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Systematic literature review of implementations of precision agriculture

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ABSTRACT

Agriculture production highly depends on water and soil factors which increasingly need to be utilized efficiently. Precision agriculture, through the set of information technologies that it uses, allows to effectively manage these resources. This work aims to gather the existing knowledge on technologies used in precision agriculture and ways to discern the most appropriate one for different contexts in agricultural processes. A systematic literature review is performed to identify precision agriculture implementations and to answer questions such as the type of technologies used, criteria for their comparison and selection, and the existence of frameworks that help to decide what technologies to implement. A total of 3,949 publications were reviewed, of which 259 addressed the posed research questions. The findings are that remote sensors are the most used technology, the required knowledge is an important criterion for deciding to implement precision agriculture, and no framework was found that guides its implementation.

1. Introduction

Nowadays, there have been important concerns regarding the long-term impact of soil and water supplies, because they are no longer considered inexhaustible or plentiful resources. Here, it has been observed that Precision Agriculture (PA) can often help to maximize these and other resources with the objective of minimizing losses and waste. In addition, PA can increase the yield of crops, as well as reduce the variability and input costs. PA describes a suite of Information Technologies (IT) and is focused on producing immediate benefits by being conscious of the environment (Yost et al., 2017).

IT used in precision agriculture allow to collect different data of the land which permits farmers to recognize temporal and spatial variations in the production resources, facilitating the application of the necessary treatments with a greater precision (Aubert et al., 2012). Some of the potential benefits of PA are to reduce costs by only applying fertilizer where they are required, based on soil samplings and analysis of the yield data, or to improve the management of water resources, optimizing the performance through automated harvesting practices (Mintert et al., 2016).

In addition, the use of IT contributes to an adequate decision making, from the point of view of the technical-productive, economic and environmental management. Instead of managing a whole land based on a hypothetical average condition, which may not exist anywhere in the field, a PA implementation uses a wide variety of technologies that collect site-specific data and applies site-specific management practices (Paxton et al., 2011; Rodríguez et al., 2017).

PA greatly helps farmers who require to optimize their resources. However, to date, its adoption rates remain below expectations (McConnell, 2019; Pathak et al., 2019; Higgins et al., 2017). Among the reasons for this is that the initial investment required to implement PA technologies and procedures is considerable and that this is a long-term investment. Moreover, the complexity of the novel IT that are used in PA implies a greater degree of learning skills for their correct adoption and management (Pathak et al., 2019), which varies among every individual and can thus affect an appropriate implementation (Orozco and Ramírez, 2016). There are many technological solutions offered in the market which fulfill distinct functions and can be combined with each other. However, farmers are required to possess a minimum knowledge to appropriately select the right combinations among the available IT (Higgins et al., 2017).

In most cases, each land presents unique management characteristics so not every IT will help to determine the causes of variability among them and it would be expensive to implement all IT right away. To avoid this, it has been recommended to use an incremental approach for their implementation as it has shown to currently be the best strategy. This strategy considers the incorporation of one or two technologies for every iteration and carefully evaluating the results (Tripathi et al., 2013; Shannon et al., 2018).

Given the above, a Systematic Literature Review (SLR), based on the

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original guidelines proposed by Kitchenham and Charters (2007), has been performed with the objective of identifying the IT used in precision agriculture that are presented in literature, as well as criteria for their comparison and selection and frameworks that help in the decision process for choosing the adequate IT for the different contexts and characteristics of an agricultural process. This information could prove to be useful for experts in the area, such as researchers, students and farmers interested in incorporating technologies when faced with the problem of selecting the most adequate technologies to implement in a farm, or for IT suppliers when they need to recommend an IT to their clients.

This publication extends from a previous work that has been presented during the III International Conference on Agro BigData and Decision Support Systems in Agriculture (BigDSSAgro 2019) (Cisternas et al., 2019). Here, a more extensive and detailed analysis has been realized over the set of publications selected during the SLR, allowing the generation of additional graphic material as well as the findings obtained from a more in-depth review.

The remainder of the publication is organized as follows: Section 2 expands on the motivations behind the realization of this study. In Section 3, the selected research methodology, that is, a SLR, is described and its planning and realization are presented, whereas its results are shown in Section 4. A discussion about the main findings of the review is given in Section 5. Finally, Section 6 provides the conclusions and future work.

2. Motivation

Precision agriculture is a management strategy that utilizes information technologies to collect useful data from distinct sources, with the aim of supporting the decisions associated to the production of crops. It consists on recognizing, locating, quantifying and recording the spatial and temporal variability of every agricultural unit. This way, it is possible to provide a differentiated agronomic management for every specific site (Lizarazo Salcedo et al., 2011). PA emerged in the early 80s and is characterized by allowing to efficiently utilize resources, reducing unnecessary money investments and environmental contamination, and obtaining benefits from the economic, social and environmental areas (Li and Zhao, 2010; Min et al., 2011).

Precision agriculture includes all of the production practices that use IT for adjusting the use of supplies so that it is possible to obtain the desired product, or for monitoring the result. Some examples of IT for PA are variable rate technologies, yield monitors and the various kinds of sensors (Marote, 2010). The technologies utilized by PA include both hardware devices and software systems that process the data captured by the devices, providing the necessary information for the decision making processes.

Some of the most relevant benefits of PA are the reduction in the use of water, fertilizers, herbicides and pesticides, as well as the required workforce. Instead of managing the whole field based on hypothetical average conditions that may not really be true to reality, a PA approach recognizes the specific differences of the lands and adjusts the required management actions based on this. PA offers the potential of automatizing and simplifying the gathering and analysis of information. It even allows quickly deciding and implementing management actions for small areas in big fields (Llumipanta et al., 2015; Tripathi et al., 2013).

Despite of all the benefits that are provided by PA, it has been observed that its current adoption rate is not high (Melchiori et al., 2013; McConnell, 2019). This is due to distinct factors, where a lack of knowledge on the use of PA plays an important role, for instance: (i) the farmer can tend to favor investing on other technologies, such as seeding improvements, assuming that it would be of greater help than PA (Schimmelpfennig and Ebel, 2011), (ii) PA adoption can be seen as a too complex and multidimensional process (Pathak et al., 2019), and (iii) it is necessary to adequately select the proper IT solutions for the farmer's needs (Higgins et al., 2017), .

Regarding the latter point, it is important to highlight that distinct IT provide different benefits and possess different needs that must be addressed (Nair, 2011). A previous study shows that the relative advantages of PA technologies are a major determinant for farmers to adopt PA (Pathak et al., 2019). However, the costs associated to the implementation of PA must also be considered, as some technologies require a significant investment (Schimmelpfennig and Ebel, 2011). An strategy for addressing this is to use an incremental approach for the implementation, evaluating the benefits obtained from the implemented IT on each cycle (Tripathi et al., 2013; Shannon et al., 2018). However, the problem regarding the required knowledge about what IT would be the best fit for each crop still remains as an issue.

