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Scientific development of smart farming technologies and their application in Brazil

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ABSTRACT

Smart farming (SF) involves the incorporation of information and communication technologies into machinery, equipment, and sensors for use in agricultural production systems. New technologies such as the internet of things and cloud computing are expected to advance this development, introducing more robots and artificial intelligence into farming. Therefore, the aims of this paper are twofold: (i) to characterize the scientific knowledge about SF that is available in the worldwide scientific literature based on the main factors of development by country and over time and (ii) to describe current SF prospects in Brazil from the perspective of experts in this field. The research involved conducting semi-structured interviews with market and researcher experts in Brazil and using a bibliometric survey by means of data mining software. Integration between the different available systems on the market was identified as one of the main limiting factors to SF evolution. Another limiting factor is the education, ability, and skills of farmers to understand and handle SF tools. These limitations revealed a market opportunity for enterprises to explore and help solve these problems, and science can contribute to this process. China, the United States, South Korea, Germany, and Japan contribute the largest number of scientific studies to the field. Countries that invest more in R&D generate the most publications; this could indicate which countries will be leaders in smart farming. The use of

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both research methods in a complementary manner allowed to understand how science frame the SF and the mains barriers to adopt it in Brazil.

1. Introduction

Technological development, such as the use of electronic systems and data transmission, has introduced radical changes to the agricultural working environment in recent years. These changes demand updated information from production systems and from markets and agents involved in production to provide decision-making information for production as well as for the strategic and managerial issues involved.

Smart farming (SF), based on the incorporation of information and communication technologies into machinery, equipment, and sensors in agricultural production systems, allows a large volume of data and information to be generated with progressive insertion of automation into the process. Smart farming relies on data transmission and the concentration of data in remote storage systems to enable the combination and analysis of various farm data for decision making.

Demographic trends, including aging populations and continued migration of people from rural to urban areas, have attracted the attention of researchers, because labor issues may become a scarcity factor in agriculture. In addition to these trends, the intensification of climate change will continue to alter growing conditions, such as the temperature, precipitation, and soil moisture, in less predictable ways [1]. SF tools can help reduce these impacts, keep them constant or reduce production costs in agricultural activities, and they can assist in minimizing environmental constraints [2].

The literature on smart farming and smart agriculture is recent. The concept and terms associated with SF have not reached a consensus in the scientific literature [3]. Rapid developments in the internet of things (IoT) and cloud computing are propelling the phenomenon so-called smart farming [4]. The basis for advancement in this sector involves a combination of internet technologies and future-oriented technologies for use as smart objects [5–8]; however, there is no still established concept for these technologies in agriculture [3].

Considering this context, this research aims to achieve the following objectives: (i) to characterize the scientific knowledge about SF that is available in the worldwide scientific literature based on the main factors of development by country and over time and (ii) to describe current SF prospects in Brazil from the perspective of experts in this field. Most publications that are available on this topic, and extensive information, had to be derived from the gray literature; furthermore, the discussed applications are mainly from Europe and Northern America [3].

Identifying how science frames SF over time, countries and targeted research can help drive new research with the objective of covering areas that have received less attention; this will develop new approaches to better understand SF and illuminate new applications. Furthermore, analysis of the SF Brazilian market has allowed us to identify the stages and main barriers to adoption for this technology.

These two steps have contributed to understanding the economic and social aspects that may determine the emergence of a new technical-economic paradigm in agriculture. A new techno-economic paradigm, corresponding to a new set of more profitable and viable productive practices – in terms of inputs, methods and technology choices – along with new organizational structures, business models and strategies [9]. SF can become a new techno-economic paradigm in agriculture.

In this research, Brazil was chosen because of its agricultural potential and the role of technology in increasing productivity and production in the country. The Brazilian agricultural sector has modernized from the 1960s. Brazil is making a successful transition from a net importer of food in the 1960s to a strategic worldwide producer in 2014 [10]. Since the 1990s, while world production has been stagnating, Brazilian agriculture has been dynamic and growing [10]. The impact of these technologies in a country such as Brazil can contribute to the increasing demand for food production if these technologies become widespread.

It is difficult to affirm whether this new set of technologies, in the context of SF, will keep pace with the increasing yields that have been accomplished by previous revolutions, such as the green revolution. SF have the potential to change both the farm structure and the wider food chain in unexplored ways, which is what occurred with the widespread adoption of tractors and the introduction of pesticides in the 1950s [3,11,12].

Given the persistent food shortage and population growth around the world, it is estimated that a 70% increase in world food consumption must be achieved from 2009 to 2050 [13]. The technologies linked to SF will be important in meeting this challenge of increased food production in the face of constraints such as climate change and other environmental issues.

1.1. *Smart farming background*

SF is a concept that originated with software engineering and computer science [14] that arrived with the addition of computing technologies and the transmission of data from agriculture, within an overall environment of virtually ubiquitous computing [3]. These computing elements are embedded in objects and interconnected with each other and the internet.

The SF field comprises other terms with similar meanings, such as smart agriculture. Accordingly, overlapping interfaces and technologies exist and encompass ideas such as precision agriculture and management information systems in agriculture, which have been derived from the idea of the farm management information system (FMIS) [14]. FMIS is defined as a system that is designed for collecting, processing, storing, and disseminating data in a required format to perform operations and functions on rural properties [15].

The use of SF tools is possible due to the use of sensors in agriculture. A sensor is an electrotechnical device that measures physical quantities from the environment and converts these measurements into a signal that can be read by an instrument. Among the measurements read by sensors are the following: temperature, humidity, light, pressure, noise levels, presence or absence of certain types of objects, mechanical stress levels, speed, direction, and object size [16].

Also noteworthy is the internet of things (IoT), a term that is one of the technologies related to SF, which was introduced by Kevin Ashton, a British entrepreneur, in 1999, and that shares the concept of an intelligent environment with FMIS [17]. The IoT allows objects to be controlled remotely via an existing network infrastructure, creating opportunities for more direct integration between the physical world and computer-based systems.

The use of IoT depends on the internet infrastructure, and this presents several shortcomings, especially when dealing with a large number of network devices and the integration with other systems [18]. SF tools introduce a new level of technology into agriculture, including robotics, mapping and geomatics technologies, decision making and statistical processes. The most promising SF technologies incorporate advances in sensors, data analysis, telemetry, and positioning technologies, but the development and dissemination of these technologies may require time and investment. There are a number of other factors that can influence a new technological paradigm.

One of the discussions about new technologies has emerged from the study of Schumpeter [19], who reported on the essence of economic development in relation to innovation. Technological innovation changes production patterns and can differentiate between economic development in regions and countries [20].

