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Scientific Development of Smart Farming Technologies and The Applications In Brazil

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A B S T R A C T

Smart farming involves the incorporation of information and communication tech- nologies into machineries, equipments, and sensors for the use in agricultural production systems. New technologies such as the IOT and cloud computing are expected to advance this development, introducing more robots and artificial intelligence into farming. Therefore, the goal of this paper are twofold: (a) to characterize the scientific knowl edge about Smart farming that is available in the worldwide scientific literature based on the main factors of development by country and over time and (b) to describe current Smart farming prospects in Brazil to the perspective of experts in this field. The research involved conducting semi-structured interviews with market and researcher experts in Brazil and using a biblio metric 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 smart farming evolution. Another limiting factor is the education, ability, and skills of farmers to under- stand and handle smart farming 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 sci entific studies to the field. this could indicate which countries will be leaders in smart farming.

Keywords: Agricultural innovation, Big data, Data in agriculture, Information technology, Text mining

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1. INTRODUCTION

Technology development, such as for use of electronic systems and data transmissions, has introduced radical changes to the agricultural working nature in recent years. These change to the 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 based on the incorporation of information and communication technologies into machinery, equipment, and sensors in agriculture production systems, allows the large storage 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 con- tinued 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 con- tinue to alter growing conditions, such as the temperature, precipitation, and soil moisture, in less predictable ways smart farming tools can help reduce these impacts, keep them constant or reduce production costs in agricultural activities, and they can assist in minimizing environmental constraints.

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

Considering this context, this research aims to achieve the following objectives: (i) to characterize the scientific knowl- edge about SF that is available in the worldwide scientific lit- erature based on the main factors of development by country and over time and (ii) to describe current smart farming prospects in Brazil from the perspective of experts in this field.

Identifying how science frames smart farming 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 smart farming and illuminate new applications. Furthermore, analysing of the smart farming Brazilian market has allowed the people to identify the stages and main barriers to adoption for technologies.

These two steps have contributed to understanding of economic and social aspects that may determine the emer- gence of a new technical process in agriculture. A new technical process, corresponding to a new set of more profitable and viable productive practices – in terms of inputs, methods and

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technology choices along with new organizational structures, business models and strate- gies. smart farming can become a new technical process in agriculture.

In this research, Brazil is chosen because of its agricul- tural potential and the role of technology in increasing pro- ductivity 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. Since the 1990s, while world production has been stagnating, Brazilian agriculture has been dynamic and growing. 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 technolo- gies, 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 unex- plored ways, which is what occurred with the widespread adoption of tractors and the introduction of pesticides in the 1950s.

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. The technologies linked to smart farming will be important in meeting this challenge of increased food production in the face of constraints such as climate change and other environmental issues.

2. *Smart farming theory*

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

The smart farming field comprises terms with similar meanings, such as smart agriculture. Accordingly, collapsing interfaces

and technologies exist and encompass ideas such as preci- sion agriculture and management information systems in agriculture, which have been derived from the idea of the farm management information system (FMIS). FMIS is defined as a system that is designed for collecting, processing, storing, and disseminating data in a required format to per- form operations and functions on rural properties.

The using of smart farming tools is possible due to use of sensors in agriculture. A sensor is an electric technical device that measuring 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

Investments in R&D are needed, as there are degrees of technology accumulation and different efficiencies in tech- nology and innovative research processes when comparing different regions and countries. According to the World Bank, there has been a concentration of R&D investment expenditures (i.e., % of gross domestic

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product) in 2013 for both public and private R&D in certain countries, including South Korea (4.15%), Japan (3.47%), Denmark

(3.60%), Ger- many (2.85%), and the USA (2.81%). The nature of technolo- gies has been suggested to be broadly similar to those that characterize science, that is, there is the expectation that these countries can lead research, because SF requires inter- related technologies originating from areas of management, electronics, production

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. 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. SF tools introduce a new level of technology into agriculture, including robotics, mapping and geomatics technologies, One of the discussions about new technologies has

emerged from the study of Schumpeter, who reported on the essence of economic development in relation to inno- vation. Technological innovation changes production pat- terns and can differentiate between economic development in regions and countries.

Periods of breakdown of technological processes introduce a whole wave of new products and processes, gen- erating fundamental changes in a society (structural changes), with more profitable and viable productive practices.

In the agricultural sector, profound structural changes have occurred with the incorporation of mechanization and chemistry. These are examples of techno-economic para- digms 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. However, to change the techno-economic paradigm, formal and institutionalized organiza- tion of research and development (R&D) departments may be necessary.