Thus, with the motivation to address the above issues, the objective of this study is to perform a systematic literature review that identifies the IT that have actually been used in PA, as well as the existing implementations of PA in literature, and the criteria that have been used for comparing and selecting the distinct IT, including frameworks and tools that use these criteria. The identification of this information can help to find trends on the use of the various IT for the distinct implementations, as well as to systematize the decision process that is required to adopt PA.

3. Research methodology

This study has been performed as a systematic literature review by adapting the guidelines of Kitchenham and Charters (2007). The goal was to obtain knowledge about the main information technologies used in precision agriculture, as well as documented implementations of PA. In addition, the SLR was also used for identifying comparison and selection criteria that allow to guide the implementation of precision agriculture.

A SLR differs from traditional literature reviews mainly because they are formally planned and executed systematically and methodically. A good review must be independently replicable, which gives them greater scientific value. Moreover, by finding, evaluating and summarizing all available evidence on a specific research topic, a high level of validity can be obtained through their conclusions (Genero Bocco et al., 2014). Fig. 1 illustrates the process carried during this review.

First, the planning of the review was performed, which considered the establishment of the need for research and the definition of the search and review protocols. Two supervisors analyzed this planning and assessed its adequacy. Subsequently, a general search was conducted on the different sources specified during the review planning. This search was done both in English and in Spanish, with the objective of achieving a greater scope. From the search results, a partial review was performed, obtaining a list of potentially useful publications. Duplicate publications were then removed. Finally, the remaining ones were analyzed in-depth and the list of useful publications for this research was obtained.

The planning and realization stages of the review are described next, whereas the analysis of results is presented in Section 4.

3.1. Planning of the systematic literature review

The objective of the review was to identify existing proposals for the use of IT in the context of precision agriculture in literature, as well as detecting criteria for their comparison and selection. Additionally, the possible existence of a framework that uses these criteria was also surveyed. Based on this objective, the following research Questions (Q) were formulated to define in more detail the need for research:

Q1. What technologies are used in precision agriculture?
Q2. What implementations of precision agriculture are recorded in literature?

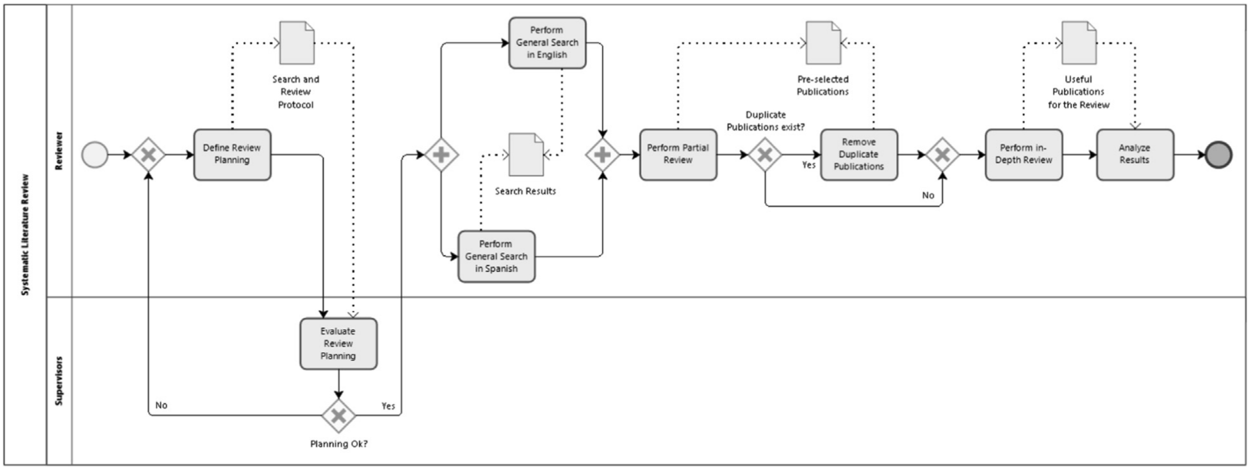

Fig. 1. Process taken for performing the Systematic literature Review.

Q3. What criteria exist to compare and select the technologies used in precision agriculture?
Q4. Is there a framework that guides the implementation of precision agriculture?

In order to perform the SLR, sources with relation to the addressed topic were used, specifically: Scopus (https://www.scopus.com/), Springer Link (http://link.springer.com/), Science Direct (http://www.sciencedirect.com/) and the National Agricultural Library (https://www.nal.usda.gov/). Google Scholar (https://scholar.google.com/) was also used to extend the research for potentially useful publications that were not indexed in the sources mentioned above.

3.1.1. Search protocol

The protocol that was used to perform the search in the sources defined above is described next. The Terms (T) and their Combinations (C) that were used for the review were specified as shown in Table 1.

Some general guidelines were defined for conducting the search in each of the sources, namely:

- In some cases, search terms may be entered in a scaled manner, restricting the results of a previous search.
- For each search performed, the first 200 results will be reviewed.
- The search results have been restricted to publications from 2010 onwards.
- If the search results have restricted access, the publication must be searched by alternative means (for example, in the personal sites of the authors).

A reference manager was used for recording the search results and their sources. In addition, the results of each search were recorded in a table containing, for each search, the source, the combination of terms, the number of publications found and the search date. For each entry in the table described above, another table was used to record the reference of each reviewed publication, its acceptance or rejection and, for the accepted publications, a brief description and the addressed research questions.

Table 1
Terms and combinations for the review.

Terms	T1: Intelligent Agriculture	T4: Implementation	T7: Analysis
	T2: Precision Agriculture	T5: Comparison	T8: Decision
	T3: Technologies	T6: Selection	T9: Framework
Combinations	C1: T1 or T2		
	C2: (T1 or T2) and (T3 or T4)		
	C3: (T1 or T2) and (T3 or T4) and (T5 or T6 or T7 or T8)		
	C4: (T1 or T2) and (T3 or T4) and (T5 or T6 or T7 or T8) and T9		

3.1.2. Review protocol

The protocol for reviewing the publications is described next. First, a partial review was conducted in order to obtain potentially useful publications for this research. This was done by reviewing the abstract of each publication. Only if necessary, the introduction and conclusions were also read, as well as part of the body of the publication, for some specific cases. Once each review was made, the decision to include or not the publication as a potentially useful one was taken, taking into consideration the criteria of this protocol. Control of the accepted and rejected publications was maintained by recording their information in tables.

