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DIEISSON PIVOTO

SMART FARMING: CONCEPTS, APPLICATIONS, ADOPTION AND DIFFUSION IN SOUTHERN BRAZIL

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Tese de Doutorado apresentada ao Programa de Pós-Graduação em Agronegócios do Centro de Estudos e Pesquisa em Agronegócios (CEPAN) da Universidade Federal do Rio Grande do Sul, como requisito para a obtenção do título de Doutor em Agronegócios.

Orientador: Prof. Dr. Paulo Dabdab Waquil– UFRGS

Co-Orientador: Prof. Dr. Edson Talamini– UFRGS

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Data da aprovação:_____/ _____/ _______.

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Dr. Bradford Barham–AAE/University of Wisconsin-Madison

____

Dr. Christian Bredemeier – PPG FITOTECNIA/UFRGS

____

Dr. Homero Dewes – CEPAN/UFRGS

____

Dr. Marcelino de Souza – CEPAN – UFRGS

I dedicate this work to the farmers and agriculture professionals that have contributed to this study. I hope that the discussions and results presented here may in the future contribute to minimize the risk of agricultural activity and make it more sustainable. Among these farmers, I dedicate especially to my father, Ruimarino.

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"Surely, nothing can be more plain or even more trite common sense than the proposition that innovation [...] is at the center of practically all the phenomena, difficulties, and problems of economic life in capitalist society."
(Joseph A. Schumpeter, 1939)

ABSTRACT

Smart Farming (SF) is a modern set technologies that can be used to improve decision making and automation throughout agricultural activities. To accomplish this, some farmers are using the Internet of Things (IoT), which is new technology that allows objects to be sensed or controlled remotely across existing network infrastructures. Further, it can create opportunities for more direct integration of the physical world into computer-based systems, which can result in improved efficiency, accuracy, and economic benefits for SF users. Besides the new areas such as IoT, Cloud Computing, Cognitive Computing and Big Data, two fields have contributed to the development of SF: Precision Agriculture (PA) and Information Technology (IT). The present study analyzed SF's innovative processes, beginning with the production of scientific knowledge through to SF's final diffusion of these technologies into agriculture. The discussion and analysis are based on the theoretical contributions of the evolutionary economy and the techno-economic paradigms and were used to analyze technological revolutions. The work consisted of three distinct methodological steps. First, to better understand the subject being studied, interviews were conducted with researchers and market professionals, from different areas, such as agriculture, electronics engineering and mechanization. During the second stage, text mining was used to analyze scientific literature on SF. In the third step an empirical research was carried out to analyze the adoption of SF technologies in real environment. To operationalize this step, a questionnaire was sent to grain farmers from the southern region of Brazil, which included Paraná, Santa Catarina, and Rio Grande do Sul. Since these grain' farmers produced 50% or more of the gross revenue in grains were included in the database. After the surveys were completed, the empirical data was used to analyze the adoption of these technologies. Based on the results, it was possible to infer that SF technologies are in the process of gestation and emergence. There has been intense scientific development in technologies, such as IoT and smart environments. Additionally, there has been a strong spillover effect from industries to agriculture. Because of this, it is expected that the number of SF innovations available to the market will grow over the next several years. The study indicated main factors that a farmer chose to adopt SF were: potential increase in productivity, better process quality, cost reduction, and a greater knowledge of cultivated areas. Additionally, adding in these factors, education had the positive effect on the adoption of georeferenced soil sampling. The adoption of an autopilot spray pilot and management software was positively influenced by the size of the area. The results of the study have indicated that a higher level of schooling tends to increase the probability of adopting these technologies. It was also found that high equipment

costs, the low qualification of rural workers, the precariousness of Internet access in Brazilian rural regions, and the need to insert a lot of data and information in specific programs available to take advantage of SF technologies are the main barriers faced by grain producers, which contribute to their delay in implementing SF technologies. Additionally, it has been verified that the machines used in the grain production systems are becoming digitalized—the availability of equipment with sensors and automated processes are rapidly increasing. However, from the famers' perception, many technicians and consultants, such as agronomists and agricultural engineers, have not yet adapted to the new context of agriculture, with growing implementation of SF technologies amongst farmers. Thus, the question remains whether farmers and technical consultants can take advantage of available SF technologies and, if so, whether they can use these technologies to help them make decisions and monitor their farming practices. The results of this research can be used to further understand how SF technologies are being used among Brazilian grain producers.
Keywords: Innovation, Future Farming, FMIS, Smart Agriculture, Agriculture 4.0.

RESUMO

O Smart Farming (SF) é um novo conjunto de tecnologias que podem ser usadas para melhorar a tomada de decisões e a automação em atividades agrícolas. Para isso, alguns agricultores começaram a utilizar a Internet das Coisas (IoT), que é uma tecnologia que permite que os objetos sejam detectados ou controlados remotamente em infraestruturas de rede existentes. Esse processo tende a criar oportunidades para uma integração mais direta do mundo físico com sistemas baseados em computador, gerando maior eficiência, precisão e benefícios econômicos para os usuários de SF. Além das novas áreas como IoT, Computação em Nuvem, *Cognitive Computing e Big Data*, dois campos contribuíram para o desenvolvimento de SF: Agricultura de Precisão (AP) e Tecnologia da Informação (TI).A presente tese analisou o processo de inovação no contexto da SF, desde a produção de conhecimento científico até a fase de difusão dessas tecnologias na agricultura, sendo que, o objeto de estudo contemplou as propriedades rurais de grãos. A discussão e análise realizadas no trabalho têm como base teórica o aporte da economia evolucionária e o paradigma tecnoeconômico usado para analisar revoluções tecnológicas. O trabalho consistiu de três etapas metodológicas distintas. A primeira, de caráter exploratório, foi realizada por meio de entrevistas com especialistas de diferentes áreas, visando melhor compreender o tema estudado. Na segunda etapa, realizou-se um levantamento na literatura científica acerca do tema. De posse dessas informações, operacionalizou-se uma pesquisa empírica para analisar a adoção dessas tecnologias no ambiente real. Para isso, foram aplicados 119 questionários com produtores de grãos da região Sul do Brasil (Paraná, Santa Catarina e Rio Grande do Sul), sendo adotada amostragem estratificada, pois foram considerados produtores cujas propriedades produzissem 50% ou mais da receita bruta em grãos.Com base nos resultados, foi possível inferir que as tecnologias de SF encontram-se no processo de gestação e emergência. Observou-se um intenso desenvolvimento científico em tecnologias como IoT e ambientes inteligentes, bem como um forte efeito de "*spillover*" de outras indústrias para a agricultura. Entretanto, espera-se que nos próximos anos, o número de inovações disponíveis ao mercado na área de SF cresça. Os principais fatores de adoção de SF observados no trabalho foram: a) aumento de produtividade, b) melhor qualidade de processo, c) redução de custos, e d) maior conhecimento de áreas cultivadas. Da mesma forma, alguns fatores aumentaram a adoção de tecnologias em diferentes intensidades e maneiras. A educação teve o efeito significativo e positivo na adoção de tecnologias georeferenciadas de amostragem de solo. A adoção do piloto de pulverização do piloto automático e *softwares* de gerenciamento teve influência positiva do tamanho da área. Os resultados da tese sinalizaram que um maior grau de escolaridade, tende a aumentar probabilidade de adoção dessas tecnologias. As principais barreiras que atrasam a entrada dos produtores de grãos na SF foram: a) o preço dos equipamentos, b) baixa qualificação do trabalho rural c) a precariedade do acesso à Internet nas regiões rurais brasileiras, e d) necessidade de inserir muitos dados e informações em *software*. Verificou-se assim que as máquinas empregadas nos sistemas produtivos de grãos estão passando pelo processo de digitalização, especialmente pelo aumento da disponibilidade de equipamentos com sensores e processos automatizados. No entanto, na percepção do produtor rural, grande número de técnicos e consultores ainda não está adaptado ao novo contexto da agricultura. Com isso, permanece o questionamento acerca da capacidade do produtor e dos consultores técnicos de acompanhar e aproveitar o potencial das tecnologias de SF na tomada de decisão na propriedade rural. Os resultados desse trabalho, inéditos no contexto brasileiro, avançam no sentido de compreender a difusão da SF no contexto brasileiro.

