score of 1) to red (average score of 2). Therefore, a blue (cold) or red (hot) term indicates that publications in which the term occurs have low and high average citation impacts, respectively (van Eck et al. 2013); in the case of term year maps, the earlier (blue) or later (red) years when the term appear. In the term year maps, the color of a term indicates the average publication year of all the publications in which the term occurs. As for the term citation map, colors were used that range from blue (score of 2006 or earlier), to green (score of 2008) to red (score of 2010 or later). Therefore, blue terms are those occurring mainly in older publications. On the other hand, if a term is colored red, the term occurs mainly in publications that are more recent. To avoid overlapping labels, only a subset of all labels is displayed in the maps.

Before starting with the analysis in VOSviewer, a thesaurus file (text file) was created to ensure consistency for different spelling and synonyms (an example: Real Time Kinematic was changed to RTK). VOSviewer offers also the possibility to clean the data by omitting those terms considered not relevant for analyses through a selection mask. Using such functionality, the research group streamlined the thesaurus omitting terms related to time, publishers' names and geographical locations (i.e., names of cities or countries) or terms that could be used ambiguously (an example: addition or view). However, it should be noticed that a term map represents a simplified version of the reality and this can lead to loss of information and to a partial representation of the investigated field (van Raan 2014). This limitation should be considered when interpreting a term map.

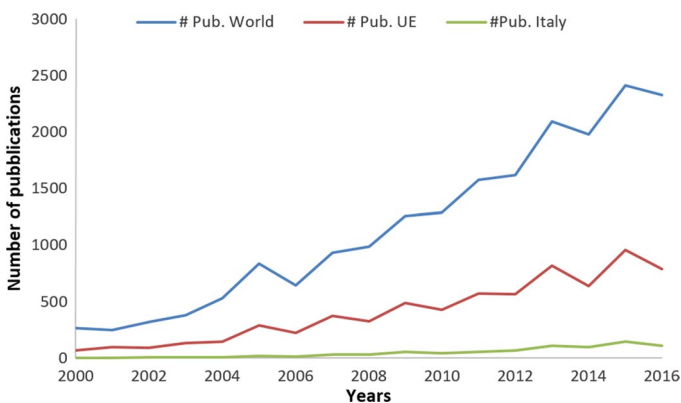
## Results

### Publication trends

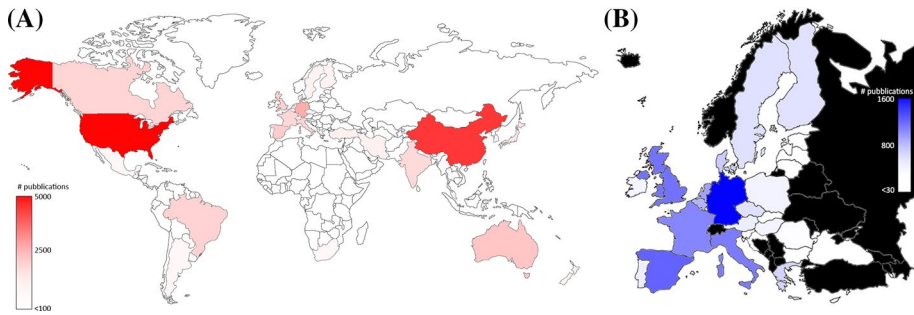
A total of 17,756 scientific publications were retrieved from Scopus database over 17 years among which 6947 and 820 from EU countries and Italy respectively. Approximately, 62.8% of them were research papers, 29.8% were conference papers, 4.2% were review papers, 2.6% were book chapters and the remaining 0.6% were books. Altogether, 126