It was defined that any publication related to any of the research questions would be included. On the contrary, any publication that contained the search terms or combinations of them, but did not contain relevant information for this research, was excluded. Subsequently, an in-depth analysis of these potentially useful publications was carried out, by reading the entirety of the publication, and thus defining whether it answered any of the research questions. When applicable, the relevant information of the publication was extracted, such as the discussed IT, the crop and the data captured by the IT, among others.

3.2. Realization of the systematic literature review

During the realization of the systematic literature review, 40 different searches were carried out (5 sources and 8 combinations each, considering both the English and Spanish searches). For each search, 200 results were reviewed, but 20 of these gave less than 200 results and, among these, 15 did not provide any. Thus, a total of 3,949 publications were subjected to a partial review to find the potentially useful ones, which resulted in the pre-selection of 1,242 publications. Subsequently, repeated publications were removed, for a total of 863 potentially useful publications. After an in-depth analysis, it was determined that 593 of the publications were not relevant to the current research, so they were removed, leaving a total of 259 useful and accepted publications. Fig. 2 graphically shows this process.

4. Results

This section summarizes the results of the study. The general results are presented first, and every posed research question is addressed afterwards.

All of the selected publications answer at least one of the research

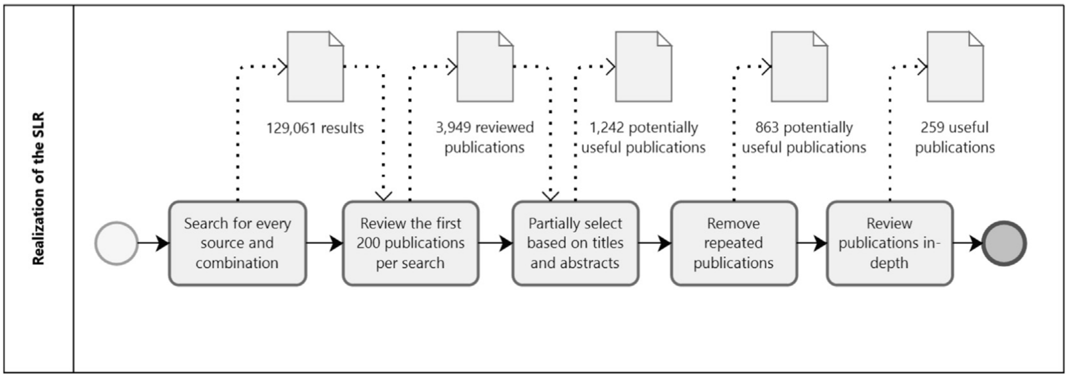

Fig. 2. Process taken during the realization of the Systematic Literature Review.

Table 2
Number of accepted publications through the SLR.

ID	Research Question	Publications
Q1	What technologies are used in PA?	257
Q2	What implementations of PA are recorded in literature?	122
Q3	What criteria exist to compare and select the technologies used in PA?	19
Q4	Is there a framework that guides the implementation of PA?	0

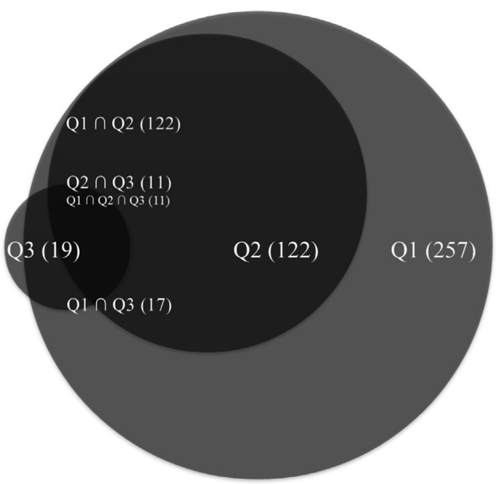

Fig. 3. Relations between the sets of publications that answer every research question.

questions. Table 2 shows the number of publications that answer each research question. Since the first question is general, almost all of the selected publications answer it. The other questions are increasingly more specific, so fewer publications that address them were found. Fig. 3 shows the relations between the sets of publications that answer every research question. For example, Smiljkovikj and Gavrilovska (2014) presents a GPS implementation in a corn field and also develops an information system. This publication addresses both Q1 and Q2, as it identifies the used technologies and also realizes a PA implementation. It should be noted that no publication that proposed a framework to guide the implementation of PA was found. A list containing all of the references for the accepted publications in this SLR can be found in the supplementary materials (http://colvin.chillan.ubiobio.cl/mcaro/cisternas/precision-agriculture/slr/).

A detailed analysis of the results, for every research question, is provided next.

4.1. Technologies used in precision agriculture

Among the selected publications, 257 of them help to answer this question to some extent. This is because IT are the basis of PA, thus providing the groundwork for the other research questions, so they have been reviewed more often in the literature. In addition, computer applications that have been developed to use the technologies more efficiently, that is, software, systems and techniques that are complementary to the use of IT, were found. These often need the use of IT as a prerequisite for capturing the necessary data for their functioning. Thus, the results of this research question can be divided into the technologies and the software used in precision agriculture. Fig. 4 shows the relations between the sets of publications that mention IT and software. On one hand, most of the publications focused on describing IT, while others only mentioned software. On the other hand, many of the publications presented the use of both IT and software. For example, Stoorvogel et al. (2015) belongs to the intersection of sets that use both IT and software, as it mentions sensors (an IT) and yield maps (a software).

A total of 10 IT were identified through the SLR. The function of these IT is to store, recover, transmit and manipulate agricultural data such as the land, crop and environmental conditions, among others. The identified IT are the following: (i) Global Positioning System (GPS), (ii) Multimedia (devices that allow capturing images or videos, such as smartphones or cameras), (iii) Nanosensors, (iv) Remote sensors, (v) Sensors in General (where the publications only described the data that they captured), (vi) Unmanned Aerial Systems (UAS), (vii) Unmanned Aerial Vehicles (UAV), (viii) Unmanned Ground Vehicle (UGV), (ix) Variable Rate Technology (VRT), and (x) Wireless Sensor Networks (WSN).

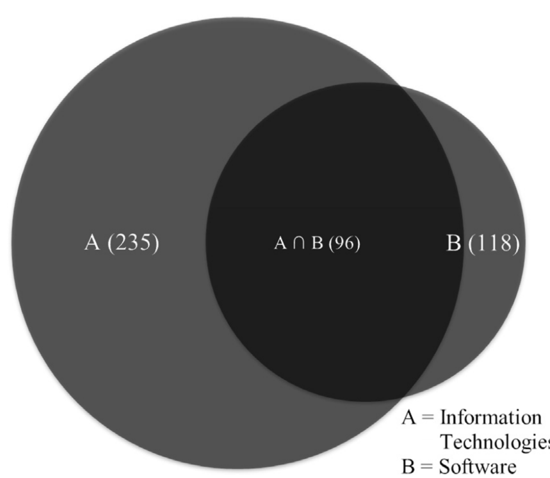

Fig. 4. Relations between the sets of publications that mention IT and Software.