Investments in R&D are needed, as there are degrees of technology accumulation and different efficiencies in tech- nology and innovative research processes when comparing different regions and countries. According to the World Bank, 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%), Ger- many (2.85%), and the USA (2.81%). The nature of technolo- gies has been suggested to be broadly similar to those that characterize science, that is, there is the expectation that these countries can lead research, because SF requires inter- related technologies originating from areas of management, electronics, production, and other research fields.

3. Bibliometric and scientific analysis using text mining

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

The key- words 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 are obtained from the data collection. Of these, some did not possess the avail- able 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 veteri- nary or agronomic fields). By the end of this process, 179 sci- entific 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 are excluded. Stopwords are considered to be non-informative since they do not summarize the content that the text addresses in a satisfactory way. The exclusion dictionary from the soft- ware 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 key- words 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 are 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-

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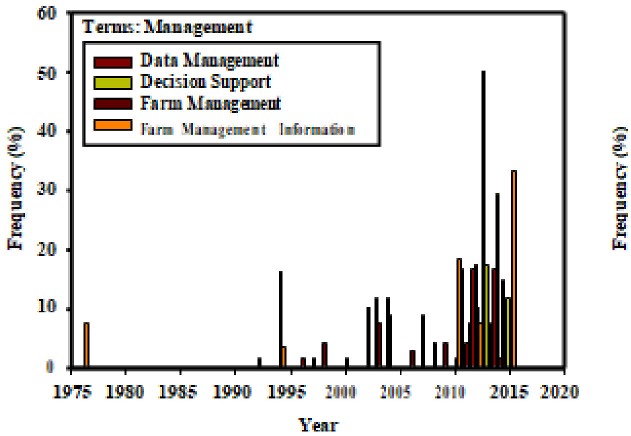
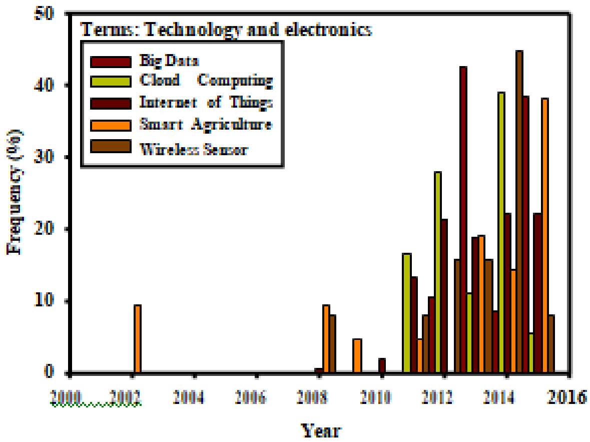
Fig. 1 – The process of collecting, selecting, organizing, and extracting knowledge from scientific publications while applying text-mining techniques.





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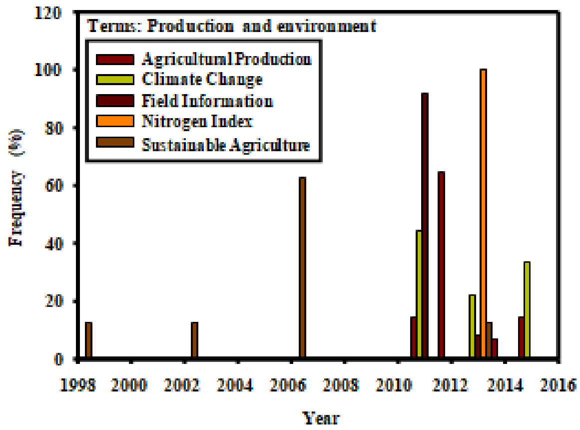

Fig. 2 – Number of publications (occurrence and intensity) of terms selected in the scientific literature. Each of these factors contained five terms that encom- passed the most frequent terms of the analysis.

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 coeffi- cient. This coefficient is used to compare the similarity and diversity of sample sets, assuming values from 0 to 1. The clo- ser the index is to 1, the more similar the terms are

4. Results and discussion

SF prospects in Brazil

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

Expert 1

In relation to the smart farming 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 ini- tial process of developing technologies, with various agents and organizations entering and seeking opportunities to gen- erate innovations.

The smart farming market in Brazil is more invested in agriculture than in livestock. In livestock smart farming in Europe, there are a large number of farmers using these technologies, 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 plant- ing and harvesting via telemetry to connect, for example, the combine harvester with industry data. Another SF tool used in this sector is the

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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. Drones with infrared cam- eras and GPS technology are transforming agriculture due to their enhancement of decision making and risk management. 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 smart farming tools is currently focused on machinery and equipment, and the companies in this sector are responsible for implementing the first proto- types on integrated farms. Some of these agents, such as computing businesses, agricultural companies and startup companies that are set up close to the academic environment are discovering opportunities in smart farming, 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 and Salami and Ahmadi. That is, the technologies related to smart farming are still in early development, but the possibilities are numerous. In agriculture, the develop- ment 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, espe- cially 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.