Palavras-chave: Inovação, Fazenda do Futuro, Agricultura Inteligente, FMIS, Agricultura 4.0.

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CHAPTER 1: INTRODUCTION

In 2015, the United Nations (UN) established the 2030Agenda, with 17 macro objectives for Global Sustainable Development (UN, 2018). Among them, Goal 2 stands out: "End hunger, achieve food security and improved nutrition and promote sustainable agriculture," and especially item 2.4, “By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production [...]”. After the beginning of agriculture, agricultural techniques and technologies were used at various times to respond to these challenges, especially population growth (BOSERUP, 2011)

Again, these challenges are presented to agricultural production systems. For example, the world's population is expected to reach 10 billion by 2050, thereby increasing demand for food by 50 percent over 2013 in a scenario of average economic growth (FAO, 2017). Income growth in low- and middle-income countries would accelerate a transition from food, with greater consumption of meat, fruits and vegetables in relation to cereals, requiring proportional changes in production, putting more pressure on natural resources (FAO, 2017).

The limitations to meet this scenario of growth in food demand are numerous and require actions different from those used in the 20th century. Among them are the lower agricultural production growth rates around the world, the lesser amount of land available for agricultural expansion, and the competition in land use with urban areas (FAO, 2017). Knowledge and innovations from the green revolution, previously used (MAZOYER; ROUDART, 2008), especially from chemistry and biology, may not be enough to face the challenges presented now.

In this context, new technologies and innovations need to emerge to be used in agricultural production systems and address these challenges, as observed throughout the history of agriculture (MAZOYER; ROUDART, 2008; BOSERUP, 2011). A set of technologies that have already been used by farmers in this sense, since the end of the 20th century, is Precision Agriculture (PA) (ADRIAN *et al.*, 2005; TEY and BRINDAL, 2012). PA seeks to understand and manage crop variability to increase the efficiency in the use of farm resources. As an example, the application of variable rate of inputs and the use of autopilot tools to minimize errors in operations.

Like PA, Information Technology (IT) has been used since the beginning of the 1990s in agriculture, to improve management and production management in agribusiness. According to the Brazilian Agricultural Research Company (MASSRUHÁ, 2014), Information and Communication Technologies (ICT) have contributed significantly to the various areas of knowledge in agribusiness, allowing the storage and processing of large volumes of data, process automation and the exchange of information and knowledge. The potential of IT lies in its transversality, which can add value and benefit to different areas, such as research, market and business and environment.

In the report prepared by the US government, called Computational Science: Ensuring America's Competitiveness (MASSRUHÁ, 2014), the President’s IT Advisory Committee presented IT as the third axis of scientific research, with theory and experimentation, allowing scientists to build and simulate models of complex phenomena, such as climate change, which could not be replicated in laboratories.

In recent years, a new set of technologies has emerged, including Big Data Analytics, Internet of Things (IoT), Artificial Intelligence and Robotics in Agriculture (MASSRUHÁ, 2014; WOLFERD, 2017). All these technologies are part of a broad concept, still little explored in the literature called, "Smart Farming", "Smart Agriculture" or Agriculture 4.0. This concept also includes PA and IT technologies (WOLFERD *et al.*, 2017; PIVOTO *et al.*, 2017), presented previously.

In this study, SF refers to the set of technologies that aims to make agricultural decision-making processes and performance faster, more efficient and digital, going towards the automation of agricultural processes. They include the already used PA and IT technologies, but also emerging technologies and innovations in robotics, artificial intelligence, Big Data and IoT, which can bring significant changes to agricultural production systems, based on past revolutions that have altered the structure and the dynamics of the whole economy (FREEMAN; PEREZ, 1988).

Among the factors that allowed SF to emerge are the reduction in the cost of sensors and electronic devices and the capital inflow of investors and companies from other sectors in this area. In electronics and sensors, for example, the average price of IoT sensors for agriculture fell from US$ 1.50 in 2004 to US$ 0.50 in 2016 (CBINSIGHTS, 2017). Second, corporate investment in artificial intelligence is expected to increase from US$6.0 billion in 2016 to US$13.93 billion in 2017 (CBINSIGHTS, 2017). Also, there was the emergence of startups, seeking to generate solutions in various areas of agriculture. In addition to the reduction of costs of sensors and the increase in investments by companies in the sector, there are many agricultural and economic benefits that SF can generate, such as: i) improved management of the production and farm; ii) dissemination of important information; iii) improvement in the planning, monitoring and follow-up of integrated production; iv) access to the latest research results in the area; and, v) automation of activities (GELB; VOET, 2009).

However, agriculture involves biological systems that are inherently heterogeneous, which reflects on the agricultural production ecosystem. Production areas can vary in moisture content, soil chemistry and physics in one square meter resolution. Likewise, climatic patterns vary greatly, both spatially and temporally, for precipitation and solar radiation. The agricultural environment is different from the environments in which smart technologies have emerged. Comparing natural environments with the controlled environment of a semiconductor manufacturing industry found that, because of external forces, levels of precision and accuracy in agriculture are lower than in other industries (MASSRUHÁ,2014).

SF has the potential to bring gains to agribusiness organizations and agents. However, uncertainties about the technologies, barriers and feasibility in the context of production systems are not elucidated in the literature and may compromise the diffusion process of these technologies.

1.1 RESEARCH PROBLEM

1.1.1 Initial questions: scientific production

The context presented in the introduction shows that SF technologies can positively impact agribusiness. Despite this, agriculture is still one of the last sectors to undergo the process of digitization and use of Information and Communication Technologies (ICTs) when compared to other sectors of the economy (CBINSIGHTS, 2017). Similarly, the scientific literature on the subject is still incipient (WOLFERD *et al.*, 2017). Analyzing the economic context and the dynamics of innovations and structural changes in the economy and society shows that technological revolutions originate from previous scientific development in other areas of knowledge (DOSI, 1984; FREEMAN, PEREZ, 1988). Subsequently, this scientific knowledge undergoes technological and commercial development by organizations, becoming an innovation when accepted by the market.

To understand this process of technological development and innovation in SF, it is important to comprehend the current scenario of science and the state of the art of scientific production. With this, we ask: How is the concept of SF defined in the scientific literature? How has science addressed this issue? Which countries and institutions are leaders in the production of knowledge on this subject?