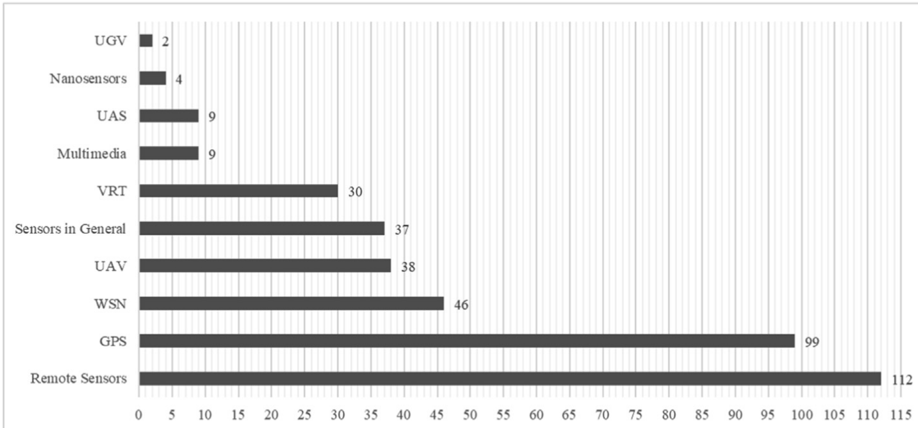

Fig. 5. Information technologies used in precision agriculture.

The number of publications that mention every IT is presented in Fig. 5. It can be seen that the distinct kinds of sensors, especially the remote ones, are the most used technology, This is probably because they have the ability to measure many different parameters depending on the user's requirements, such as temperature, humidity, pH, soil nutrients, water level and conductivity, among others (Kumar and Ilango, 2018).

Fig. 6 shows the distribution of publications per year for each IT. It can be seen that the number of publications has remained relatively constant every year.

Regarding the software, systems and techniques described by the selected publications, the following have been identified: (i) Geographic Information Systems (GIS), (ii) Multispectral Images, (iii) Soil Mapping, (iv) Variable Rate Applications (VRA), (v) Variable Rate Fertilization (VRF), (vi) Variable Rate Irrigation (VRI), (vii) Yield Maps and (viii) Yield Monitors.

Fig. 7 presents the number of publications that address every software or technique. It can be seen that GIS is the most researched. This could be because of its importance for storing the data required for analysis and long-term decision making (Markoski et al., 2015). This tool is used as a basis for other software or techniques when they need a previous set of data to process or interpret. In this manner, GIS is often combined with Yield Maps and other technologies. Fig. 8 shows the distribution of publications per year in relation to the software and techniques. In most years, GIS is the most researched.

4.2. Precision agriculture implementations

A total of 122 publications that describe PA implementations were found. These described the technologies that were applied in a crop to observe and/or to modify diverse factors that influence in its growth such as humidity, temperature, solar radiation or water level. Among these publications, it was observed that 69 of them indicated specific crops for the implementations. On the other hand, 38 of the publications indicated the agricultural activities that were addressed for the implementation, and 57 considered the elaboration of information systems that would support the implementation. It must be mentioned that, for 5 of the publications, although they addressed the implementation of IT in precision agriculture, they did not explicitly indicate an specific kind of crop, addressed a defined activity or elaborated a system for the implementation. The relations between the sets of publications that focus on the distinct aspects of PA implementations that have been described are shown in Fig. 9. For example, Rokhmana (2015) indicates all of the above, as it realizes an implementation for the activity of seeding on a sugar cane field and also develops a UAV platform.

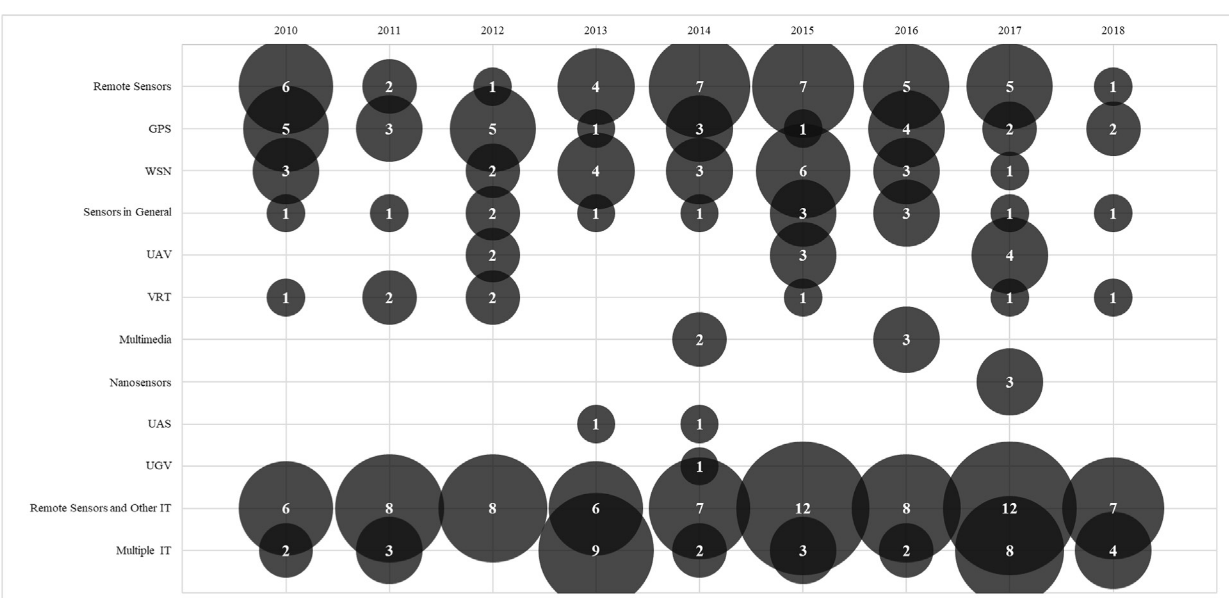

Fig. 6. Distribution of publications per year, in relation to the addressed IT.