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.

According to Expert 2, telemetry technology enables real- time monitoring of agricultural activities, where the property manager can access this information on a smart phone or a computer. Additionally, these new technological data are not only in traditional tables but can also appear in other for- mats, such as sounds or images. 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 indicates that the most common functions in software linked to smart farming 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.

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Expert3 : The main advances in have occurred in automatic data col-lection, 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 oper-ations. If there is a cost increase in collecting the data and

processing it, farmers will be less likely to adopt these technologies. New technologies in smart farming can cause additional adaptations and modifications of tools, changing how farms are organized and making smart farming 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 compa- nies 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 tradi- tional data-processing platforms. Big data is particularly challenging for farmers, especially those running smaller operations.

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

Expert 4

In addition to the use of smart farming 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.. Fruit crops, which have a high value per hectare, could benefit greatly from the application of smart farming.

For Expert 4, integration between the different systems

available on the market was one of the main limiting factors to smart farming evolution. The acquisition and analysis of information has arisen from diverse sources that are located at many sites. 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 cohe- sive interoperability among services and stakeholders. For example, in the production of grapes for winemaking, it is still difficult to integrate weather information from the meteoro- logical stations of national networks with soil information. Future internet infrastructure is expected to handle these shortcomings.

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5. Barriers to the adoption of smart farming technologies

Technology adoption is a process with a certain level of heterogeneity in terms of the factors that affect it. It is very useful to understand these factors in the process of technol- ogy adoption in order to increase the rate of adoption.

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 . corroborate this notion, explaining that the lack of integration among the available tools on the market limits smart farming 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; how- ever, these initiatives are emergent. Integration across sys- tems is one of the areas where smart farming 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 cre- ate 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 communica- tion 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 usereffectiveness.

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. There is a large opportunity, both in Europe and in Brazil, for the integration of data in order to generate information and knowledge.

6. Education and understanding of farmers and the lowtechnology stage 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 educa- tion among rural workers is one of the main challenges to adopting technologies in Brazil, comparing to other developed countries. This knowledge comprises both the educational foundation and the technological sophistication needed to manage the tools.

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In Brazil, 27% of rural landowners are illiterate, 9% did not complete elementary school (non-illiterate), and 53% have only an elementary education. This may indicate a possi- ble barrier to the diffusion of innovations in technologies such as smart farming in Brazilian agriculture.. Therefore, education could increase farmers' ability to process information, make deci- sions, and use smart farming. In the same way, the skills obtained from education facilitate farmers' use of computers and smart farming.

Another aspect related to education and knowledge is the low level of technology adoption on some farms and in cer- tain 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 accom- modate the high level of technology involved smart farming tools.

The generation and diffusion of technology has been rela- tively successful in a restricted portion of agricultural produc- ers 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.

The smart farming 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.

7. Poor telecommunications infrastructure in rural areas Another obstacle raised by Expert 3 is the precarious telecom- munications infrastructure in Brazil, which makes data trans- mission via devices such as mobile phones and tablets unreliable. smart farming 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 pesti- cides, require high-quality internet connection to produce results.

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

4.54% of farms had computers in Brazil, and only 1.87% of Brazilian farmers accessed the internet on their farms. 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. 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 smart farming adop- tion in Brazil.

8. Difficulty with data edit from equipment, machines, and software

In Expert 4's perception, the producers' lack of ability to orga- nize and manipulate data obtained by the equipment's sen- sors is an obstacle. The expert reported, for

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example, that some experimental weather stations installed on rural prop- erties 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 accept- ability and usability, causing the farmers to revert to using ad hoc calculations via, for example, standard spreadsheet software. With the largest volume of data available, analyt- ical 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 smart farming as presented by Wathes Despite the great potential of livestock smart farming, most farmers and other stakeholders do not currently have the skills to

Table 1 – 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

use these technologies effectively. 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.

9. Exploring the smart farming 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.

Factor analysis

In characterizing the scientific literature on smart farming, the most relevant terms are presented in table 1. 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 sus- tainability do appear; however, they are relatively recent to the literature.

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The term ‘‘internet of things” within the area of ‘‘technol- ogy and electronics” appears more frequently in publications. This term appears with increasing frequency in publications related to smart farming (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 comput- ing.

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 smart farming. 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

Table 2– 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%		18.2%		74.4%
	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	73.6%	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 smart farming tools is possible due to the use of sensors in agriculture.