**Table 1** Top 20 sources of publications on precision agriculture from 2000 to 2016

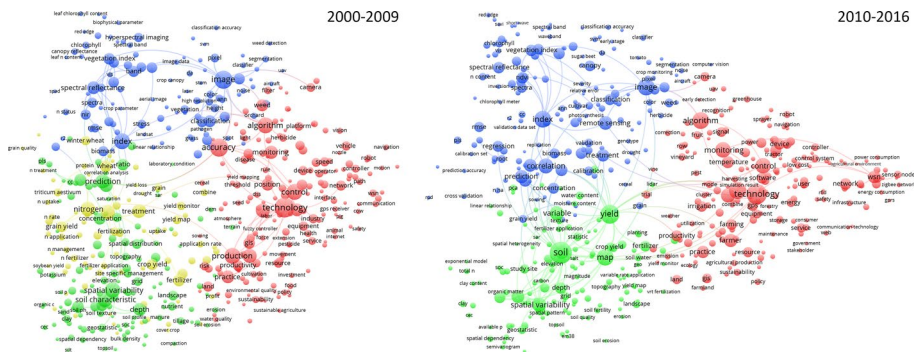
Source	<i>N</i>	%
Computers and Electronics in Agriculture	692	7.2
Precision Agriculture	655	6.8
Nongye Gongcheng Xuebao - Transactions of the Chinese Society of Agricultural Engineering	456	4.7
Proceedings of SPIE (The International Society for Optical Engineering)	344	3.6
Nongye Jixie Xuebao - Transactions of yhe Chinese Society for Agricultural Machinery	342	3.6
Agronomy Journal	316	3.3
Biosystems Engineering	269	2.8
Geoderma	228	2.4
Transactions of the Asabe	188	2.0
International Geoscience and Remote Sensing Symposium IGARSS	182	1.9
International Journal of Remote Sensing	180	1.9
Remote Sensing	167	1.7
Sensors Switzerland	162	1.7
Applied Engineering in Agriculture	158	1.6
Remote Sensing of Environment	155	1.6
Soil Science Society of America Journal	150	1.6
Field Crops Research	148	1.5
Acta Horticulturae	145	1.5
Transactions of The American Society of Agricultural Engineers	135	1.4
IFIP Advances in Information and Communication Technology	131	1.4

**Fig. 1** Trends in precision agriculture research publications from 2000 to 2016 in Italy, EU countries and world

journals have been involved in the field. The most active sources of publication were Computers and Electronics in Agriculture ( $N=692$ ; 7.2%), Precision Agriculture ( $N=655$ ; 6.8%), Transactions of the Chinese Society of Agricultural Engineering ( $N=456$ ; 4.7%) (the top 20 journals were reported in Table 1). Figure 1 depicts the PA publication frequencies from 2000 to 2016 in Italy, EU countries and world. With regard to the total works



**Fig. 2** Maps of the world (a) and EU (b) countries. The color intensities are related to frequencies of publications In the B map, black countries do not belong to EU



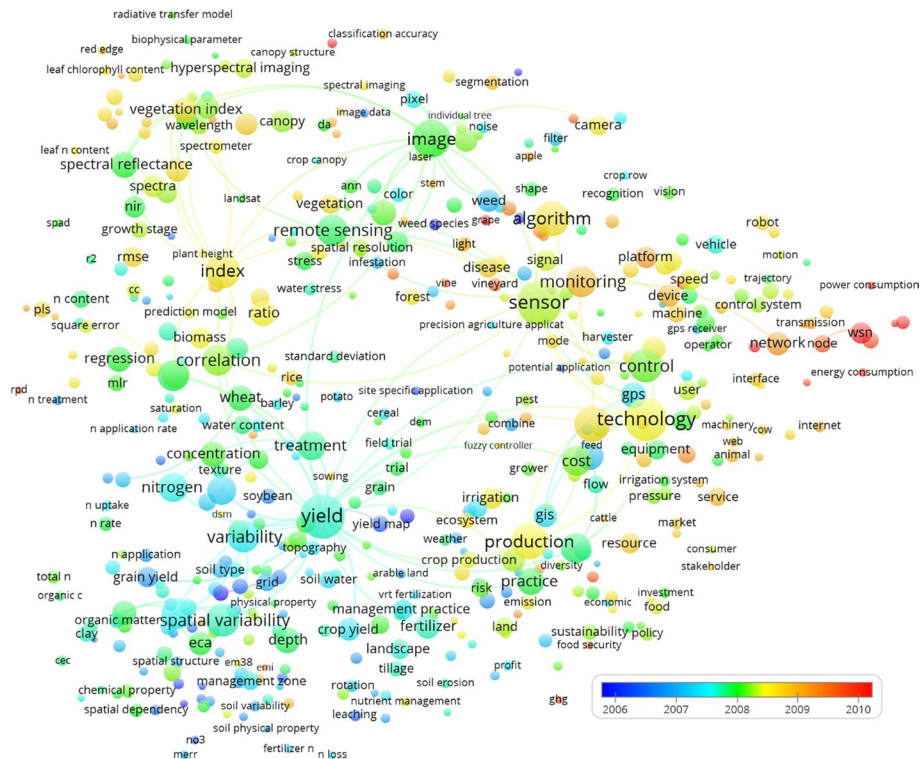
**Fig. 3** Term maps based on world precision agriculture publications from the time slice 2000–2009 and 2010–2016. Lines (100) indicate co-occurrence links between terms