1.1.2 Intermediate questions: the market and diffusion of technologies

In Brazil, grain production is one of the most important production chains in agribusiness, with greater potential for area expansion than other countries (FAO, 2018). Brazil is an example of success in adopting technologies in tropical agriculture, especially in crops such as soybean, corn, cotton and sugar cane. The country changed from a net food importer to an exporter (VIEIRA FILHO; FISHLOW, 2017). Some grain production indicators demonstrate this process of evolution in Brazilian agriculture. Soybean yield, for example, increased from 1,748 kg/ha in the 1976/77 crop to 3,364.1 kg/ha in the 2016/17 harvest (CONAB, 2018). Meanwhile, total production in the same period rose from 12.1 million tons to 114.07 million tons.

This growth was due to the incorporation of technologies, available lands and the management skills of Brazilian farmers' agricultural production systems. The challenges that arise, especially in the context of SF technologies, are different from the previous ones. The areas of land available for expansion of activities still exist, but their value for acquisition increased, making the need for profitability in the larger production systems even greater.

For example, there are intense changes in data collection, analysis and interpretation methods (KAY, EDWARDS, DUFFY, 2014). Electronic sensors and processors used in large-scale industries are now affordable and feasible for farms. Last century, managers had scarce information, often incomplete and difficult to access. Now, managers are facing a new type of problem: a great amount of information and difficulty to use it in a useful way (KAY, EDWARDS, DUFFY, 2014).

This wide availability of technologies can create greater challenges for farmers when deciding which ones to adopt. The mere availability of technologies in the market does not ensure that they will be disseminated to economic agents. There are elements that influence the speed of diffusion of these technologies in the field, already mentioned by other authors (ROGERS, 1995). The big question that emerges is: Will producers be able to use the potential of the information generated and collected in agriculture and the technologies available to improve decision-making processes and the procedures in Brazilian farms? What are the determinants and limitations for Brazilian farmers to be able to use SF technologies?

1.1.3 Final questions: provision of services

The new concept of integrating the information in farms opens new possibilities for grain producers but can bring several changes for managers. A first aspect to be highlighted is the possibility of a new advisory relationship with technical professionals in the area, such as agronomists, veterinarians and administrators. With greater volume of remotely transmitted data and automatic information, professional consultants can send daily reports and information to farmers, seeking better management assistance. On the other hand, what are the challenges for technical consultants to advise farmers in the context of smart farming? The next section delimits the objectives of this research, based on this context and the questions presented here.

1.2 OBJECTIVES

1.2.1 General objective

To analyze the innovation process in the context of SF, from the production of scientific knowledge to the diffusion phase of these technologies in agriculture, having as the study object grain farmers in the Southern Brazil.

1.2.2 Specific objectives

Based on the general objective, these are the specific objectives:

(i) characterizing the scientific knowledge on SF available in the scientific literature based on the main development factors per country and over time.

(ii) describing the current perspectives of SF in Brazil from the perspective of specialists in this field.
(iii) identifying the main SF technologies used in grain production systems in the South of Brazil and the farmers' perception regarding the technical assistance of companies and consultancies in this area.
(iv) identifying and analyzing determinants and limitations that influence the decisions made by grain producers regarding the adoption of SF technologies.

1.3 JUSTIFICATION

From a macroeconomic point of view, as already presented, the challenges for the growth of agricultural production are high in relation to the demands of society (FAO, 2017). The adoption of SF technologies can be a way to meet the demands of society, such as food security, sustainability and environmental preservation.

From a microeconomic approach to agricultural production systems, from the perspective of farmers in farms, the permanence of producers in grain production requires gains in productivity or reduction of costs; for this, they need to move forward in adopting technologies that lead to this. From an economic and social point of view, if SF technologies prove to have optimizing results, farmers who do not adopt them will be excluded from the activity.

Regarding the adoption of technologies and their importance, agriculture, in general, uses technologies developed for agriculture, such as hybrid seeds, transgenics, agricultural machinery. On the other hand, the adoption of smart farming technologies may present specificities in terms of adoption determinants that are not yet elucidated in the literature.

Studying SF can assist in improving technology development, assessing the technology transfer effectiveness, understanding the role of politics for the adoption of new technologies, and demonstrating the impact of investing in the generation technology. In addition, it is in the interest of agribusiness organizations and institutions to know the diffusion dynamics of SF technologies to strategically position themselves and adjust their objectives.

1.4 THESIS STRUCTURE

This thesis consists of six chapters. The first brings the introduction, contextualizing and inserting the research problem that originated this work. The second chapter presents the theoretical framework that supports the analyses and discussions carried out here and the methodological procedures used. Chapter 3 discusses SF state of the art in both scientific and market contexts. This chapter uses text mining and interviews with area experts.

Chapter 4 presents a descriptive analysis of the adoption of SF technologies by grain producers in southern Brazil and the role of technical consultants in the diffusion of these technologies. Chapter 5, with the use of statistical modeling, discusses the determinants and limitations for the adoption of SF by the producers. Finally, Chapter 6 brings the final considerations of this work.

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CHAPTER 2: THEORETICAL FRAMEWORK AND METHODOLOGICAL PROCEDURES

This chapter presents the theoretical framework used as a basis for the work, in addition to the methodological procedures employed. The theoretical framework section reviews the origin of studies about innovation in economic sciences and its role for economic development. The next section presents different lines of study on innovation in agriculture and reviews the main factors that influence the adoption of technologies by farmers.

The methodological procedures section describes the methods used to carry out the work, in three steps. A first and second steps are of a qualitative nature, with exploratory interviews and a review of the literature on the subject, and a third, quantitative step, through empirical research.

2.1 TECHNIQUE, TECHNOLOGY AND TECHNOLOGICAL INNOVATION

Technology and technological innovation are the main elements for changing the structure of the economic system and, consequently, of society (FREEMAN; PEREZ, 1988). This debate began with Marx in the second half of the 19th century, focusing on the link between technology and its consequences for the workforce, and decisive contributions were made by Schumpeter in the first half of the 20th century, when technology began to be analyzed further in development economics (FREEMAN, 2008).

Given the central role of technology and innovations for this study, it will analyze a few authors and one of the main theoretical approaches to this context, neo-Schumpeterian economics. Before advancing further into the debate regarding technological innovation, it is important to differentiate between technique and technology. Techniques are methods and processes applied to specific human activities, involving skills, and have been present since the dawn of mankind (ORLIKOWSKI, 1992). Techniques are often based on tacit knowledge, acquired by the process repetitions, resulting in the precise and accurate execution of an activity. Technology, on the other hand, is a systematized body of knowledge, aided by scientific development, which can be applied to solve practical problems in society. In this study, this definition will be used to refer to the concept of technology during the discussions and the result analysis.

The next section analyzes the innovation process, its origins and concepts. As highlighted in the introduction to this chapter, Schumpeter was the pioneer in discussing innovation and presenting it as determinant for the dynamics of capitalism. But, what is meant by innovation? Schumpeter (1988) states that innovation is part of the innovative process, which consists of three sequential phases: (i) invention, (ii) innovation and (iii) diffusion. The difference between invention and innovation is that an invention is a new knowledge whose application may or may not be economically viable, whereas innovation refers to an essentially economic phenomenon, like the commercialization of a new product or the implementation of a new process, and diffusion is the dissemination of this new technology throughout the market.