Subsequently, Perez and Freeman and Perez [21–22] introduced the concept of a techno-economic paradigm as a way of describing how a technology and innovation emerges. In this perspective, technology is much more than a matter of science or engineering [23], it has economic and social aspects. Periods of breakdown of technological paradigms introduce a whole wave of new products and processes, generating fundamental changes in a society (structural changes) [21], with more profitable and viable productive practices [9].

In the agricultural sector, profound structural changes have occurred with the incorporation of mechanization and chemistry. These are examples of techno-economic paradigms that have influenced the entire economy. The current use of the internet of things, in smart environments, and the use of cloud computing can become a new techno-economic paradigm [6,7]. However, to change the techno-economic paradigm, formal and institutionalized organization of research and development (R&D) departments may be necessary [24].

Investments in R&D are needed [25], as there are degrees of technology accumulation and different efficiencies in technology and innovative research processes when comparing different regions and countries. According to the World Bank [26], there has been a concentration of R&D investment expenditures (i.e., % of gross domestic product) in 2013 for both public and private R&D in certain countries, including South Korea (4.15%), Japan (3.47%), Denmark (3.60%), Germany (2.85%), and the USA (2.81%). The nature of technologies has been suggested to be broadly similar to those that characterize science [27], that is, there is the expectation that these countries can lead research, because SF requires interrelated technologies originating from areas of management, electronics, production, and other research fields.

2. Methods

2.1. *Expert interviews*

Considering the initial SF stage in Brazil, and the existence of few enterprises and professionals dedicated to this subject, we conducted interviews with four Brazilian experts. The number of interviewed experts followed the concept of saturation, which is when the collection of new data does not contribute to more information related to the issue under investigation [28]. The number of experts interviewed, despite being low, enabled a satisfactory view of the SF scenario in Brazil. Smart farming is a relatively new concept, and knowledge about its applications and implications for research and development is not widespread [3].

The Brazilian experts were chosen for their relevance in agribusiness and for being pioneers in their areas of expertise. Table 1 shows the profiles of interviewed experts. The interviews were held in person with one expert and through web conferencing with the other three respondents. Furthermore, a semi-structured interview guide was used (see Appendix A). The duration of the interviews was 60 min, on average. The interviews were recorded (with permission from the interviewees) and then transcribed into a text editor for later analysis. This content analysis was used to analyze the experts' answers. This step followed three phases: analysis, material exploration, treatment of results and interpretation. The results are presented based on the respondents' answers, which are divided into two areas: a panorama of SF in Brazil and barriers to adopting these technologies.

2.2. *Bibliometric and scientific analysis using text mining*

The second stage of the research consisted of a bibliometric survey of the Web of Science database (Institute for Scientific Information Knowledge), which was accessed through the Portal of the Library of the Federal University of Rio Grande do Sul, provided by Higher Education Personnel Improvement Coordination (CAPES). The bibliometric data characterized the dynamic evolution of scientific production in SF from 1975 to 2015. The database was chosen for its scope and use in other bibliometric studies [29–32].

This step consisted of the use of keywords to search for scientific documents related to SF. The definition of the set

Table 1 – Profiles of experts interviewed.

Expert	Profile Description	Area
Expert 1	Expert 1 has a PhD in agricultural engineering and presides over the Brazilian Precision Agriculture Commission of the Ministry of Agriculture, Livestock, and Supply. He acts as the interface between machine and agricultural equipment areas, especially related to sensors, spatial variability, productivity maps, localized application of inputs, sowing, fertilization, and harvesting.	Precision agriculture and SF
Expert 2	Expert 2 is a coordinator of research and technical testing of the products and technologies of the largest national precision agricultural and SF machine and equipment company in Brazil. He is responsible for the implementation of a telemetry and data management system from the machines and equipment developed by the company, seeking to integrate with other agents involved with the farmer	Precision agriculture and SF
Expert 3	Expert 3 has a master's in agricultural engineering and is an employee in the area of product development and marketing for the company with the most agriculture machinery sales in Brazil. Expert 3 is responsible for the implementation of the company's smart farming strategy and for establishing relationships with resellers of machines for products that represent these new technologies.	Precision agriculture and SF
Expert 4	Expert 4 is an agronomist, holds a doctorate in electrical engineering, and works at the Agricultural Automation Laboratory of the University of São Paulo. Expert 4 is a leader in the Applications and Services Working Group of the Brazilian Internet of Things Forum. He has several projects in the area of traceability systems with the use of the internet of things.	Research on agricultural automation

of keywords was obtained from interviews with experts (as described in the first stage) as well as from recurrent tests. It was chosen a combination of keywords that would return the highest number of results related to the subject. The keywords used in this step were "smart agriculture", "smart farming", "farm management information system", "farm management system", "big data" and "agriculture", "internet of things" and "agriculture". These keywords were inserted separately into the field "topic" in the Web of Science.

A total of 371 scientific publications were obtained from the data collection. Of these, some did not possess the available summary or were not relevant to the research topic. In other words, documents that had no available abstract or no relation to information technology and computing elements were excluded (e.g., some laboratory experiments in veterinary or agronomic fields). By the end of this process, 179 scientific documents were included in the bibliometric and text mining analysis (Fig. 1).

The text mining analysis involved several steps. First, the title, abstract, and keywords of scientific papers were inserted into QDA Miner software v. 6.0.2 (Provalis Research). They were organized according to their year of publication and country of origin (see Fig. 2).

Second, the stopwords from these texts were excluded. Stopwords are considered to be non-informative since they do not summarize the content that the text addresses in a satisfactory way [33]. The exclusion dictionary from the software package was used in this step. Thus, articles, numerals, and prepositions that were not relevant for the analysis of the subject were excluded.

Third, in order to identify the terms most frequently used in the literature, text mining of the title, abstract, and keywords of the selected texts was performed using the WordStat module in the QDA Miner software. The WordStat module returned the following parameter values for each of the terms found in the database: (i) frequency (number of times a term occurred); (ii) percent display (relative frequency percentage of terms among the total number of words in the document); (iii) percent cases (percentage of cases where the term occurred); and (iv) the term frequency multiplied by the inverse document frequency (the TF* IDF value), which is an index for measuring the relative importance of the terms in a corpus of documents.