published till 2016 (100%), the number of publications relative to the period 2000–2009 accounts only for around 32% for EU countries and world, while it was equal to 21% for Italy. The number of publications generally increased after 2006.

One hundred and forty-five countries publishing at least one publication related to PA research. Figure 2 represents the world and EU countries where the color intensities are related to frequencies of publications. The world situation shows that USA published 19.7% of total publications ( $N=2601$ ), followed by China (15.6%,  $N=3900$ ), Germany (6.4%,  $N=1590$ ) and Australia (4.4%,  $N=1111$ ) (Fig. 2a). The EU situation shows that Germany published 18.9% of total EU publications, followed by Spain (11.6%,  $N=975$ ), United Kingdom (10.4%,  $N=873$ ) and Italy (9.8%,  $N=820$ ) (Fig. 2b).

### World evolution of research topics and their citation impacts

Figures from 3, 4 and 5 respectively represent the term maps (Fig. 3), term year map (Fig. 4) and term citation map (Fig. 5) from 2000 to 2016. In the term maps colors are used to identify clusters of related terms, while in the citation map the colors indicate the average citation impact of publications in which the term occurs while in the year map the colors indicate the timing for term occurrence (Table 2).

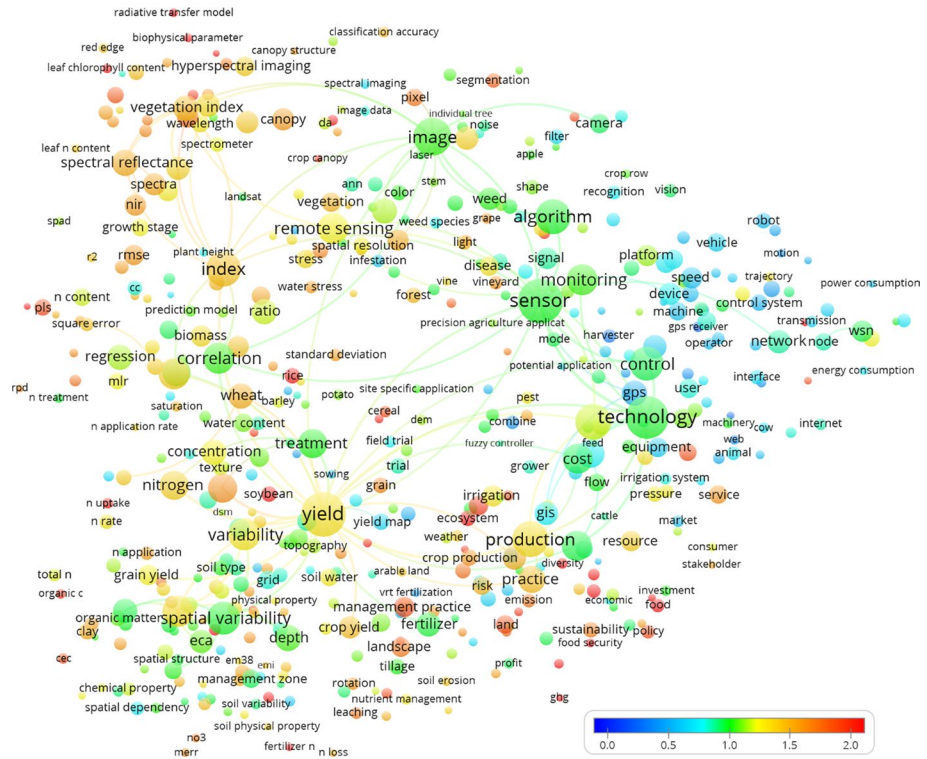


**Fig. 4** Term year map based on world precision agriculture publications ( $N=17,756$ ) from the time slice 2000–2016. The color of a term indicates the average publication year of all precision agriculture publications in which the term occurs (in the title or abstract). (blue and red represents earlier and more recent publications respectively). Lines (100) indicate co-occurrence links between terms (Color figure online)

Figure 3 shows the world term maps constructed for the period 2000–2009 (left side) and for the period 2010–2016 (right side). The about 500 terms displayed on the maps are grouped in four (2000–2009) and three (2010–2016) clusters. Clusters seem to be more overlapped in the earlier period, in details the green and yellow ones appear completely overlapped. Red clusters of both periods represent the technology and algorithm based terms (right side of both graphs); other important terms within the red cluster were “control”, “monitoring”, “algorithm”, “production” and “accuracy”. Blue clusters in both period represent the indices and image analysis related terms (upper-left side of both graphs). Green and yellow clusters of the 2000–2009 period tend to merge into the green cluster of the 2010–2016 map showing terms related to soil and yield.