‘‘Cloud computing” technology enables the Thterm first appeared in the literature in 2011, with seven obser- vations in the manuscripts analyzed by 2014. For Experts 1 and 4, this area requires more attention, particularly regard- ing the security and privacy of stored data. Expert 3’s com- pany continues to develop its agronomic information systems, with access restricted to farmers/owners.

Analysis of the main terms present in the scientific publi- cations also reveals an emphasis on sustainability and envi- ronment, as seen under the factors ‘‘climate change” and ‘‘sustainable agriculture”. One of the objectives in the devel- opment and diffusion of smart farming technologies is that they mini- mize the negative effects on the environment caused by agriculture and livestock.

Country analysis

The country[1] with the highest number of publications ana- lyzed 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

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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 technolo- gies. 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 scien- tific knowledge linked to SF is illustrated in Table 2. China stands out in the area of ‘‘technology and electronics”. The

three terms analyzed in this factor have high frequency: ‘‘in-

ternet 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 smart farming are tech companies that were tradi- tionally not active in agriculture. For example, some Japa- nese technology firms, such as Fujitsu, have been advising farmers with their cloud-based farming systems. 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. The United States and Germany also have a high fre- quency 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 technolo-gies) as well as human capital to advance development.

After analyzing the countries that are leaders in these technologies (table 2), it is worth noting that they have the largest investments in R&D in the world

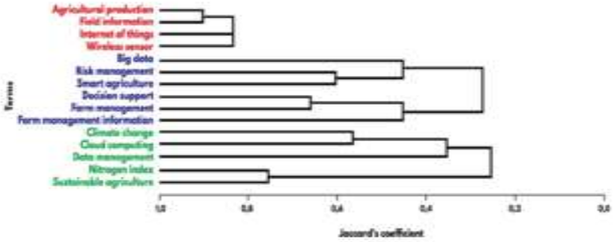

Fig. 3 – Dendrogram with the most frequently used terms in the analyzed scientific literature.

Evolution of the scientific literature

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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’’ ree- merges in 2011, when 15 publications appear throughout the year. The return of the discussion of this term in the liter- ature 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 smart farming 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 smart farming 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 con- cerning 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 agri- cultural 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 dis- cussions and do not have significant applications in the agri-cultural environment.

Cluster analysis

The Jaccard coefficient was used to analyze the similarity in the occurrence of the most frequent term in the scientific lit- erature (grouped into three clusters) (Fig. 3). The Jaccard coef- ficient 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 sen- sor’’, ‘‘field information’’, and ‘‘agricultural production’’ are closer, showing that these technologies are beginning to inte- grate 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. Key areas of change include real-time forecasting, tracking of physical items, and reinventing business processes.

The second cluster includes terms such as ‘‘big data’’, ‘‘smart agriculture’’, ‘‘decision support’’, ‘‘farm management’’, and ‘‘risk management’’. The Jaccard coefficient demon- strates 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 fail- ure, and provide information knowledge for decision making. This is expected to lead to radical changes in farm man- agement because of access to explicit information and decision-making capabilities that were previously not possi- ble, through the traditional way of collecting and analyzing data, either technically or economically. Consequently, there has been a rise of some ag-tech companies that push this data-driven development further , seeking to sell services and data to farmers.

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The third cluster used terms such as ‘‘climate change”, ‘‘cloud computing”, ‘‘data management”, ‘‘nitrogen index”, and ‘‘sustainable agriculture”. Climate change and sustain- able agriculture terms associated with cloud computing and data management exhibited concern for applied new tech- nologies to reduce the impact from agriculture on the envi-

ronment. 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 smart farming implementation, especially for sustain- ability and climate change.

FINAL CONSIDERATIONS

Analysis of the literature terms highlighted different con- cerns attributed to the use of smart farming between those noted by the experts and those observed in the scientific literature. The first focus of the scientific literature was on developing tech nology for smart farming. 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 pro- duction system and the environment.

The Brazilian market is in the initial development phase of smart farming 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 equip- ment, and the companies in this sector are responsible for implementing the first prototypes on integrated farms.

Among the barriers to development and adoption of smart farming 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 commit- tees and strategic alliances between companies. Some start- ups 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 smart farming tools. The low level of rural schooling in the available labor force constrains further diffusion of these technologies in Brazilian agricul- ture. 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 smart farming research is associated with how much countries spend on R&D annually.

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Countries that invest more in R&D have the highest number of publica- tions. 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 smart farming scientific knowledge cre- ation 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 soft- ware 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 col- lected 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 devel- opment. 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 sev- ere 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 sbject

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