After finding the most frequent terms, the fourth step was to classify these terms into three factors: (i) management; (ii) technology and electronics; and (iii) production and environ-

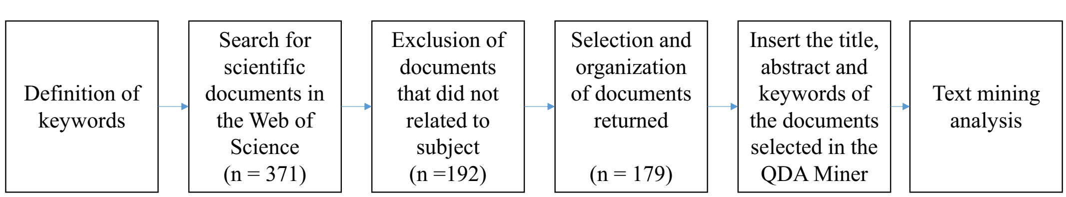

Fig. 1 – The process of collecting, selecting, organizing, and extracting knowledge from scientific publications while applying text-mining techniques.

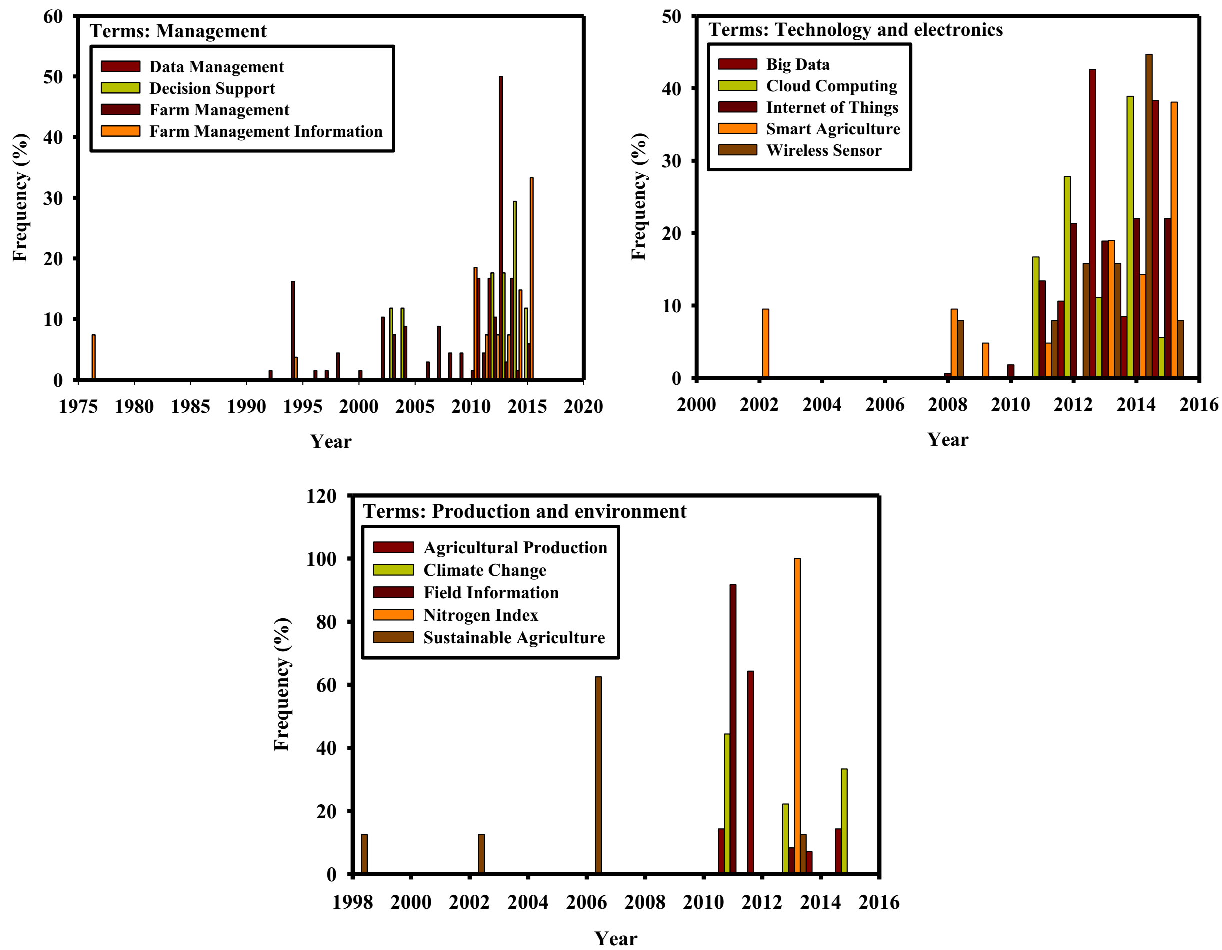

Fig. 2 – Number of publications (occurrence and intensity) of terms selected in the scientific literature.

ment. Each of these factors contained five terms that encompassed the most frequent terms of the analysis.

Fifth, in order to improve the analysis, the terms were associated in clusters. For this purpose, they were grouped by similarity index, obtained with the aid of the dendrogram function of the WordStat software, using the Jaccard coefficient. This coefficient is used to compare the similarity and diversity of sample sets, assuming values from 0 to 1. The closer the index is to 1, the more similar the terms are [21].

3. Results and discussion

3.1. SF prospects in Brazil

This section presents the qualitative results obtained from interviews with specialists. First, an overview of SF in Brazil is provided; then, the main barriers to adoption are discussed.

3.1.1. Expert 1

In relation to the SF prospects in Brazil, Expert 1 pointed out that the tools and technologies available in smart farming are not yet present in large numbers, especially in Brazil. According to the respondent, the market is undergoing an initial process of developing technologies, with various agents and organizations entering and seeking opportunities to generate innovations.

The SF market in Brazil is more invested in agriculture than in livestock [34]. In livestock SF in Europe, there are a large number of farmers using these technologies [35], such as robotic milking. In contrast, in Brazil, livestock SF is still under development, with some prototypes remaining at the farm level.

One of the agricultural sectors that uses SF most heavily in Brazil is sugarcane. Expert 1 reported that this sector uses many global positioning system (GPS) technologies for planting and harvesting via telemetry to connect, for example, the combine harvester with industry data. Another SF tool used in this sector is the unmanned aerial vehicle, which is used to observe planting failures and to analyze the need for the application of nitrogen fertilizers in sugarcane.

For SF, the potential of unmanned aerial vehicles (UAVs) has been well-recognized [36,37]. Drones with infrared cameras and GPS technology are transforming agriculture due to their enhancement of decision making and risk management [3,38]. These are just some of the technologies within the scope of SF. These are technologies that are also essential to precision agriculture but that provide the possibility for automation and the remote control of operations, one of the great powers of SF.

The supply and development of SF tools is currently concentrated on machinery and equipment, and the companies in this sector are responsible for implementing the first prototypes on integrated farms. Some of these agents, such as computing businesses (e.g., IBM, Google), agricultural companies (e.g., Monsanto), and startup companies that are set up close to the academic environment are discovering opportunities in SF, such as systems for monitoring the appearance of diseases or recommendations for the quantity to be irrigated.