The number of terms appear almost equal in both periods (510 vs. 495), slightly increased in the red cluster (from 185 to 197), definitely decreased in the green-yellow cluster (from 217 to 133) and decisively increased in the blue one (from 108 to 165). The important decrease of the yellow-green cluster was mainly due to the decreasing of terms related to fertilization and nitrogen. Within the red cluster, in the recent period, it is possible to observe, on the right side, a more distinct sub-cluster including terms related with networks (i.e., “wsn” for wireless sensor network, “sensor node”, “zig-bee network”). In the same cluster, animal farming and forestry terms are both slightly





**Fig. 5** Term citation map based on world precision agriculture publications ( $N=17,756$ ) from the time slice 2000–2016. The color of a term indicates the average citation impact of the publications in which the term occurs, where blue, green and red represent a low, average and high citation impact respectively. Lines (100) indicate co-occurrence links between terms (Color figure online)

represented although not visible in figure due to the zoom level. In the blue cluster, it is possible to observe a trend toward an increasing and better definition of statistical terms and techniques (lower area of the blue cluster) and of hyperspectral related terms (top-left area of the blue cluster). From the period 2000–2009 (Fig. 3a) to the recent one (Fig. 3b) it is possible to observe as the three main clusters tend to separate. Such a phenomenon can be ascribed to the external sub-clusters: networks related terms (on the right of the red cluster), hyperspectral related terms (on the top-left of the blue cluster) and geostatistics related terms (on the bottom-left of the green cluster).

Figure 4 shows the trend in type of research over the period 2000–2016. It is possible to observe how the earlier terms (bluish in Fig. 4) are related to the green-yellow cluster in Fig. 3 (i.e., terms related to soil and yield). The later terms (reddish in Fig. 4) are mainly related to networks (sub cluster on the right side of the red cluster in Fig. 3), precision viticulture and other sparse ones, such as “ghg” (i.e., greenhouse gas), “rpd” (i.e., ratio of percentage deviation; Infantino et al. 2015), “classification”.