Innovations enable a shift in production function, with changes in cost curves, or the creation of new production functions through new combinations (SCHUMPETER, 1982). The driving element for the evolution of capitalism is innovation, as described by Schumpeter (1988), by introducing new products or production techniques, the emergence of new markets, sources of raw materials or industrial compositions. The people who implement these new combinations, inserting innovations in the production system, are called innovators, and can also be inventors, or not.

Despite being part of the context of "invention-innovation-diffusion", technological innovation has a greater influence than the others on the process of economic development, as discussed by Conceição (2002). Therefore, economists are highly interested in studying it. Innovation triggers a series of transformations, which transcend strictly technological limits, spreading new processes and products, and affecting institutionalized habits and social customs (CONCEIÇÃO, 2002). This study finds that innovations in famers can bring about changes in the relations and organizational structures between the agents involved in different sectors, which will be explored in the later chapters.

Based on Schumpeter's ideas, new authors and ideas emerged within the context of evolutionary or neo-Schumpeterian economics. This new approach to economics is divided into two lines, with authors that follow Nelson and Winter's (1982) evolutionary and microeconomic approach; the macroeconomic approach to 'paradigms and technological trajectories' by Perez (1983); or Dosi (1984) and Freeman and Perez's (1988) technoeconomic paradigm. Thus, the different versions of this approach elaborate models in which both behavioral variables and structural variables have reciprocal action, generating trajectories of change and structural transformation.

This new theoretical construction reinforced the central role of technical progress as a determining source of economic growth. One of the most important principles to understand evolutionary economics is that the dynamics of economy is based on innovations. Neo-Schumpeterian authors reaffirm Schumpeter's statements about innovation and its role in the economic system, placing technology as the center of analysis in the process of growth and economic change.

The macroeconomic approach describes the difference between technological changes within a given paradigm and the construction of a new one. On the one hand, when change processes occur within existing paradigms, the innovation patterns follow the normal trajectories defined by their technological limits and are conditioned to environmental factors such as demand and relative prices. On the other hand, changes in a technoeconomic paradigms depend fundamentally on advances in science and technologies available to economic agents, and represent major discontinuities in change patterns, bringing about a new wave of innovations.

From Perez's (1983) concept, Dosi (1984) and Freeman and Perez (1988) advanced theoretically and proposed the concept of technoeconomic paradigm. Freeman and Perez (1988) believe that after the industrial revolution, capitalism went through five waves of growth, or technoeconomic paradigms, which were supported by scientific advances. The era of computer science and telecommunications stands out as an example, based on the development of computer science and microprocessors. These advances have led to technological revolutions, which have in common the process of innovating or changing current technology.

Perez and Freeman (1988) believe that changes in technological paradigms affect all economy sectors. According to Perez (1983) and Freeman and Perez (1988), periods of rupture with technological paradigms bring a wave of new products and processes, bringing about fundamental changes in society (structural changes). This is an important element for technologies related to smart agriculture, since they can potentially lead to structural changes in agriculture.

The microeconomic approach studies innovation and consequent transformations of companies and industrial structures. The evolutionary paradigm presented by Nelson and Winter (1982) connects the notions of search and selection of innovation by the environment and by market pressure. Assuming that agents can always discover new technologies and new patterns of behavior, this would generate diversity. Also, collective interactions inside and outside markets act as selection mechanisms, resulting in differentiated growth of entities that have different technologies, routines and strategies.

Put simply, the evolutionary paradigm is based on the notions of *search* for innovations on the part of companies, and *selection* of innovations by the market (NELSON; WINTER, 1982). Companies participate in the competition to remain and grow in the market (VIEIRA FILHO, 2009), generating or copying innovations from competitors, and the market selects which of them remain, an analogy to the Darwinian selection theory.

Companies whose innovations are not selected by the market are eliminated from the market via competition (NELSON; WINTER, 1982). For evolutionary economists, the ability of companies to respond to changes and to the selection environment depends on four factors (NELSON; WINTER, 1982): i) Learning and routine; ii) Path dependency; iii) Environment and selection; and iv) Central competence.

Some models have emerged to explain the innovation process, but two stand out: *technology push* and *demand pull*. According Rothwell (1993), the technology push model is a simple linear model, in which through the technological development of products and activities related to manufacturing, new products are put on the market. In this model, the research and development areas assume a determining role, since innovations come from companies' internal efforts. This concept is closely related to the object of this study, since companies that operate in this sector invest highly in the development of products.

At the other extreme, demand pull, innovation arises from the needs of the market, with the business development sector responding to the stimuli of customers and consumers. In this model, innovation occurs due to a demand for new services and products by consumers. It is important to note that in the real world, a hybrid strategy for the development of innovations can exist.

Another important segmentation is the types of innovation. Freeman and Perez (1988) classify them into radical innovation (represented by a structural break in the model so far in force) and incremental innovation (related to product, process or organizational improvements). Radical innovation comes with the development and introduction of a whole new product, process or entirely new way of organizing production. This type of innovation may represent a structural break with the previous technological standard, giving rise to new industries, sectors and markets.

Innovations can also have an incremental nature, linked to improvements in a product, process or production organization within a company (FREEMAN, 1988). Numerous examples of incremental innovations, many of them imperceptible to the consumer, can lead to improvements in technical efficiency, increased productivity, reduced costs, improved quality and promote changes that expand a product or process.

One important characteristic of innovation processes is that they are intrinsically marked by uncertainty. This is because innovative activities involve not only a lack of detailed knowledge about the costs and results of different alternatives, but also lack of knowledge about the alternatives and results of the innovative process (DOSI, 1988).

Next, a review of innovations in the field of agriculture, which is the focus of this study, is presented.

2.2 TECHNOLOGY INNOVATION, ADOPTION AND DIFFUSION IN AGRICULTURE

Innovations, as presented in the previous section, are central to the process of economic development. This is not different in agriculture. According Schultz (1964), technological changes are the main factor shaping agriculture since the late 20th century, and the incorporation of technology in agricultural activities is crucial to increase the production of different agricultural products (VIEIRA FILHO; FISHLOW, 2017).

A study by Sunding and Zilberman (2001) compared patterns of agricultural production in the United States between 1920 and 1995 and found that while agricultural land fell from 350 to 320 million acres[1], the share of agricultural labor decreased substantially from 26% of the population to only 2.6%. In addition, over the same period, the number of people employed in agriculture decreased from 9.5 million to 3.3 million. Nonetheless, agricultural production in 1995 was 3.3 times higher than in 1920 (SUNDING; ZILBERMAN, 2001).

The data presented above are consequences of the introduction of new technologies in agricultural production systems such as mechanization, chemical inputs and, by the end of the 20th century, communication and information technology. Sunding and Zilberman (2001) state that the literature on innovation is diverse and developed its own vocabulary, distinguishing two main lines of research: innovation generation and research on the adoption and use of innovation.

One pioneering work on technology adoption was conducted in 1940 by two sociologists, Bryce Ryan and Neal Gross, who conducted a study on the diffusion of hybrid corn seed with farmers in Iowa, USA, sparking an interest regarding the innovation diffusion S-curve, which had been drawn up in 1903 by the French sociologist Gabriel Tardes

[1] Unit used to measure land. 1 acre = 0.404 hectare.