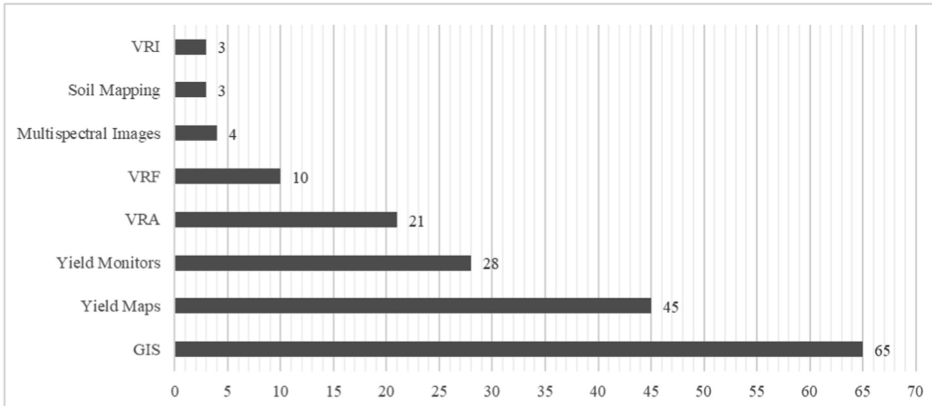

Fig. 7. Software and techniques used in precision agriculture.

Among the implementations of PA, a total of 23 kinds of crop have been identified, as shown in Fig. 10. The most frequently seen crops were corn, sugar cane, wheat, cotton, grape and soybean. It should be noted that each crop has different qualities and factors to consider for an optimal performance, such as climate, soil type and necessary nutrients, among others.

In addition to the kinds of crop, some of the identified implementations indicated one or more agricultural activities that were focused on for said implementation. This is because each activity has its own requirements. Five activities were identified, as shown in Fig. 11. These are: (i) disease, pests and weeds control, (ii) fertilization, (iii) harvest, (iv) irrigation, and (v) seeding. The distribution of the publications is relatively similar, although harvest and seeding have been researched some more.

Finally, there are implementations that considered the elaboration of information systems in order to use the technologies more efficiently. The identified systems can be divided in two sets: Activity-Related (AR) systems and Technology-Related (TR) systems. The former are systems developed for supporting the distinct activities of the growing season, whereas the latter are systems focused on supporting the implementation of specific technologies. The relations between the two sets of systems can be seen in Fig. 12. For example, Yang and Chen (2015) is included in both sets as it develops both an irrigation (AR) system and a local positioning (TR) system.

The AR systems were mainly developed with the objective of monitoring the whole growing season. For example, in Smiljkovikj and Gavrilovska (2014), a system called SmartWine is created to help in the implementation of WSN in vineyards. On the other hand, there are also more specific systems that focused on some of the agricultural activities mentioned above. Fig. 13 shows the number of publications that elaborated AR systems. The most commonly developed ones are monitoring systems, which are used during all activities. Decision Support

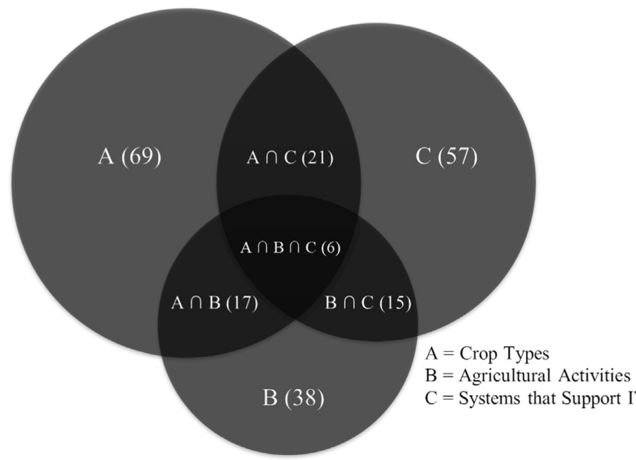

Fig. 9. Relations between the sets of publications that focus on distinct aspects of PA implementations.

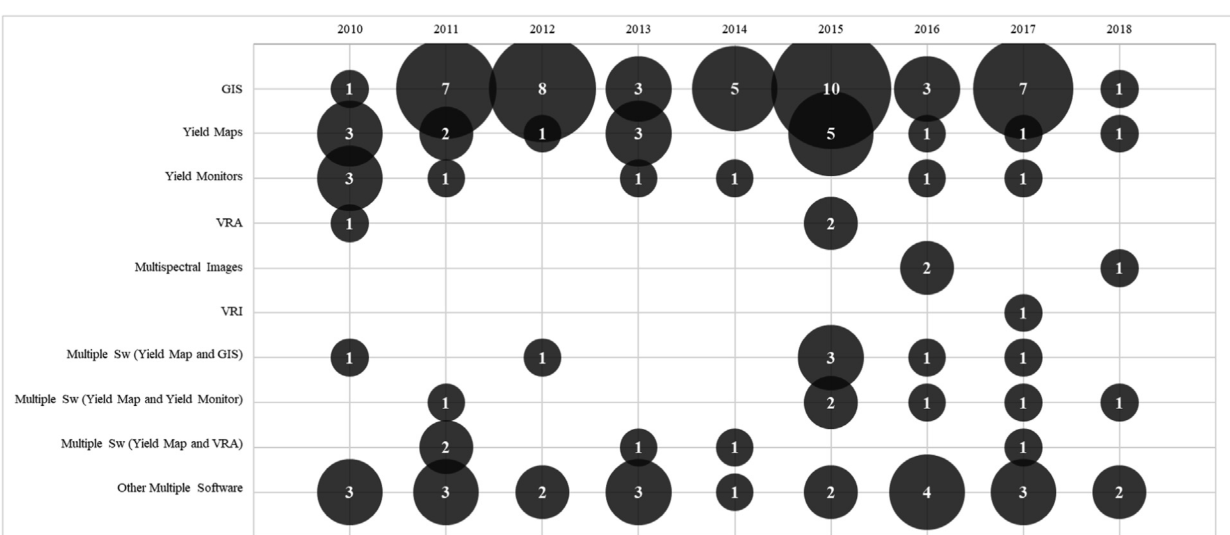

Fig. 8. Distribution of publications per year, in relation to the addressed software and techniques.