Expert 1's statements are in line with the results presented by Fountas et al. [2] and Salami and Ahmadi [39]. That is, the technologies related to SF are still in early development, but the possibilities are numerous. In agriculture, the development and incorporation of new technologies occurs more slowly than in other areas, such as the industry in general as well as electronics, car, and food industries.

Expert 1 has observed that agricultural digitization, especially in Brazil, but not the application of smart technologies, such as is occurring in industry. For this expert, there is a long way to go until the incorporation and diffusion occur at a large scale for artificial intelligence and other technologies that turn agriculture or farm into a smart concept farm.

3.1.2. *Expert 2*

Expert 2 described the following current applications of tools and technologies related to smart farming that are available in the Brazilian market: machinery and equipment based on telemetry, automation systems for machinery and equipment (e.g., satellite guidance systems, regulation mechanisms such as seed flow controllers, fertilizers, and pesticides), data-collection systems (e.g., input sensors and records of meteorological variables), and geo-referenced soil sampling for mapping the fertility of crop fields (followed by the prescription and application of acidity and fertilizer correctives in amounts that vary according to the fertility conditions in each place).

According to Expert 2, telemetry technology enables real-time monitoring of agricultural activities, where the property manager can access this information on a smartphone or a computer. Additionally, these new technological data are not only in traditional tables but can also appear in other formats, such as sounds or images [40]. These technologies are the first step to creating a smart farm. From the development of real-time monitoring technologies, one can develop control tools and technologies.

Exploratory research conducted in Europe [2] indicated that the most common functions in software linked to SF are field operations management (63%), reporting (57%), finance (45%), and site-specific management (40%). In Brazil, geo-referenced soil sampling for mapping the fertility of crop fields was the first SF to be used; this was followed by the prescription and application of acidity and a fertilizer corrective [41].

3.1.3. *Expert 3*

The main advances in SF have occurred in automatic data collection, with no interference from the producer or operator. This increases the volume of data available for analysis, as described by Expert 3. He pointed out that the collection of information for farmers is secondary compared to field operations. If there is a cost increase in collecting the data and processing it, farmers will be less likely to adopt these technologies [42]. New technologies in SF can cause additional adaptations and modifications of tools, changing how farms are organized [42] and making SF adoption more difficult.

The sensors contained in new equipment and machines have made a larger volume of data available at no additional cost to farmers. This has generated a new challenge of how to analyze and use the generated data. A lot of the data remain underexplored by farmers, and today, researchers and companies are working to develop more tools that can link to big data.

Big data is a collection of very large datasets with a great diversity of types, making it difficult to process using traditional data-processing platforms [43]. Big data is particularly challenging for farmers, especially those running smaller operations. Some questions related to big data remain unanswered; for example, who will analyze the data and give suggestions to producers?

According to Expert 3, his company seeks to integrate SF technologies, which would allow customers, business partners, and service providers to make use of the data that the machines report. He also mentioned that the demands of service providers, farm agents, and farmers are being considered in the development of equipment and systems. The company's strategy centers on enabling communication among all stakeholders within the SF system.

3.1.4. *Expert 4*

In addition to the use of SF in the production of annual crops, Expert 4 reported on the use of these technologies for real-time quality monitoring in vineyards, fruit crops, and coffee as well as in the transportation of food products. The use of SF in fruit crops is associated with attempts to increase the quality of the product. This is done via sensors attached to the crops that are used to measure variables such as humidity, temperature, and soil conditions, thus predicting diseases and insect attacks. Fruit crops, which have a high value per hectare, could benefit greatly from the application of SF; however, the use of SF technologies in fruit growing by Brazilian producers remains incipient [44].

For Expert 4, integration between the different systems available on the market was one of the main limiting factors to SF evolution. The acquisition and analysis of information has arisen from diverse sources that are located at many sites [15]. The problem is that companies are slow to build compatible systems that enable communication and data transmission between different machines and agricultural implementations or different management systems.

There is still no standardized solution for simple and cohesive interoperability among services and stakeholders. For example, in the production of grapes for winemaking, it is still difficult to integrate weather information from the meteorological stations of national networks with soil information. Future internet infrastructure is expected to handle these shortcomings [18].

3.2. *Barriers to the adoption of SF technologies*

Technology adoption is a process with a certain level of heterogeneity in terms of the factors that affect it [45]. It is useful to understand these factors in the process of technol-

Table 2 – Summary of the variables that limit SF technology adoption by Brazilian farmers.

Barriers to adoption	Informant
Lack of integration among systems	Expert 1 and Expert 4
Education and knowledge of farmers and low technological levels on Brazilian farms	Expert 2 and Expert 3
Poor telecommunications infrastructure on rural properties	Expert 3
Difficulties in manipulating data and information obtained from equipment and machines	Expert 3 and Expert 4

ogy adoption in order to increase the rate of adoption. The main barriers limiting the adoption of SF technologies by Brazilian farmers are presented in Table 2.

3.2.1. *Lack of integration among systems*

Regarding the technology adoption barriers on farms, Expert 1 reported a number of challenges, including the integration of computer systems. Farmers are not loyal to one brand and tend to acquire equipment from several companies. Fountas et al. [2] corroborate this notion, explaining that the lack of integration among the available tools on the market limits SF adoption by European producers.

Several companies are working on systems integration and methods for crosschecking data from different sources in order to integrate information about climate and soil; however, these initiatives are emergent. Integration across systems is one of the areas where SF technologies need to advance by incorporating decision making, production, and property management tools. Due to reduced agricultural machinery and equipment sales, companies are trying to create new products and services by providing after-sales machinery and agricultural implementation services, such as configuration services, the optimization of remote machine regulations, and recommendations based on the data obtained from machines.

Experts 1 and 4 mentioned a gap between agricultural science and information science, which must be overcome if technologies are to be developed; this requires interaction between researchers and interdisciplinary groups. Expert 4 elaborated on this, noting that the technologies are poorly integrated, especially when traceability and the communication of information along the supply chain are required. Emphasis during the development of an information system should be placed less on design and more on learning what the farmers do and how they operate in order to increase user effectiveness [15].

The basis for enhanced decision making is the availability of timely and high-quality data. The current situation on European farms is that most data and information sources are fragmented, dispersed, difficult, and time consuming [2]. There is a large opportunity, both in Europe and in Brazil, for the integration of data in order to generate information and knowledge.

3.2.2. *Education and knowledge of farmers and the low technological level of farms*

Expert 3 cited lack of knowledge as the main difficulty for farmers when they purchase agricultural machinery that incorporates a higher level of technology. The level of education among rural workers is one of the main challenges to adopting technologies in Brazil, compared to other developed countries. This knowledge comprises both the educational foundation and the technological sophistication needed to manage the tools.