(MACHADO, 2008). According Machado (2008), the work by Ryan and Gross (1940) found that some innovations spread quickly, generating a steep S curve. Based on this curve, Ryan and Gross ranked Iowa farmers in categories related to how long they took to adopt this innovation (hybrid corn). The five categories were (i) innovators, (ii) early adopters, (iii) early majority, (iv) late majority, (v) late adopters.

This study observed that the first adopters were more cosmopolitan, a variable indicated by the greater frequency of trips to the Iowa capital, Des Moines (MACHADO, 2008). Several other variables influence this people to adopt innovations before others, which will be further explored in the next section.

After this sociological study, the studies by Griliches (1957) and Mansfield (1961) identified empirical regularities for technological diffusion, creating models represented by curves and using econometric models. According to Vieira Filho and Silveira (2013), in Mansfield's (1961) epidemiological approach, diffusion is driven by expectations of production gains with the adoption of an innovation and driven by a progressive spread of information about the technique and the economic characteristics linked to the technology. In Griliches (1957), the goal is to analyze under what circumstances technology is generated and propagated in agriculture.

Vieira Filho and Silveira (2013) criticize the previously presented model regarding the adoption of a hybrid seed, analyzed only as a simple introduction of a productive input immediately adaptable to the conditions of each region. The authors believe that, in addition to the rates of hybrid-seed adoption by farmers, it is valid to explain regional developmental differences in terms of acceptance and productive viability.

Other authors with important contributions to the studies on technological innovation in agriculture were Hayami and Ruttan (1988). According to them, technical innovation aims to save scarce resources and intensify the use of abundant resources. The approach by Hayami and Ruttan (1988) uses two types of technology: one mechanic, which reduces the need of labor forces, and one biological, which protects the earth.

In summary, technological introduction aims to increase productivity and reduce production costs, as described by Vieira Filho and Silveira (2013). For the authors, not every innovation is successful, and it is possible to divide them into three types that are inserted in the context of the modernization of agriculture:

i) In the first one, there is an increase in net income, through the increase in productivity, without marginal cost reductions – such as inputs that need a large amount of fixed capital, tractors, harvesters, machinery and equipment. Smart farming tools, the object of this study, are part of this*;*

ii) In the second one, productivity increases and the marginal cost decreases, with techniques with low fixed-capital expenditure and high variable cost value – such as fertilizers, pesticides, concentrated feed;

iii) The third one is linked to innovations that provide greater return, by increasing productivity while reducing marginal costs, since they do not require additional costs. Examples include planting techniques and adequate plant spacing.

The technological change in agriculture is a consequence of Schumpeterian competition in the evolutionary perspective (VIEIRA FILHO, CAMPOS E FERREIRA, 2005). Agricultural growth depends on the growth of the capital stock. Buainain *et al.* (2013) also corroborates this new pattern in Brazilian agriculture, where land is no longer central to generating wealth, and capital has assumed this role.

Buainain *et al.* (2013) state that Brazilian agriculture was inserted in a Schumpeterian context, in which competition acts as a coercive factor for the adoption of minimum economic-institutional standards, and agricultural producers are subjected to the driving and imposing forces of competition by the market and by regulatory institutions that represent consumers. Capital has become central, since it enables producers to innovate and remain competitive in the market. The next section presents the literature related to the adoption of technologies.

2.3 FACTORS THAT INFLUENCE TECHNOLOGY ADOPTION

Innovation in agriculture is a dynamic process, as discussed in the first section of this chapter. Also, there are different fields of knowledge that seek to understand the variables and reasons that lead individuals or organizations to adopt an innovation. This section presents a review of authors and articles that address the subject of adoption of innovations and technologies in agriculture, mainly those that focus on the adoption of precision agriculture technologies and information technologies by agricultural producers. The items to be analyzed were defined based on the works by Knowler and Bradshaw (2007); Souza Filho *et al.* (2011), Tey and Brindal (2012), and Pierpaolia *et al.* (2013).

The following presents the socioeconomic dimension and the factors inserted in this dimension that influence the process of adopting technologies.

2.3.1 Socioeconomic factors

Socioeconomic factors refer to the individual characteristics of the main decision-maker of a farm. Based on Souza Filho *et al*. (2011), Tey and Brindal (2012), and Pierpaolia *et al*. (2013), the main variables and socioeconomic determinants generally analyzed in the process of adoption of technologies are age, education, experience, time dedicated to agricultural activity and size of property.

One of the socioeconomic variables that can influence the adoption of technology is education, especially the technologies that are the object of this study. Some studies demonstrate the positive effect of education in the process of technology adoption in agriculture (ABDULAI; HUFFMAN, 2005; ABDULAI *et al*., 2008; ASHRAF *et al*., 2009). Feder *et al*. (1985) believe that the level of education can increase farmers' ability to process information, make decisions and acquire new technologies, especially management technologies.

Alvarez and Nuthall (2006) observed that skills obtained with education facilitate the use of computers and Farm Management Information System (FMIS) by farmers. In a study conducted by Carrer, Souza Filho and Batalha (2017) with citrus producers in Brazil, farmers' education had a positive effect on the probability of using computers. The explanation for this, according to the authors, is that more educated farmers expressed greater demand for information and greater ability to assess the benefits of using computers as a tool to support management in decision making. These individuals who are more educated are also more skilled in using computers for administrative tasks, which tends to increase the marginal efficiency of the technology. According to Carrer, Souza Filho and Batalha (2017), the estimated marginal effect for the variable indicates that the probability of computer adoption increased by 20% among citrus producers with a university degree, *ceteris paribus*.

Especially regarding information and communications technologies (ICT) and Precision Agriculture (PA), education, analyzed in the present study through the level of schooling, can be an important factor to positively influence the adoption. This variable was tested in the empirical part of the work.

Experience with agricultural activity is another variable that can impact the technology adoption process. On the one hand, more experience with agricultural activity, measured by age or years of work with agriculture, is a positive factor in the adoption of technologies, since it is linked to better management skills (SOUZA FILHO *et al.*, 2011). On the other hand, older producers may be less "energetic" or have a shorter planning horizon, especially if they do not have a successor in the production unit. Younger producers are more easily attracted to novelties and are likely to adopt technologies first, especially in the context of Smart Farming (RAHM; HUFFMAN, 1984; ANOSIKE; COUGHENOUR, 1990; D'SOUZA *et al.*, 1993).

Age can also negatively influence the process of technology adoption. In the literature, the adoption of information technology presented a decline with increasing age (CHARNESS; BOOT, 2009; CZAJA *et al.,* 2006). One of the explanations for the inverse relationship between age and IT adoption is the decline of fluid intelligence with advancing age. However, other factors, including behavioral variables and other cognitive abilities, may also influence this (SOUZA FILHO *et al.*, 2011).

The size of the property can influence the adoption of technologies, and the adoption of an innovation tends to occur earlier on larger properties. Just *et al.* (1980) show that, given the uncertainty and fixed costs of transactions and information associated with innovations, there may be a critical limit on the size of agricultural property for adoption, which often prevents small farms from adopting a certain type of technology.

In general, innovations with large fixed transaction costs are less likely to be adopted by smaller farms. However, Feder *et al.* (1985) point out that the problem of indivisible technology can be solved by the emergence of a service sector (i.e.: a credit service or a consultant) that can transform an indivisible technology into a divisible one. In Brazil, service companies are responsible for the popularization of precision agriculture, which can be intensified with the new smart farming tools.