The world citation map revealed highly cited terms such as “food”, “farm level”, “environmental impact” in the central bottom side of the graph, “soil variability”, “N fertilizer” in another part of the same area, “leaf chlorophyll content”, “biophysical

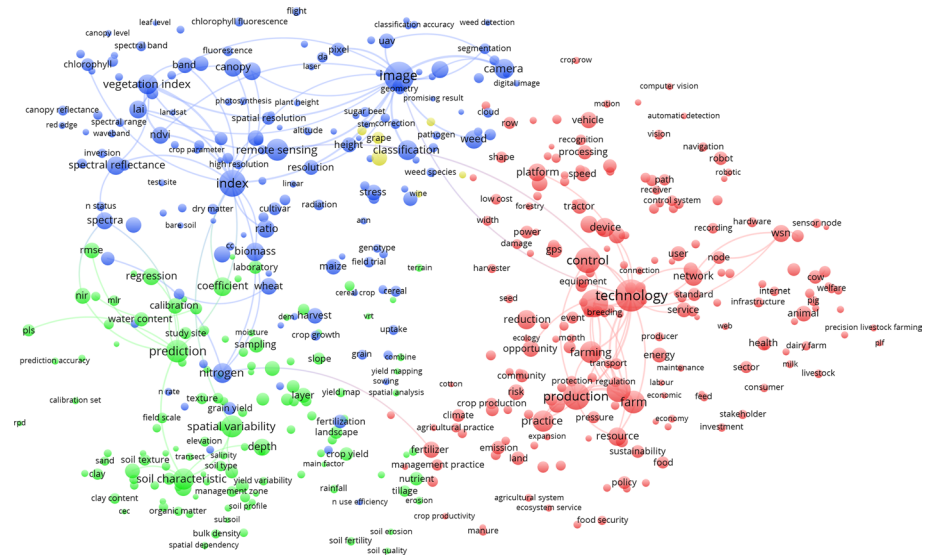
**Table 2** Top 20 countries publishing on precision agriculture from 2000 to 2016

Country	<i>N</i>	%
United States	4949	19.7
China	3900	15.6
Germany	1593	6.4
Australia	1111	4.4
Spain	976	3.9
United Kingdom	879	3.5
Brazil	858	3.4
Italy	820	3.3
Canada	811	3.2
France	757	3.0
India	725	2.9
Netherlands	605	2.4
Belgium	487	1.9
Japan	462	1.8
Denmark	355	1.4
Malaysia	302	1.2
Greece	300	1.2
Iran	267	1.1
Israel	257	1.0
Turkey	244	1.0

parameter”, “radiative transfer model” in the upper-left side of the image and “rice” in the center of the map (Fig. 5).

### EU situation of research topics

Figure 6 shows the EU term maps constructed for the whole period 2000–2016. The about 500 terms displayed on the maps are grouped in four clusters. Like Fig. 3, a red cluster representing the technology related terms, was on the right side of the graph; other important terms within the cluster are “control” and “production”. A blue cluster, representing the indices and image analysis related terms, is positioned on the upper-left side of the graph. A green cluster, representing terms related to soil and spatial variability is positioned on the lower-left side of the graph. A fourth small yellow cluster, absent in the world map (Fig. 3), representing precision viticulture terms, is positioned within the blue cluster. Although viticulture appears in the world maps, here it clusters separately underlining its importance in EU (were Italy, France and Spain lead the segment) with a total production representing the 55.7% of the world wine production in 2015 (European Commission 2017). Apart from the yellow cluster, green and blue clusters are partially overlapped. Considering a similar number of total terms extracted from world and EU papers (around 500), and being EU a subset of world, and considering the whole period (2000–2016), the number of terms of the red cluster is higher for EU countries (209 vs. 168), while the number of terms of the green cluster is decisively lower (126 vs. 177) and the number of terms of the blue cluster is approximately the same (156 vs. 153). With respect to the world situation (Fig. 3), in EU animal farming, livestock and related terms are of greater importance,