In Brazil, 27% of rural landowners are illiterate, 9% did not complete elementary school (non-illiterate), and 53% have only an elementary education [46]. This may indicate a possible barrier to the diffusion of innovations in technologies such as SF in Brazilian agriculture. One study has reported a positive relationship between education and adoption of management technologies [34]. Therefore, education could increase farmers' ability to process information, make decisions, and use SF [47]. In the same way, the skills obtained from education facilitate farmers' use of computers and SF [48].

Another aspect related to education and knowledge is the low level of technology adoption on some farms and in certain regions of Brazil. Expert 2 stated that his company faces limits in the development of radical innovations because such products are not readily adopted on farms or have a low potential to generate good results. Most farms employ a low technological level of management, which does not accommodate the high level of technology involved SF tools.

The generation and diffusion of technology has been relatively successful in a restricted portion of agricultural producers in Brazil. For example, a high proportion of rural producers, especially in the northern and northeastern regions of Brazil, still exhibit low use of fertilizers, machines, and equipment [10].

The SF technologies (telemetry, real-time monitoring, and automation, for example) that the experts describe were developed for properties that already use a high level of technology. Rural properties that have not adopted technologies could not receive any profit from adopting SF technologies.

3.2.3. *Poor telecommunications infrastructure in rural areas*

Another obstacle raised by Expert 3 is the precarious telecommunications infrastructure in Brazil, which makes data transmission via devices such as mobile phones and tablets unreliable. SF requires real-time connection with the internet to enable the use of information. Many of the office operation control systems, such as seed volume, fertilizers, and pesticides, require high-quality internet connection to produce results.

According to data from the agricultural census by the Brazilian Institute of Geography and Statistics [30], only

Table 3 – Total frequency of smart farming terms present in the scientific literature from 1975 to 2015.

Factors	Terms	Frequency	Number of cases	TF•IDF
Management	Farm management	68	34	45.0
	Farm management information	27	16	26.7
	Decision support	17	9	21.1
	Risk management	13	3	22.3
	Data management	6	4	9.5
Technology and electronics	Internet of things	164	61	66.9
	Big data	47	17	45.2
	Wireless sensor	38	24	30.9
	Smart agriculture	21	15	21.4
	Cloud computing	18	10	21.5
Production and environment	Agricultural production	14	10	16.7
	Field information	12	3	20.6
	Sustainable agriculture	8	4	12.7
	Nitrogen index	9	1	19.7
	Climate change	9	3	15.4

4.54% of farms had computers in Brazil, and only 1.87% of Brazilian farmers accessed the internet on their farms [34]. Although these statistics are from the last Brazilian census (in 2006), and this scenario has changed considerably, some new grain production regions (e.g., the midwestern and northeastern regions of Brazil) still have poor mobile internet signals.

Furthermore, access to IT by Brazilian farmers tends to occur predominantly on large farms [34]. In recent years, with the expansion of mobile telephones, a greater number of rural producers have gained access to mobile internet; however, input speed and signal quality are still limited. Access to the internet has been one of the main challenges to SF adoption in Brazil.

3.2.4. *Difficulty with data manipulation from equipment, machines, and software*

In Expert 4's perception, the producers' lack of ability to organize and manipulate data obtained by the equipment's sensors is an obstacle. The expert reported, for example, that some experimental weather stations installed on rural properties generate a relevant amount of data; however, in most cases, the producers do not know how to use the information and lack the programs to convert these data into a more accessible form.

Complex systems present a challenge in terms of acceptability and usability, causing the farmers to revert to using ad hoc calculations via, for example, standard spreadsheet software [2]. With the largest volume of data available, analytical systems and graphical interfaces need to increase the capacity for farmer data analysis with useful and easy-to-read information.

There is a trend toward integrating sensors and computers to analyze livestock SF, as presented by Wathes et al. [49]. Despite the great potential of livestock SF, most farmers and other stakeholders do not currently have the skills to use these technologies effectively [49]. Farmer advisors and those involved in the production process need to adapt to the new availability of data and information in productive systems and learn how to handle these systems.

3.3. *Exploring the SF scientific literature: a text-mining approach*

This section presents the results of a bibliometric analysis carried out on the scientific literature. To understand how the scientific literature frames SF can help to understand the themes and foci that predominated in the beginning, while at the same time contributing to visualization of new approaches for studying this subject.

3.3.1. *Factor analysis*

In characterizing the scientific literature on SF, the most relevant terms are presented in Table 3. The factor with the greatest number of terms is "technology and electronics". There is an imbalance between the terms attached to technology, management, and environment. The focus of the current work is on the development of technologies. The aspects related to production management, environment, and sustainability do appear; however, they are relatively recent to the literature.

The term "internet of things" within the area of "technology and electronics" appears more frequently in publications. This term appears with increasing frequency in publications related to SF (especially after 2010), and it is linked to the search for communication between physical objects and computer systems.

Commonly known as internet of things, it provides a vision of a world in which the internet extends into the real world, embracing everyday objects by utilizing the power of combining ubiquitous networking with embedded systems, radio-frequency identification (RFID), sensors and actuators. The software and equipment developed for this theme will focus on connectivity, internet of things, and cloud computing [18,50].

The term "big data" is recent in the literature and has received attention from researchers. This term is related to technology and electronics and is associated with SF. Big data is used to refer to an increase in the volume of data, which are difficult to store, process, and analyze through traditional database technologies [50].

Table 4 – Total frequency (%) of relevant terms in the analyzed scientific literature, by country, 1945–2015.

Factors	Terms	China	USA	South Korea	Germany	Japan	Other
Management	Data management	66.7%			16.7%		16.6%
	Decision support	17.6%					82.4%
	Farm management		7.4%	22.1%			70.5%
	Farm management information	3.7%	3.7%		16.2%		76.4%
	Risk management	84.6%		7.7%			7.7%
Technology and electronics	Big data	2.1%	21.3%	12.8%	4.3%	34.0%	25.5%
	Cloud computing	50.0%	5.6%			11.1%	33.3%
	Internet of things	75.6%	5.5%		1.2%		17.7%
	Smart agriculture	9.5%	4.8%	28.6%	4.8%	14.3%	38%
	Wireless sensor	50.0%			5.3%	5.3%	39.4%
Production and environment	Agricultural production	78.6%					21.4%
	Climate change			22.2%			77.8%
	Field information	100.0%					–
	Nitrogen index		100.0%				–
	Sustainable agriculture		75.0%				25.0

The term "wireless sensor" appears in the third position in the factor "technology and electronics". This term reinforces the experiences described by the respondents, especially Expert 3, who highlighted the change in the technology of storage and transmission of data, previously via memory cards, for remote-data transmission. The use of SF tools is possible due to the use of sensors in agriculture [16].