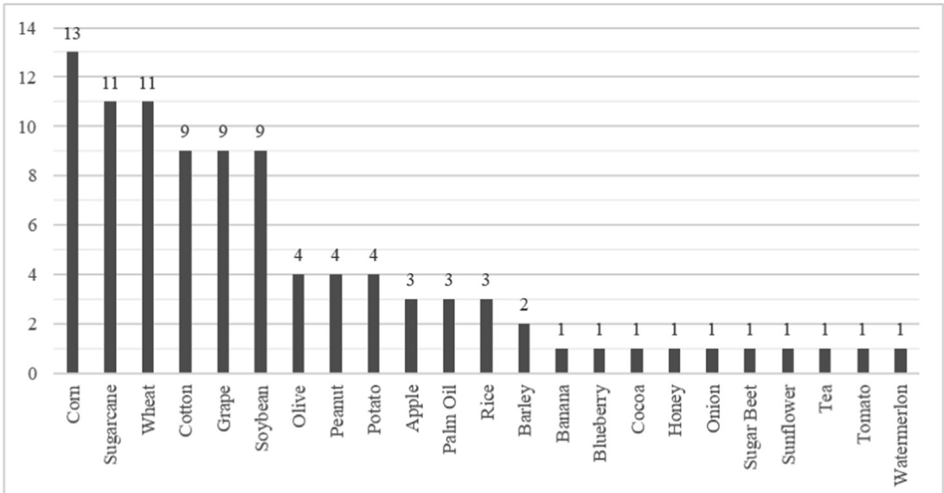

Fig. 10. Crops mentioned during PA implementations.

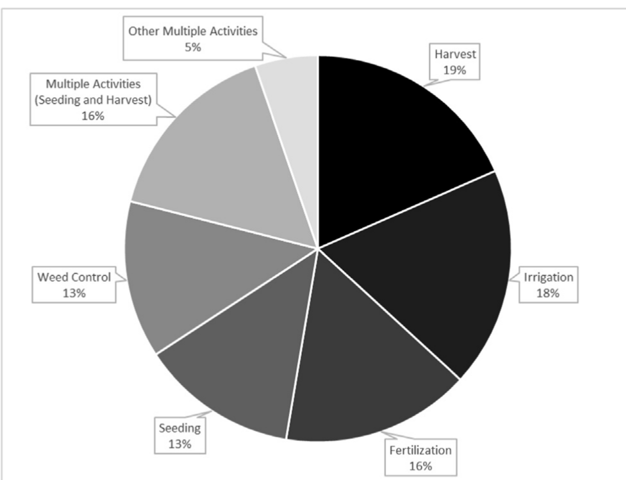

Fig. 11. Agricultural activities considered during PA implementations.

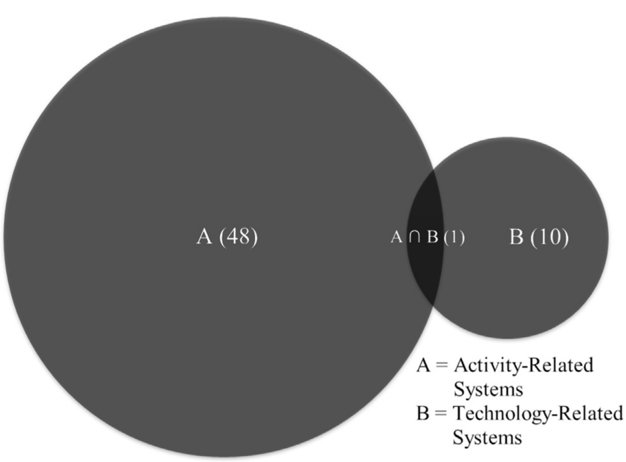

Fig. 12. Relations between the sets of publications that mention Information Systems.

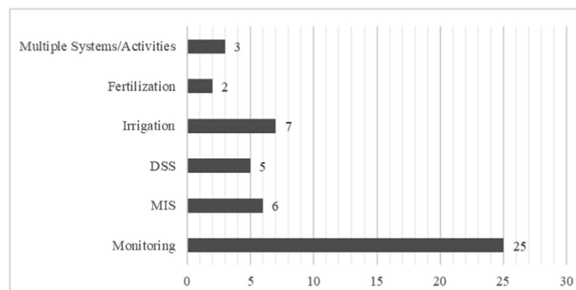

Fig. 13. Elaborated AR systems during PA implementations.

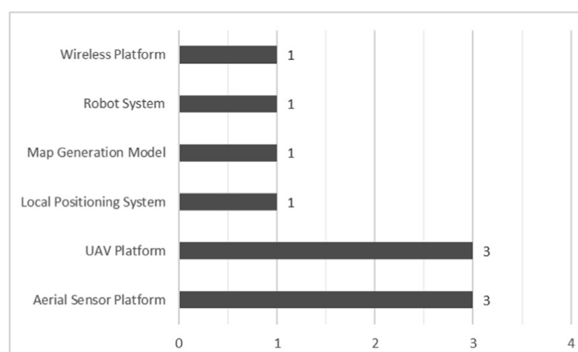

Fig. 14. Elaborated TR systems during PA implementations.

Systems (DSS) and Management Information Systems (MIS) that are also used for supporting all of the activities were found as well.

Few TR systems were found. These mainly focused on supporting specific technologies, such as sensors and UAV. The identified TR systems can be observed in Fig. 14.

4.3. Criteria for the comparison and selection of information technologies in precision agriculture

Only 19 publications were found that directly answered this question. They mainly focused either on the comparison of IT on a specific crop or on the comparison of the adoption level of the IT.

The adoption of various technologies is surveyed in Winstead et al. (2010), indicating that they have different uses, objectives and needs that affect adoption, so every IT can cover distinct necessities.

In Nair (2011), a study is conducted on PA from an economic point of view on cotton production. The publication indicates factors that influence the adoption of IT, such as the type of technology chosen, education level and the need to use of computers.

The obstacle that farmers prefer to invest in new technologies regarding seeds rather than in PA is indicated in Schimmelpfennig and Ebel (2011). In addition, it claims that there are many environmental and managerial factors that influence the adoption of precision agriculture. An example of this is the education of the technology operator, because there are problems that may require a higher degree of expertise, like in information management. Another factor that is considered is the cost associated with the technology. For example, the use of VRT requires a significant investment in equipment to apply fertilizers and pesticides or to sow at variable rates.

Factors that influence the adoption of PA are mentioned in Tey and Brindal (2012). These factors are: Socio-economic, such as the education or knowledge of the farmers; Agro-ecological, namely farm specialization; Institutional, like the region of the farm; Informational, such as the perceived usefulness of extension services in the implementation of PA practices; Farmer perception, for example, on the profitability; Behavioral, like the willingness to adopt the technology; and Technological, that is, the technology to use.

In Babu (2013), a model to provide PA services is created, where various data of interest are indicated. Three kinds of information are highlighted: static information, such as the crop calendar that includes the necessary activities for its growth during the distinct phases; semi-dynamic information that is specific for each season of the terrain; and dynamic information, that is, information obtained in real time based on various weather and soil factors. On the other hand, the publication identifies other necessary parameters, such as land size, type and variety of crop, among others.

Motivations for users to adopt PA are explained in Melchiori et al. (2013). These motivations are the reduction of production costs, the increase in the yield, the use of the latest technologies and a decrease in the amount of work to be done.