When analyzing the use of information technologies, Woodburn *et al.* (1994) observed that the adoption of computers and management systems tend to happen with greater intensity in larger farms. The authors believe that in large farms, the coordination of production processes tends to be more complex than in small farms, increasing the need and the potential marginal benefits of the use of computers and FMIS (WOODBURN *et al.*, 1994).

2.3.2 Information sources

Another important item in the technology adoption process is the information sources that convey the message that there are innovations available for adoption. Rogers (2003) was one of the pioneer authors to insert information as a determinant variable in the process of adopting innovations. The information that influences the adoption process can be spread by consultants, mass media (TV, radio, internet), extension services or, more recently, information and communication technologies, ICTs.

When analyzing the origin of the information sources, we highlight the social networks with the potential of information sharing in which the farmers participate. Participation in social networks is important to share information and experiences between farmers and other agents of the agro-industrial chain (CARRER; SOUZA FILHO; BATALHA, 2017). This sharing of information and experience generates more learning about the characteristics of new technologies, increasing the likelihood that farmers will adopt them (SOUZA; MONTEIRO; CASWELL, 2009; DILL et al., 2015).

In modern agriculture, some sources of information are important for the technology adoption process. There are, for example, technical consultants who participate in seminars, congresses, universities and who are up-to-date with the technologies and innovations related to management, mechanization, among other elements that integrate the production system.

Contact with technical consultants can increase the use of technologies, especially smart farming. In a study carried out by Carrer, Souza Filho and Batalha (2017), the presence of technical assistance had a positive impact on the adoption and intensity of FMIS. For the authors, technical assistance is a form of information transfer that increases the knowledge of farmers and their employees about the availability of new production and management technologies. Visits to farms by specialists increase the likelihood of correct use of existing technologies, increasing farmers' confidence in adopting new technologies. In addition, experts can assist farmers and their employees in the proper management of new technologies. The effect of the consultants on the process of adopting intelligent agriculture technology was tested in the empirical part of this study.

2.3.3 Institutional factors

Institutional factors are linked to the environment surrounding farmers, such as characteristics of their region and the existence of agricultural policies, public technical assistance, legislation that encourages adoption, among other variables. Regarding the characteristics of the region, for example, producers located in regions that have greater financial and natural resources may be more likely to adopt (TEY; BRINDAL, 2012).

Another factor that tends to stimulate the adoption of technologies is rural credit, especially for technologies that demand a high initial investment value, like some equipment for adopting precision agriculture. Specific credit lines for adopting innovations and technologies can increase the likelihood of adoption by farmers. An example were the subsidized interest rates in Brazil that encouraged the renewal of the fleet of agricultural machinery and implements, through the MODERFROTA[2] (BARICELO; BACHA, 2013). This renovation made possible the use of machines and equipment with greater operational capacity, greater efficiency and new technological resources with the possibility of inserting farms in the context of smart farming.

The institutional environment also influences the minimal infrastructure required for technology adoption. One of the constraints for adopting smart farming, especially ICT-related technologies, is the network infrastructure available in the region that surrounds farmers, especially in developing countries. The empirical part of the study will present the perception of the farmers on this item, as a barrier to adopting smart farming.

2.3.4 Technology characteristics and adopters' perception

This topic deals with elements linked to characteristics of the technology and the perception of farmers regarding the adoption of technology. Among the perceived characteristics, relative advantage stands out. The perceived relative advantage refers to the adoption potential perceived by the adopter in comparison to not adopting (ROGERS, 2003). Among the relative advantages, profitability is a concern when considering any capital-intensive agricultural technology, including PA (TEY; BRINDAL, 2012), since, in general, farmers seek to minimize the risk of economic losses (TEY; BRINDAL, 2012).

In the field of environmental psychology, other factors have also been used to understand the behavior of farmers towards the adoption of agricultural practices. For example, Morgan *et al.* (2015) present factors related to pro-environmental behavior, such as self-efficacy and temporal orientation. Self-efficacy refers to the producers' perception of their ability (economic, for example) to be able to adopt a certain technology. The temporal orientation is related to the profile of the producer and decision-making horizon (whether immediate or not).

[2] It is the Program for the Modernization of Agricultural Tractors and Associated Implements and Harvesters coordinated by the Ministry of Agriculture and with treasury resources that offer resources with subsidized interest and long-term payment terms.

The factors described in the above paragraphs can affect the knowledge, perception and consequently the decision-making of farmers regarding whether or not to adopt an innovation. Perception and knowledge are strongly linked in the process of adoption by farmers (MEIJER *et al.*, 2012). It is noteworthy that, while knowledge comes from sources of information and experiences, perception is related to the point of view and may often not coincide with reality (MEIJER *et al*., 2012).

Carrer, Souza Filho and Batalha (2017) identified a positive effect of overconfidence for the adoption and use of FMIS, confirming the hypothesis based on the behavioral finance literature: farmers with greater confidence are more likely to invest, and tend to overestimate the results of their decisions. These factors, in turn, increase the probability of adoption and use of new technologies, especially related to IT.

Adoption is a learning process with two distinct aspects, as presented by Abadi, Ghadim and Pannell (1999). The first is the collection, integration and assessment of new information to enable better decisions on innovation. At the beginning of the process, the producer's uncertainties about the innovation are high, and the quality of decision making may be low. As the process continues, if it does, uncertainty is reduced, and better decisions can be made (MARRA *et al.*, 2003).

Another aspect of learning is improving the producer's skills for using innovations (ABADI, GHADIM and PANNELL, 1999). Most agricultural innovations require a certain level of knowledge and ability to be used, and there may be a wide variety of options in the method of implementation (e.g.: time, sequencing, intensity, scale).

In the context of the study, the analyzed technologies present sequential adoption, that is, the producer needs to adopt some technologies to be able to adopt others, reinforcing the role of learning. Adoption or failure to adopt one of them may limit the progress of other technologies in the production system.

2.4 Methodological procedures

The study had three different methodological steps. The first, of an exploratory nature, consisted of interviews with specialists from different areas, pioneers in the discussion and use of smart farming technologies. In the second stage, based on the interviews and information gathered from the experts, the scientific literature on the subject was reviewed. After selecting the literature, the text mining technique was used to identify trends and the main subjects discussed in the literature. With this information, an empirical research was carried out to analyze the actual adoption of these technologies. The following is a detailed description of the procedures used to complete the chapters that make up the results of this thesis.

2.4.1 Chapter 3: Exploratory Analysis

The first step of the research was exploratory. Considering the initial stage of SF in Brazil and the existence of few companies and professionals dedicated to this subject, semi-structured interviews were conducted with four Brazilian specialists. The number of experts interviewed followed the concept of information saturation, which occurs when collecting more data does not contribute more information related to the issue under investigation (MASON, 2010). The number of experts interviewed, although low, provided a satisfactory idea of the scenario of Smart Farming (SF) in Brazil. It is emphasized that SF is a relatively new concept, and the knowledge about its applications and implications for research and development is not diffused (WOLFERT; VERDOUW; BOGAARDT, 2017).

The Brazilian specialists were chosen for their relevance in agribusiness and for being pioneers in their areas of expertise. The interviews were conducted in person with one specialist, and through web conferences with the other three. In addition, a semi-structured interview script was used. The duration of the interviews was approximately 60 minutes. The interviews were recorded (with the permission of the participants) and then transcribed for later analysis. Content analysis was used, following four stages: analysis, exploration of the material, treatment of results, and interpretation.