"Cloud computing" technology enables the use of SF. This term first appeared in the literature in 2011, with seven observations in the manuscripts analyzed by 2014. For Experts 1 and 4, this area requires more attention, particularly regarding the security and privacy of stored data. Expert 3's company continues to develop its agronomic information systems, with access restricted to farmers/owners. The information linked to machines or equipment is shared with the authorized company's plant only for the purposes of maintenance and remote control settings.

Analysis of the main terms present in the scientific publications also reveals an emphasis on sustainability and environment, as seen under the factors "climate change" and "sustainable agriculture". One of the objectives in the development and diffusion of SF technologies is that they minimize the negative effects on the environment caused by agriculture and livestock [14].

3.3.2. *Country analysis*

The country[1] with the highest number of publications analyzed was China (31.84%), followed by the United States (8.94%) and South Korea (8.38%). Although South Korea has a small amount of arable land, it has important centers of research and technology development as well as companies in the electronics and computer industry, which provides a favorable environment for the development of SF technologies. Countries such as Germany and Japan also stand out, with a high number of publications in the scientific literature at 6.15% and 5.59%, respectively.

Analysis of the five countries that produce the most scientific knowledge linked to SF is illustrated in Table 4. China stands out in the area of "technology and electronics". The three terms analyzed in this factor have high frequency: "internet of things", "cloud computing", and "wireless sensor", demonstrating mastery in science production in this area. China also stands out in the production of knowledge related to "field information" and "agricultural production" when considering the factor "production and environment".

The most frequent factor developed by Japan has been in "technology and electronics". Japan has a small agricultural area, but, based on the data, there is a strong presence of R&D in technology in agriculture. South Korea is similar to Japan; this is due to its small land area and low relevance in the global context in terms of food production. However, these countries have large companies and technology research centers, particularly in the computer and electronics sectors, making their development and studies related to agriculture significant.

The new players in SF are tech companies that were traditionally not active in agriculture [3]. For example, some Japanese technology firms, such as Fujitsu, have been advising farmers with their cloud-based farming systems [3]. This firm collects data (rainfall, humidity, soil temperatures) from a network of cameras and sensors across the country to help farmers in Japan better manage their crops and expenses [51].

The United States and Germany also have a high frequency of terms linked to this theme, but the frequency is less than that of China. SF requires that resources be invested in the R&D of software and hardware (among other technologies) as well as human capital to advance development.

After analyzing the countries that are leaders in these technologies (Table 4), it is worth noting that they have the largest investments in R&D in the world. South Korea is the world's leading spender on R&D as a percentage of its gross domestic product (GDP); it invested 4.29% of its GDP in R&D in 2014. Japan is in the third position, expending 3.58% of its GDP on R&D [14]. In terms of total resources, the United States, followed by China and Japan, has consistently spent the most on R&D.

[1] Considering the country of origin of the first author listed in the text.

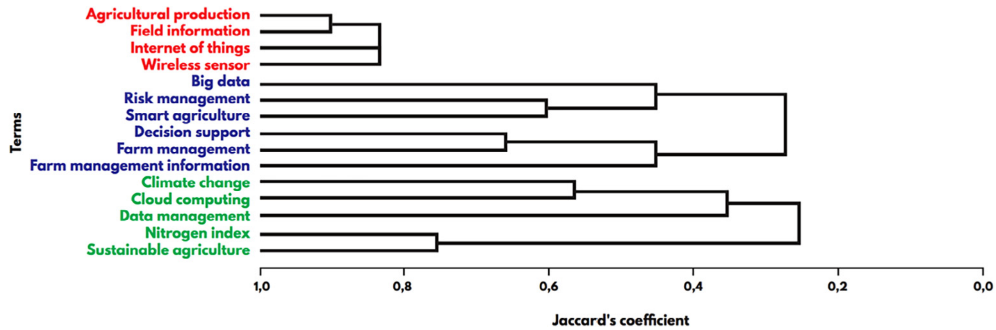

Fig. 3 – Dendrogram with the most frequently used terms in the analyzed scientific literature.

3.3.3. *Evolution of the scientific literature*

By analyzing the evolution of the scientific literature, the first publication on the subject was from 1976; it focuses on a farm management system. The term "farm management" reemerges in 2011, when 15 publications appear throughout the year. The return of the discussion of this term in the literature may be related to the progress of research, with the use of information technology and the new possibilities of managing the farm with technologies linked to SF, especially the possibilities of automation that arise from this concept.

The term "data management" appeared in 2011; this is a developing field, as cited by Expert 4, and it is important to the advancement and dissemination of SF tools. According to this expert, the advancement of these technologies depends on developing software to analyze and process the data generated by the sensors and on creating an easy-to-use interface.

The term "decision support" appears in the literature in 2003, not reappearing until 2012. Expert 1 reports that the Brazilian market offers few decision-making resources concerning overall farm management. This may be due to fewer technologies and systems being available for zootechnical or agronomical issues, since current SF processes center on agricultural machinery and implements. Expert 1 discusses the concept of hyper-interconnected systems, or systems with multiple objects communicating in real time for decision making; however, these ideas are restricted to academic discussions and do not have significant applications in the agricultural environment.

3.3.4. *Cluster analysis*

The Jaccard coefficient was used to analyze the similarity in the occurrence of the most frequent terms in the scientific literature (grouped into three clusters) (Fig. 3). The Jaccard coefficient calculates the similarity of the selected terms; the closer to 1, the greater the similarity of the terms.

The first cluster of terms has the greatest similarity and consists of items related to technology factors and production management. The terms "internet of things", "wireless sensor", "field information", and "agricultural production" are closer, showing that these technologies are beginning to integrate production areas, initially in experimental areas.

While there are doubts about whether farmers' knowledge can be replaced by algorithms, SF applications are likely to change the way farms are operated and managed [12]. Key areas of change include real-time forecasting, tracking of physical items, and reinventing business processes [52].

The second cluster includes terms such as "big data", "smart agriculture", "decision support", "farm management", and "risk management". The Jaccard coefficient demonstrates that these technologies, especially "big data", are being studied in the context of agriculture in order to reduce risk in production systems, decrease the risk of process failure, and provide information knowledge for decision making.

This is expected to lead to radical changes in farm management because of access to explicit information and decision-making capabilities that were previously not possible, through the traditional way of collecting and analyzing data, either technically or economically [40]. Consequently, there has been a rise of some ag-tech companies that push this data-driven development further [53], seeking to sell services and data to farmers.