A management model is proposed in Morales and Augusto (2013). This model indicates that IT can be classified according to their performed functions, such as recovering or analyzing data, among others.

In Burlacu et al. (2014), soil samples are highlighted as an important comparison factor because they allow obtaining a general distribution of the chemical and physical properties of the soil. Similarly, climatic factors are highlighted as they affect crop yield.

A comparison between PA and traditional agriculture is made in Demattê et al. (2014). Differences such as network sampling, production variation, plant failure and costs are discussed. In addition, it indicates that an important aspect is the analysis of the soil of the land.

A research to determine why cotton producers choose to adopt soil sampling, yield monitors and remote sensors over other technologies is performed in Watcharaanantapong et al. (2014). The publication indicates factors that can influence the adoption of IT for PA. These factors were the availability of the technologies in the market, the characteristics of the farmers, such as their age, education, possession of computers and experience using technologies, and the characteristics of the land, such as their extension and income that they provide.

In Pignatti et al. (2015) a list of drivers for the adoption of technological innovations in agriculture is provided. Ease of use, effectiveness, usefulness, resource savings and compatibility are mentioned as relevant features for an innovation to be adopted. Trials, demonstrations, experience and knowledge sharing, and support from qualified third parties are also included among the facilitating factors for conveying and promoting innovations. Finally, public funding, agricultural policies and market conditions are identified as factors that may tip the balance in the process of adopting innovations in PA.

The economic and environmental impacts of PA are researched in Schieffer and Dillon (2015), indicating that it is important to consider the costs of the IT to adopt.

Comparisons of different technologies and techniques during their adoption are presented in Griffin et al. (2016). One factor that affects this is the ability to manage the technology. If the knowledge or skills that are required are too high, then there is a higher chance that the technology will be abandoned.

In Schimmelpfennig and Ebel (2016), it is stated that the larger the size of the field is, the higher the interest to adopt information technologies will be. Factors related to the operator's knowledge, the associated costs and soil samples are mentioned. Here, soil samples are described as a diagnosis of soil nutrients and micronutrients. In addition, it can be inferred that the technology prerequisites are considered a factor as well, since they cannot be installed in a random order due to the requirements that need to be met beforehand.

The materials that influence how farmers come to learn about and engage with PA are researched in Higgins et al. (2017). It emphasises the need to understand and take into account the tacit and experimental knowledge of the farmers as some technologies require a higher level of knowledge.

In Kendall et al. (2017), barriers and facilitators for the adoption of PA in China are presented from the perspective of two key groups of stakeholders: agricultural experts, and farmers and end-users. The publication indicates that the most prominent barrier is the current lack of suitability of the technologies to address the challenges of small land management zones because PA technologies are currently focused on the production on large farms. It is also mentioned that end-users within larger farms are inferred to be younger with high educational levels, which increases the willingness and ability to engage with PA technologies. Additionally, the immediate benefits of PA technologies are observed to be difficult to evaluate and quantify. The publication concludes mentioning that, although PA technologies were regarded as a significant scientific advance in farming practice, they were not perceived to be relevant for the agronomic and socioeconomic conditions on small to medium farms.

Different types of sensors are compared in Raghunandan et al. (2017), based on their cost, efficiency, application and type of data captured, among other factors.

In Zhou et al. (2017), IT trends among cotton producers are provided, helping them to make adoption decisions. The publication indicates that the time given for analysis is important to adopt IT, as it is necessary to research the technologies that are available.

Finally, the survey presented in Far and Rezaei-Moghaddam (2018) researches factors influencing the impact of precision agriculture. According to the results, experts found that the perceived usefulness, the perceived ease of use of the technology, the knowledge of precision agriculture, and the behavioral attitude have the most effect on the adoption of the technologies.

To synthesize the previous information, Table 3 provides a summary of the described publications, including the distinct criteria that each of them contribute for the comparison and selection of technologies in precision agriculture implementations.

In summary, although there is a low number of publications that make comparisons between different IT and techniques, it is important to analyze the advantages and disadvantages of the technologies in a variety of situations to learn which is the most convenient in each case.

Given the above, the remainder of the accepted publications in this SLR have been analyzed to identify possible criteria that could be inferred based on the distinct proposed implementations. As a result, 11 possible criteria and their possible associated values were established. These are presented in Table 4.

4.4. Frameworks for the guidance of precision agriculture implementation

No publication could be found through this SLR that proposed any kind of framework or tool that guided the implementation of PA by using the criteria that have been identified in this research or any other.

5. Discussion

The main findings of the SLR are discussed here. This review allows to not only learn about the state of the art regarding the use of IT and software in precision agriculture, but it also serves as a way to identify the principal contexts in which they were used, while also giving an insight on the criteria utilized when facing the need to decide what

Table 3
Summary of publications that provide comparison and selection criteria for PA.

Reference	Summary	Observed Criteria
Winstead et al. (2010)	Surveys the adoption of IT, considering that they have distinct functionalities that affect it.	Type of IT
Nair (2011)	Studies the use of PA in the cotton industry from an economic point of view.	Required Knowledge; Type of IT
Schimmelpfennig and Ebel (2011)	Highlights the need for knowledge and the relevance of the costs associated to PA.	Costs; Required Knowledge
Tey and Brindal (2012)	Mentions multiple factors that influence PA adoption.	Costs; Required Knowledge; Type of IT
Babu (2013)	Provides a model for providing PA services using static, semi-dynamic and dynamic information.	Agricultural Activity; Climate; Crop; Soil; Terrain Extension
Melchiori et al. (2013)	Explains motivations of the users to adopt PA.	Availability; Costs
Morales and Augusto (2013)	Proposes a PA management model and classifies IT based on their functionalities.	Type of IT
Burlacu et al. (2014)	Highlights that soil and climate affect crop yield.	Climate; Soil
Demattê et al. (2014)	Compares PA with traditional agriculture through distinct criteria.	Costs; Soil
Watcharaanantapong et al. (2014)	Researches the reasons that cotton producers favor some IT over others for implementing PA.	Availability; Required Knowledge; Terrain Extension
Pignatti et al. (2015)	Lists the drivers for adopting and promoting technologies in agriculture.	Availability; Costs; Required Knowledge
Schieffer and Dillon (2015)	Analyzes economic and environmental impacts of PA.	Costs
Griffin et al. (2016)	Compares IT adoption based on Required Knowledge.	Required Knowledge
Schimmelpfennig and Ebel (2016)	Asseverates that the terrain's extension motivates the implementation of PA and that it is important to evaluate the soil.	Costs; Prerequisites; Required Knowledge; Soil; Terrain Extension
Higgins et al. (2017)	Researches how farmers engage with PA.	Required Knowledge
Kendall et al. (2017)	Presents barriers and facilitators for PA adoption in China.	Availability; Costs; Prerequisites; Required Knowledge
Raghunandan et al. (2017)	Compares distinct kinds of sensors using various criteria.	Costs; Data Captured by the IT
Zhou et al. (2017)	Shows the IT trends among cotton producers.	Required Knowledge
Far and Rezaei-Moghaddam (2018)	Surveys the factors that influence the impact of PA.	Required Knowledge

Table 4
Identified criteria and their possible values.