The second step of the research consisted of a bibliometric survey of the Web of Science database, accessed through the Library Portal of the Federal University of Rio Grande do Sul, provided by the Coordination for the Improvement of Higher Education Personnel (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 (BARRETTO; LINO; SPAROVEK, 2009; CAO; SIXING; GUOBIN, 2013).

This step used keywords to search for SF-related scientific documents. The set of keywords was defined from interviews with experts (as described in the first step), as well as from recurrent tests. A combination of keywords was selected that would return the most results related to the subject. The keywords used in this step were "smart agriculture", "farm management information system", "farm management system", "big data" and "agriculture", "internet of things" and "agriculture". These keywords were entered separately in the "topic" field.

A total of 371 scientific publications were obtained from data collection. Of these, some did not have abstracts or were not relevant to the scope of the research. In other words, papers that had no available abstract or no relationship to information technology and technology elements were excluded (e.g.: some laboratory experiments in the veterinary and agronomy fields). At the end of this process, 179 scientific papers were included in the bibliometric and text mining analysis.

After that, the text mining analysis was performed using the QDA Miner v. 6.0.2 (Provalis Research) software. The analysis will be described in depth in the methodological procedures in Chapter 3, and so the operationalization will not be detailed here. After this exploratory step of the scientific literature and the Brazilian market, an empirical research was carried out to analyze smart farming in the field, based on the objectives of the study.

2.4.2 Chapter 4: Analysis of the adoption of SF tools

The third stage of the research consisted of an empirical study applied in the south of Brazil. Data were collected (Figure 1) in the area that comprehend the states of Paraná, Santa Catarina and Rio Grande do Sul. The main agricultural activities carried out in these regions are livestock production, milk production and grain production (mainly soybean, wheat and corn).

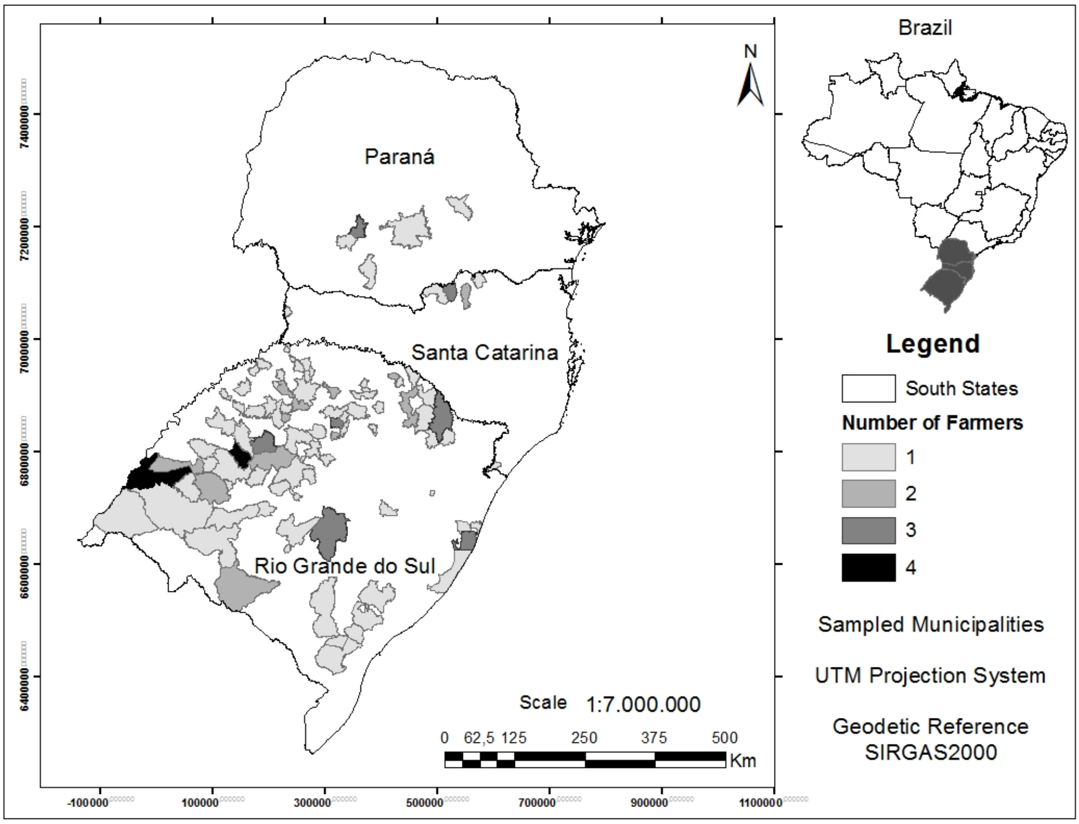

Figure1. Map of the counties where the farms are located.

The adoption of smart farming technologies was analyzed from April 2016 to December 2016. The questionnaire was based on Souza Filho *et al*. (2011), Tey and Brindal (2012), and Pierpaolia *et al*. (2013), and on suggestions from experts, with review and inclusion of questions in addition to those found in the literature. The specialists who participated in the questionnaire review were professionals from universities in areas such as Agricultural Engineering, Precision Agriculture, Rural Management, Agricultural Economics and professionals from companies in the field of agricultural machinery and implements. In total, 12 specialists were consulted.

The questionnaire is divided into several constructs (see Appendix 1). The first one was used to measure the level of acceptance of technology from farmers. For this, an interval of agreement of 5 points was used (1 = Totally disagree to 5 Totally agree =). The second construct sought to identify the percentage of adoption of precision agriculture technologies. The third construct verified the determinants and the limitations for the adoption of these technologies. To measure the limiting and determinant factors, an interval of 5 points of agreement was used (1 = Totally agree to 5 = Totally disagree). In the same way and in the same order as the constructs used previously for PA, these were used to measure IT (information technology).

Finally, questions were asked about the characteristics of the farmers and properties. The questionnaire also had a qualitative question to understand the role of technical assistance in the process of adoption of Smart Farming technologies.

Subsequently, the questionnaire was inserted into an online platform to increase the scope of data collection. To verify the adequacy of the questions, a pilot survey was applied to 32 grain farmers. After this, some issues were eliminated and adjusted.

The sampling was non-probabilistic, aiming to reach the largest possible number of farmers in the analyzed regions. Links to the questionnaires were sent through electronic lists of agricultural machinery and equipment dealers, rural unions and technical consultants. To answer the questionnaire, the famers needed to produce more than 50% of gross grain revenue (soybeans, wheat, corn etc.). A total of 1400 questionnaires were sent out and 160 were returned, but some with incomplete answers. Thus, in total, the sample consisted of 119 valid returns.

Chapter 4 presented descriptive statistics with the percentage of adoption of the technologies analyzed in the work. The qualitative information on technical assistance were also presented.

2.4.3 Chapter 5: Determining factors and limitations for the adoption of technologies

In chapter 5, the data generated with the questionnaires and the sample described previously was used to delimit four technologies that are more adopted by the grain farmers and to further the analysis of the factors responsible for the adoption. Analysis of this study comprising four technologies of SF: three of PA (georeferenced soil sampling, application of fertilizers and soil correctives at variable rate, and spray automatic pilot) and one variable linked to management tools which encompass software's for management (cost, people, productive, phytosanitary and land management). The four technologies involved were chosen because they involved different applications and areas of development within SF, especially in grains. The first two are linked to soil sampling and application at variable rate to represent crop variability management. The third, auto piloted spray, is related to automation on farm (or the attempt to do so). The fourth technology, IT, is related to information systematization or decision making.