The third cluster used terms such as "climate change", "cloud computing", "data management", "nitrogen index", and "sustainable agriculture". Climate change and sustainable agriculture terms associated with cloud computing and data management exhibited concern for applied new technologies to reduce the impact from agriculture on the environment. The term "nitrogen index" denotes concern about specific issues within the broader issue of sustainability.

Based on the Jaccard coefficient, it is possible to infer that the research has not yet been integrated with different factors such as technology, management, and environment. The development of technologies is separate from advances in management, data analysis, and sustainability issues. There is a need to integrate this research and knowledge about the potential for SF implementation, especially for sustainability and climate change.

4. Final considerations

Analysis of the literature terms highlighted different concerns attributed to the use of SF between those noted by the experts and those observed in the scientific literature. The first focus of the scientific literature was on developing technology for SF. The second was on the management of these technologies and integration in supply chains and on farms.

The third is on the impact of these technologies on the production system and the environment.

The Brazilian market is in the initial development phase of SF technology adoption, with several agents seeking business opportunities in this sector. Observing the application of these technologies in Brazil, the supply and development of SF tools are currently concentrated in machinery and equipment, and the companies in this sector are responsible for implementing the first prototypes on integrated farms.

Among the barriers to development and adoption of SF technologies, the lack of integration between the different systems within the supply chains is a primary limiting factor. This barrier could be worked through international committees and strategic alliances between companies. Some startups begin to use some open standards (e.g., Isobus) through which they are able to combine different datasets.

Another limiting factor refers to the education, ability, and skills of farmers to understand and handle SF tools. The low level of rural schooling in the available labor force constrains further diffusion of these technologies in Brazilian agriculture. This barrier can be overcome through macroeconomic policies that improve access to education, as well as trainings and courses by companies that provide these services and products and by farmers' associations.

China, the United States, South Korea, Germany, and Japan have contributed the largest number of scientific studies to this field. Leadership in publishing SF research is associated with how much countries spend on R&D annually. Countries that invest more in R&D have the highest number of publications. This could indicate which countries will be leaders in smart agriculture technologies in the future. Before it becomes a techno-economic paradigm, a consistent scientific paradigm is needed to allow these innovations to emerge.

It is interesting to note that SF scientific knowledge creation has been led by developed countries with high levels of investment in R&D, but with relatively low levels of arable land availability. Currently, scientific efforts have mainly been directed toward the development of SF hardware and software solutions. The application of these technologies at the farm level should intensify in the coming years. Therefore, it will be necessary to connect the technologies and the collected data in order to automate decision-making strategies.

The present findings show that Brazil tends to adopt SF technology but does not contribute considerably to its development. However, even the potential benefits of adopting SF technologies may be at risk. According to the barriers to adopting SF technologies reported by experts, Brazil has severe structural constraints that may take time to overcome. As a recommendation for future studies, including the terms "precision agriculture", "precision farming", and "technology information in agriculture" in the search might capture a greater number of scientific documents about this subject.

Appendix A. The questions that guided the interview questions

Item	Question
1	What cultures have companies and research institutions that prioritize developing products for SF (marketing and development)?
2	What products and services in the area of SF have been developed by companies and research institutions in Brazil?
3	What are the barriers to the development and commercialization of these new technologies in Brazil (SF)?
4	What is the profile of farmers who purchase these tools?
5	What are the barriers for rural producers to adopt these tools and technologies?
6	What are the market trends in the area of SF?

REFERENCES

[1] Brazilian Agricultural Research Corporation. Visão 2014–2034: o futuro do desenvolvimento tecnológico da agricultura brasileira: síntese. Brasília: Embrapa; 2014. Link: https://www.embrapa.br/documents/1024963/1658076/Documento+Visão+-+versão+completa/7bf520f2-7329-42c0-8bf0-15b3353c3fdb.

[2] Fountas S, Carli G, Sørensen CG, Tsiropoulos Z, Cavalaris C, Vatsanidoud A, et al. Farm management information systems: current situation and future perspectives. Comput Electron Agric 2015;115:40–50.

[3] Wolfert S, Ge L, Verdouw C, Bogaardt M. Big data in smart farming: review. Agric Syst 2017;153:69–80.

[4] Sundmaeker H, Verdouw C, Wolfert S, Pérez Freire L. Internet of food and farm 2020. In: Vermesan O, Friess P, editors. Digitising the industry: internet of things connecting physical, digital and virtual worlds. Peter Friess: River Publishers; 2016. p. 129–51.

[5] Brettel M, Friederichsen N, Keller M, Rosenberg M. How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective. IJMEA 2014;8(1):37–44.

[6] Lasi H, Fettke P, Kemper HG, Feld T, Hoffmann M. Industry 4.0. Bus Inf Syst Eng 2014;6(4):239–42.

[7] Liao Y, Deschamps F, Loures EDFR, Ramos LFP. Past, present and future of industry 4.0-a systematic literature review and research agenda proposal. Int J Prod Res 2017;55(12):3609–29.

[8] Maynard AD. Navigating the fourth industrial revolution. Nat Nanotechnol 2015;10(12):1005–6.

[9] Perez C. The financial crisis and the future of innovation: a view of technical change with the aid of history; 2010. p. 28. Link: http://www.carlotaperez.org/downloads/pubs/Crisis_and_innovation_TUT-TOC_WP_No2_8.pdf.

[10] Vieira Filho JER. Transformação histórica e padrões tecnológicos da agricultura brasileira. In: Buainain AM, Alves E, Silveira JM, Navarro Z, editors. O mundo rural no Brasil do século 21: a formação de um novo padrão agrário e agrícola. Brasília: IE-Unicamp and Embrapa; 2014. p. 395–421.

[11] Poppe KJ, Wolfert J, Verdouw CN, Renwick A. A European perspective on the economics of big data. Farm Policy J 2015;12(1):11–9.