Criteria	Example of Possible Values
Associated Costs	Price
Data Captured by IT	Humidity, pH, Temperature
Ground Factors	Nutrients, Depth, Topography
Knowledge level Needed	High, Medium, Low
Prerequisites to Implement IT	Other technologies
Role of IT	Capture Data, Analyze Data
Size of the Field	Number of Acres
Type of Crop	Rice, Blueberry, Potato
Type of IT	Drone, GPS, Sensor
Weather Factors	Temperature, Wind Speed

technology to use in different contexts.

There has been constant research over the years on precision agriculture and its technologies. This can be observed through the considerable amount of publications that were found. Most of these publications describe technologies or software that allow to recover and process data of the current condition of the different sectors of the terrain (Hunt and Daughtry, 2018; Quebrajo et al., 2018).

The remote sensor is the most researched technology. This could be due to its advantages over other technologies, like its accuracy and the different factors that it can capture (Hernandez et al., 2015). However, they also have disadvantages, like the required investment cost for achieving greater accuracy. Thus, other alternatives for data capture should still be considered based on the needs of every distinct crop (Hedley, 2015).

On the other hand, it must be mentioned that it is not enough to just capture the data, as it must be stored and subsequently transformed to information to perform an appropriate analysis. Thus, it has been observed that software and techniques have been developed for the task of processing and analyzing the data, allowing an easier interpretation of the terrain's situation. An example are the maps that show the water level of each sector using colors to show which ones have an adequate level and which require the farmer's attention (Oliver, 2013). These software and techniques allow to take decisions faster and more easily. It should be noted that the use of these technologies goes in hand with the use of sensors or other technologies that allow to collect the required data (Tripathi et al., 2013).

A reasonable number of publications have been found that discuss the implementation of IT in precision agriculture. It was detected that the implementations concentrated on applying the technologies in some of the agricultural activities, such as the seeding or harvesting stages of a crop (Higgins et al., 2017; Griffin et al., 2017). It was also noticed that the technologies were used in specific crops in each case, as each crop has different needs and conditions (Yost et al., 2017; Xia et al., 2018). Finally, it was seen that some implementations considered the development of computer systems that support the IT used for precision agriculture (Biqing et al., 2018; Faiçal et al., 2017).

Few publications were found that provide criteria for the comparison and selection of technologies in the context of PA. One of important criteria that were observed is the type of crop, since, as mentioned above, each one has different needs and not all technologies can be applied in all cases (Tripathi et al., 2013). Other relevant criteria that were seen are the types of IT and their characteristics, as well as the associated costs. Each technology requires a significant investment for the farmer (Mushtaq et al., 2013), so it is necessary to adequately know the functions that it offers, the data that it captures or processes, the results that it generates, the requirements needed for its use and the required level of knowledge. If the above are not considered, then there is a greater risk for the farmer to abandon the technology and lose the investment (Melchiori et al., 2013; Schimmelpfennig and Ebel, 2011).

One of the objectives of the SLR was to identify decision frameworks that used the identified criteria, but no publication could be found that proposed any kind of tool that guided the implementation of PA.

Through the realization of the SLR it was noted that the amount of data captured and stored by precision agriculture technologies is huge. The processing and management of such amounts of data is a challenging task when using traditional methodologies and platforms. Here, Big Data is highlighted as it can support a wide range of precision agriculture functions for discovering new insights from data and it helps to address many new and important farming decisions and problems (Bendre et al., 2015). In fact, various of the identified publications have already proposed the use of Big Data for supporting the technologies utilized in PA (Wolfert et al., 2017; Kamilaris et al., 2017; Alves and Cruvinel, 2016).

6. Conclusions and future work

The results of this systematic literature review have allowed to ascertain that, although it is still a relatively recent concept with a noticeable learning curve, precision agriculture has shown to be a greatly researched area that constantly progresses due to the needs of farmers to use resources more optimally. Moreover, the multiple implementations of precision agriculture presented in literature, as well as the technologies that are used for this purpose, have been identified through this SLR. A number of criteria and factors that motivate the decision of using certain IT, or of opting to use or not PA, have also been identified. In this manner, the main findings of this research are mentioned next.

- There is a number of different IT that have been used in the context of PA. Here, remote sensors and GPS are highlighted due to the great number of publications that make use of them. Similarly, among the software that support these technologies, GIS and yield maps have seen the most use.
- Although the implementation of PA has been identified in many different kinds of crop, five of them have notably been researched more often in literature, these are corn, sugarcane, wheat, cotton, grape and soybean. The PA implementations where also considered for distinct agricultural activities, where harvest and seeding have been researched slightly more often. Additionally, it was possible to observe that multiple information systems that used the identified IT were developed for PA implementations.
- Not many publications that proposed comparison and selection criteria for precision agriculture implementations could be identified. However, some important criteria were observed recurrently among these publications, such as the costs associated to the IT, the type of IT to implement, soil and climate factors, and the required knowledge to use the IT. The latter criterion is highlighted, as multiple publications indicate that this is one of the major factors for farmers to actually decide to implement PA, as the knowledge about PA becomes one of the greater barriers on its adoption.
- Although one of the objectives of the SLR was to identify the existence of a tool or framework that supported the decision-making of what IT should be implemented for a given crop in the context of PA, it was not possible to identify such a publication among the reviewed ones.

The results of this SLR allow to identify multiple possible future work research lines in the context of PA. Namely, focusing on technologies that have not been researched as often, such as UAS and multispectral images, or crops that also require further sampling, like blueberries and tea, could help to identify new advancements in the context of PA. Another important aspect that future research should focus on is the current need for farmers to acquire more knowledge regarding PA, as this has turned out to be one of the major factors that dissuade them from implementing IT in their fields. In this matter, a tool or framework that encompasses this required knowledge, and/or that directly supports the decision-making process of selecting the appropriate IT for a farmer's needs without relying solely on trial and error strategies that further increase the adoption costs, would be highly desirable. Thus, the future work of this research aligns with the creation of a recommendation system that, supported by the information identified through this SLR, helps farmers to compare and select the IT to implement in their fields.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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