**Fig. 6** Term map based on EU precision agriculture publications from 2000 to 2016. Lines (100) indicate co-occurrence links between terms

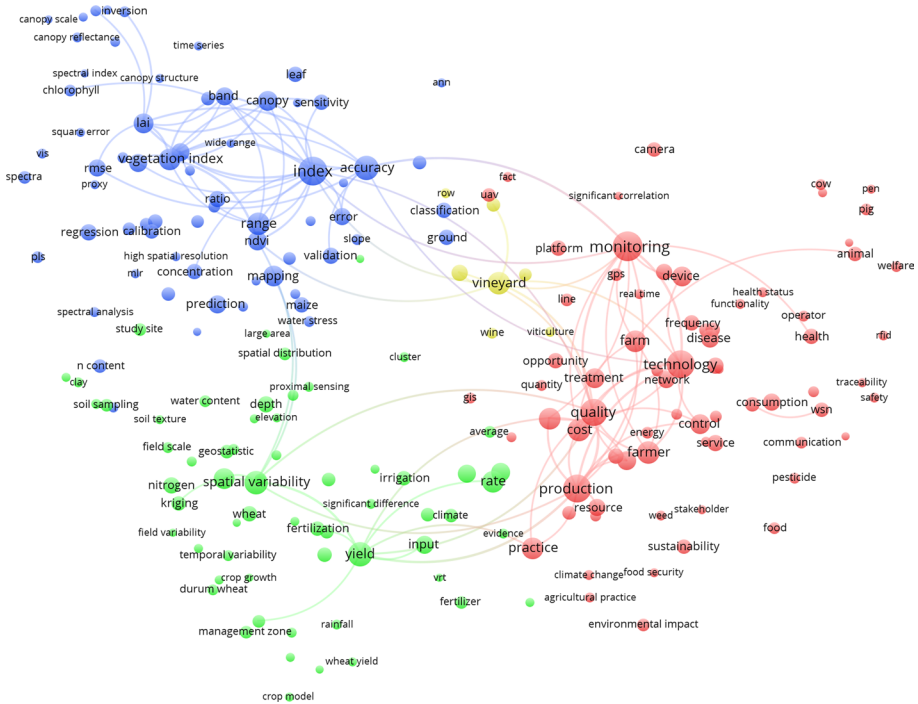
viticulture showed a greater importance acquiring an own cluster, while rice and forestry related terms are less important. In EU, it seems that environmental topics, such as climate change, are more present. The statistical terms (well represented in the blue cluster in the world map), in EU situation are placed in the green cluster, even if largely overlapped with the blue one.

### Italy situation of research topics

Figure 7 shows the Italy term maps constructed for the whole period 2000–2016. The about 200 terms displayed on the maps are grouped in four distinct clusters. Similarly, to Figs. 3 and 6, a red cluster, representing the technology related terms was on the right side of the graph; other important terms within this cluster were “monitoring”, “quality” and “production”. A blue cluster, representing index and related terms, is positioned on the upper-left side of the graph. A green cluster, representing terms related to spatial variability is positioned on the lower-left side of the graph. Similarly, to the EU situation (Fig. 6), a fourth small yellow cluster, absent in the world map (Fig. 3), representing precision viticulture terms, was positioned between the red and the blue clusters. Like in EU, animal farming terms were positioned in a slightly separated sub-part (extreme right side) of the red cluster. There are no clear terms related with precision forestry.