[12] Drucker V. Agriculture springs into the digital age. fund strategy; 2014. Link: https://www.fundstrategy.co.uk/issues/fund-strategy-sept-2014/agriculture-springs-into-the-digital-age.
[13] Food and Agriculture Organization of the United Nations. Global agriculture towards 2050. Rome: Food and Agriculture Organization of the United Nations; 2009.
[14] Beecham Research. Towards smart farming: agriculture embracing the IoT vision. Link: http://www.beechamresearch.com/files/BRL%20Smart%20Farming%20Executive%20Summary.pdfhttp://www.beechamresearch.com/files/BRL%20Smart%20Farming%20Executive%20Summary.pdf; 2014.
[15] Sørensen CG, Fountas S, Nash E, Pesonen L, Bochtis D, Pedersen SM, et al. Conceptual model of a future farm management information system. Comput Electron Agric 2010;72(1):37–47.
[16] Lehmann RJ, Reiche R, Schiefer G. Future internet and the agri-food sector: state-of-the-art in literature and research. Comput Electron Agric 2012;89:158–74.
[17] Gubbi J, Buyya B, Marusic S, Palaniswami M, et al. Internet of Things (IoT): a vision, architectural elements, and future directions. Future Gen Comput Syst 2013;29(7):1645–60.
[18] Kaloxylos A, Eigemann R, Teye F, Politopoulou Z, Wolfert S, Shrank CS, et al. Farm management systems and the future internet era. Comput Electron Agric 2012;89:130–44.
[19] Schumpeter JA. The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle. New Brunswick: Transaction Publishers; 1934.
[20] Schumpeter JA, Garcia JD. Capitalismo, socialismo y democracia. Barcelona: Orbis; 1983.
[21] Perez C. New technologies and development. In: Freeman C, Lunvall BA, editors. Small countries facing the technological revolution. London: Pinter Publishers; 1988. p. 85–97.
[22] Freeman C, Perez C. Structural crisis of adjustment, business cycles and investment behaviour. In: Dosi G, Freeman C, Nelson R, Silverberg G, Soete L, editors. Technical change and economic theory. London: Pinter; 1988. p. 38–66.
[23] Perez C. Microelectronics, long waves and world structural change: new perspectives for developing countries. World Dev 1985;13(3):441–63.
[24] Penrose ET. The theory of the growth of the firm. Oxford: Oxford University Press; 2009.
[25] Cohen WM, Levinthal DA. Absorptive capacity: a new perspective on learning and innovation. Adm Sci Q 1999;35(1):128–52.
[26] World Bank. Research and development expenditure (% of GDP). Link: http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS; 2017.
[27] Dosi G. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Res Policy 1982;11(3):147–62.
[28] Mason M. Sample size and saturation in PhD studies using qualitative interviews. Forum Qual Soc Res 2010;11(3):01–19.
[29] Barretto AGOP, Lino JS, Sparovek G. Bibliometria da pesquisa brasileira em erosão acelerada do solo: instituições, temas, espaço e cronologia. R Bras Ci Solo 2009;33(6):1845–54.
[30] Gautam P, Ryuichi Y. Reflection of cross-disciplinary research at Creative Research Institution (Hokkaido University) in the Web of Science database: appraisal and visualization using bibliometry. Scientometrics 2012;93(1):101–11.
[31] Cao Y, Sixing Z, Guobin W. A bibliometric analysis of global laparoscopy research trends during 1997–2011. Scientometrics 2013;96(3):717–30.
[32] Gomes J, Dewes H. Disciplinary dimensions and social relevance in the scientific communications on biofuels. Scientometrics 2017;110(3):1173–89.
[33] Provalis Research. WordStat: Content analysis module for SIMSTAT and QDA miner – user guide. Montreal: Canada; 2005.
[34] Carrer MJ, Souza Filho HM, Batalha MO. Factors influencing the adoption of Farm Management Information Systems (FMIS) by Brazilian citrus farmers. Comput Electron Agric 2017;138:11–9.
[35] Van Hertem T, Rooijakkers L, Berckmans D, Peña Fernández A, Norton T, Berckmans D, et al. Appropriate data visualisation is key to precision livestock farming acceptance. Comput Electron Agric 2017;138(1):1–10.
[36] Faulkner A, Cebul K. Agriculture gets smart: the rise of data and robotics. São Francisco: Cleantech Group. Link: https://www.cleantech.com/wp-content/uploads/2014/07/Agriculture-Gets-Smart-Report.pdf; 2014.
[37] Holmes M. Different industries debate the potential of UAVs and the need for satellite. Link: http://www.satellitetoday.com/ technology/2014/10/24/different-industries-debate-the-potential-of-uavs-and-the-need-for-satellite/; 2014.
[38] Anonymous. Technology helps farmers to cater climate changes effects. Link: http://www.flare.pk; 2017.
[39] Salami P, Hojat A. Review of farm management information systems (FMIS). N Y Sci J 2010;3(5):87–95.
[40] Sonka S. Big data: from hype to agricultural tool. Farm Policy J 2015;12(1):1–9.
[41] Bernardi ADC, Naime JDM, De Resende AV, Bassoi L, Inamasu R. Agricultura de precisão: resultados de um novo olhar. Brasília: Embrapa; 2014. p. 19–20.
[42] Busse M, Doernberg A, Siebert R, Kuntosch A, Schwerdtner W, König B, et al. Innovation mechanisms in German precision farming. Precis Agric 2014;15(4):403–26.
[43] Chen CLP, Chun-Yang Z. Data-intensive applications, challenges, techniques and technologies: a survey on big data. Inf Sci 2014;275:314–47.
[44] Bassoi LH, Miele A, Reisser Júnior C, Gebler L, Flores CA, Filippini JM, et al. Agricultura de precisão em fruticultura. In: Bernardi ADC, Naime JDM, De Resende AV, Bassoi L, Inamasu R, editors. Agricultura de precisão: resultados de um novo olhar. Brasília: Embrapa; 2014. p. 350–60.
[45] Foster AD, Mark RR. Microeconomics of technology adoption. Annu Rev Econ 2010;2(1):395–424.
[46] Brazilian Institute of Geography and Statistics. Censo agropecuário; 2006. Link: http://biblioteca.ibge.gov.br/visualizacao/periodicos/51/agro_2006.pdf.
[47] Feder G, Just RE, Zilberman D. Adoption of agricultural innovations in developing countries: a survey. Econ Dev Cult Change 1985;33(2):255–98.
[48] Alvarez J, Peter N. Adoption of computer based information systems: the case of dairy farmers in Canterbury, NZ, and Florida, Uruguay. Comput Electron Agric 2006 50(1):48.
[49] Wathes CM, Kristensen HH, Aerts JM, Berckmans D. Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall? Comput Electron Agric 2008;64(1):2–10.
[50] Hashem IAT, Yaqoob I, Anuar NB, Mokhtar S, Gani A, Khan SU. The rise of big data on cloud computing: review and open research issues. Inf Syst 2015;47:98–115.
[51] Carlson C. Fujitsu rolls out cloud-based big data platform for farmers; 2012. Link: http://www.fiercecio.com/story/fujitsu-rolls-out-cloud-based-big-data-platform - farmers/2012-07-19.
[52] Devlin B. The Big Data Zoo – taming the beasts: the need for an integrated platform for enterprise information. Cape Town: 9sight Consulting; 2012. Link: http://www.9sight.com/2012/10/wp-big-data-zoo.
[53] Lesser, A. Big data and big agriculture. Gigaom Research; 2014. Link: https://gigaom.com/report/big-data-and-big-agriculture.