### Discussion

PA research includes a wide area of scientific topics and involves all kind of plant, animal (including aquaculture), forest, food and fiber production. It could be also easily observed how, while precision agriculture is an affirmed and increasing discipline, the principles of



**Fig. 7** Term map based on Italy precision agriculture publications from 2000 to 2016. Lines (100) indicate co-occurrence links between terms

PA applied in forestry (precision Forestry; Corona et al. 2017) and aquaculture are still under-developed. Despite this complexity, three main groups of terms related topics were identified: (red) a group of closely related research generally linked to the term “technology”; (blue) a second one related to the terms “indices” and “image analysis”; (green) a third one related to the terms “soil” or “spatial variability”. This result indicated that a common approach in the research structure exists in each of the sets were examined. It seems that scientists all over the world tend to specialize their research according to a similar approach that entails three main specializations of investigation. The first one—technology—can include studies carried out following a technological based research, in the subjects typically covered by agricultural engineering; the second one, may entail the contribution of wider range of scientific competences, mainly related to computer sciences; the last one—soil, spatial variability—suggests a more classical agronomical and field study.

Nevertheless, some differences can be observed comparing the different considered periods (2000–2009 vs. 2010–2016) and the different geographical areas. Generally, a separation trend among the three clusters was shown. A clearer definition of term groups can be seen during the considered periods, with an increased separation of researches with statistical terms and methods. This can be simply related to the fact that along with the increasing number of works and experiments (and publications), scientist need more often to verify the statistical significance of their results. Geostatistics represents a well-known fundamental tool in PA, as reviewed by Schueller (2010). In this work, geostatistical related terms, represented in the bottom-left side of Fig. 3b, and remains strictly

related to soil mapping terms (green cluster). However, the appearance/raising importance of some terms, (e.g., “em38” and “semivariogram”) testify the increasing specialization in this research area. Similarly, the sensor network red sub-cluster (Fig. 3b) still owns to the technological main area but seem to have a leverage effect on the cluster separation. As reported by Anisi et al. (2015), wireless sensor networks represent a crucial technological advancement with several practical applications for PA purposes such as global-scale environmental monitoring, pest and disease control and animal tracing. This is confirmed also by its latest appearance in Fig. 4. As pointed out above (for the whole period 2000–2016) EU scores a substantial higher number of terms with respect to the world for the red cluster that could be ascribable to a smaller average farm size. This may have driven the research towards technological aspects while large farm size in other countries doing a substantial amount of precision agriculture research may justify the increased demands for indexing and mapping solutions. The green cluster instead shows (for the same period) in EU and World the opposite situation which may be read as the need to manage on average the spatial variability of larger farming areas.

The study provides some maps that could be interpreted giving useful information. An interesting result, for example, evidenced how, in Fig. 3, some technical terms appear, or drastically increase their importance later, such as ZigBee, ANN (Artificial Neural Networks), lidar and the ground conductivity meter (em38), some other, such as SPAD, which is one of the earliest electromagnetic sensor, tend to disappear. Other observations could be done observing the position of the crops in Figs. 4 and 5. The centrally positioned terms (potato, cereals, grape, forest) are cross-related to all the surrounding areas and therefore likely to be investigated from several scientific points of view. The same observation can be made regarding physical instruments such as lidar. Other species such as apples, instead, appear positioned close to specific terms. In particular, in Figs. 4 and 5, “apple” term is close to “shape” and “image”, evidencing some specific linkages to these kind of analytical techniques: image analysis and shape analysis (Costa et al. 2011). Policy appears to be in relation with closely surrounding terms such as “food security”, “sustainability”, “environmental impact”, “climate change” and “greenhouse gas” (Figs. 4, 5). This specialized group underlines hot terms positioned in the bottom-central side of the figures, which are recent and highly cited.

Moreover, term analysis, reflecting the research efforts into the various topics of investigations, seems to be able to properly describe the specific condition of European and Italian agricultures. In fact, some specific terms, not clearly showed examining the world situation, are visible in the analysis of European and Italian research. For example, in the European studies, terms like “livestock”, “animal farming” and other related terms showed a greater importance with respect to the world group. The terms related to “precision viticulture” constitute a separate cluster, both in Europe and in Italy, this crop being one of the most profitable and specialized agricultural enterprises in those areas. As for Italy, a notable importance is reached by the term “quality”, once again a clear indication of a specific characteristic of Italian agri-food sector. Quality of products and innovation are the main drivers of competitiveness of Italian Made in Italy on the global market (Caiazza and Volpe 2014). Indeed, Italian products have often been associated with quality, high specialization and differentiation being labelled with one (if not the highest) number of Protected Designation of Origin (PDO), Indication of Geographical Protection (IGP), etc. Moreover, in Figure a yellow cluster representing the viticultural sector appears, likely due to the importance wine represents, both culturally and economically. Italy, in fact, has recently moved up the ranks to again become again the largest wine producer in the world, producing nearly 50 million of hl in 2015 (Wine Institute 2017). The growth of PA viticulture

research in the EU is an example of regional research specialization, which lead to technological driven farming system, characterized, for example, by mapping (grapes maturity determination, soil and plant analysis through advanced sensors sampling) and VRT technologies (Matese and Di Gennaro 2015).

## Conclusion

The study contributes to a better understanding of PA research structure, showing the main lines of research and their evolution during the last years. This paper identifies issues that have been resolved and research efforts that have moved to other areas such as basic studies on spatial variability (e.g., yield mapping). The researcher attention regarding these topics may have become unfashionable with some funding agencies. This could be due to a high Technology Readiness Level (TRL) determining a certain amount of research to move towards other research areas (e.g., new algorithm, sensors development and application on platform for automated monitoring). Indeed, the agricultural engineering sector requires very specific and high level TRL researches. One of the main goal of this work is represented by these findings stimulating researchers towards more actual topics. To our knowledge, it represents the first attempt to apply term mapping analysis to the Precision Agriculture field. Through the analysis of 17,756 publications published from 2000 to 2016, it is possible to conclude the following findings: (i) the number of scientific publications continuously increased during the considered period showing the fast growing of the discipline; (ii) U.S.A. and China are still the leading countries in term of number of papers published (35.3% of the total publications); (iii) three main research specialization areas were identified: a first one more related to agriculture engineering; a second one mainly assigned to computer science related to both, the interactions among ICTs (Information and Communication Technologies) and sensing and data analysis strategies; a third one associated to agronomical studies; (iv) the term analysis can highlight specific features of regional agricultural production (e.g., viticulture) being present as specific cluster of terms.

As the first bibliometric study of precision agriculture research, this analysis is exploratory and more adept at generating hypotheses than testing them. Among the hypotheses generated, is noticeable a research trend towards sustainability and climate change. Moreover, some of the research topics observed (e.g., field and yield mapping) seems to lose their attractiveness in favor of newer topics (e.g., sensors and indices development and applications). Another hypothesis regards the identification of PA research relevant at nation level inherent specific crops with strong applicability (e.g., viticulture in Italy).

Nevertheless, there are some limitations in the term map analysis regarding both the production and the exploration of results. The interpretation of a bibliometric map is not always straightforward. There are mainly two kinds of limitations with the use of such a technique: those generated by the data and those imposed by the map. During the creation of the bibliometric dataset, the records availability could be limited, and those data could contain a certain amount of noise (mainly due to the arbitrary keywords' choice for the primary search). Another kind of problem that could arise is represented by the synonyms and homonyms (although this is normally solved with an accurate thesaurus realization). The visualization through maps is normally used for orientations using a simplified representation of reality. Such a representation implies a loss of information. VOSviewer generate a certain loss of information due to the two-dimensional representation of the terms in an Euclidean space. Despite these limitations, depending on researcher errors

and bibliometric mapping constrains, term map analysis represents a valid tool to support experts to improve their knowledge on a certain domain. Future studies may address related issues such as the analysis of collaborations among different actors (i.e., authors, organizations and countries) as well as a deeper characterization of the research carried out in different geographic regions.

**Acknowledgements** This paper was funded with the contribution of the Italian Ministry of Agriculture, Food and Forestry Policies (MiPAAF) project AGROENER (D.D. n. 26329). All the authors equally contribute to the writing of the paper and to its content.

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