The result analysis was composed by general characteristics of sample. Following we present the percentage of technology adoption analyzed individually and by levels of adoption.

We divided the sample into three levels of adoption: low adoption (adoption of one technology), medium adoption (adoption of two or three technologies) and high adoption (adoption of four technologies).

After the presentation of the technologies and sample characterization, descriptive statistics with famers' perception on the barriers and determinants of adoption were presented. Lastly, we provide the application of Logit and Poisson regression models to analyze the influence of the variables on the decision to adopt these technologies. The model selection was performed through analysis of estimators' significance, criterion Akaike selection, Pseudo R ^ 2 and p-value of Residual Deviance.

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CHAPTER 3: SCIENTIFIC DEVELOPMENT OF SMART FARMING TECHNOLOGIES AND THEIR APPLICATION IN BRAZIL[1]

Dieisson Pivoto[1], Paulo Dabdab Waquil[1], Edson Talamini[1], Caroline Pauletto Spanhol Finocchio[2], Vitor Francisco Dalla Corte[3], Giana de Vargas Mores[4].

[1]Universidade Federal do Rio Grande do Sul - UFRGS
[2]Universidade Federal do Mato Grosso do Sul - UFMS
[3]Faculdade Meridional – IMED
[4]Universidade Comunitária de Chapecó – UNOCHAPECÓ

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

Keywords: agricultural innovation, big data, data in agriculture, information technology, text mining.

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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 farms [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 (1912) [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 (1983) and Freeman and Perez (1988) [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 1). The duration of the interviews was 60 minutes, 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.

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 ThingsForum. He has several projects in the area of traceability systems with the use of the internet of things.	Research on agricultural automation

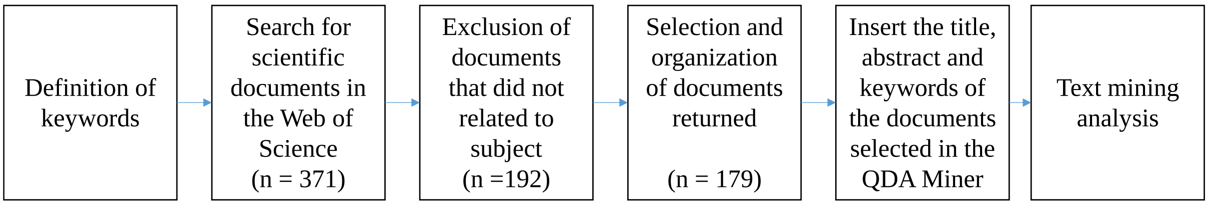
2.2 BIBLIOMETRIC AND SCIENTIFIC ANALYSIS USING TEXT MINING

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 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 (Figure 1).

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



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.

Second, the stop words from these texts were excluded. Stop words 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 Word Stat 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 environment. 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 Word Stat 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 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 lime and a fertilizers [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 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 technology 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.

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

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 farms that already use a high level of technology.

Farmers 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 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 farms 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].

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

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].

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[2] 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,

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

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].

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 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.

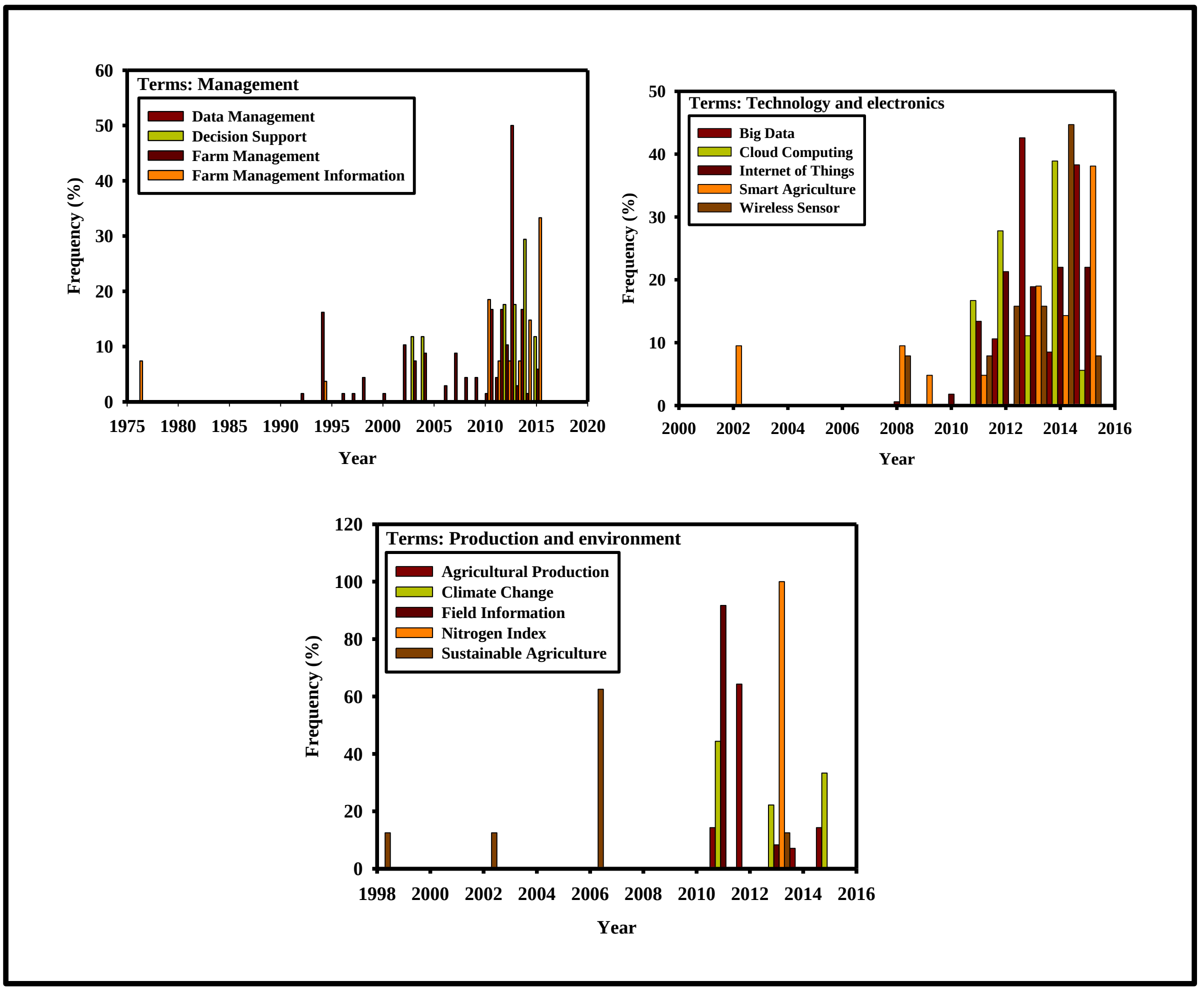
3.3.3 Evolution of the Scientific Literature

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.

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



3.3.4. Cluster Analysis

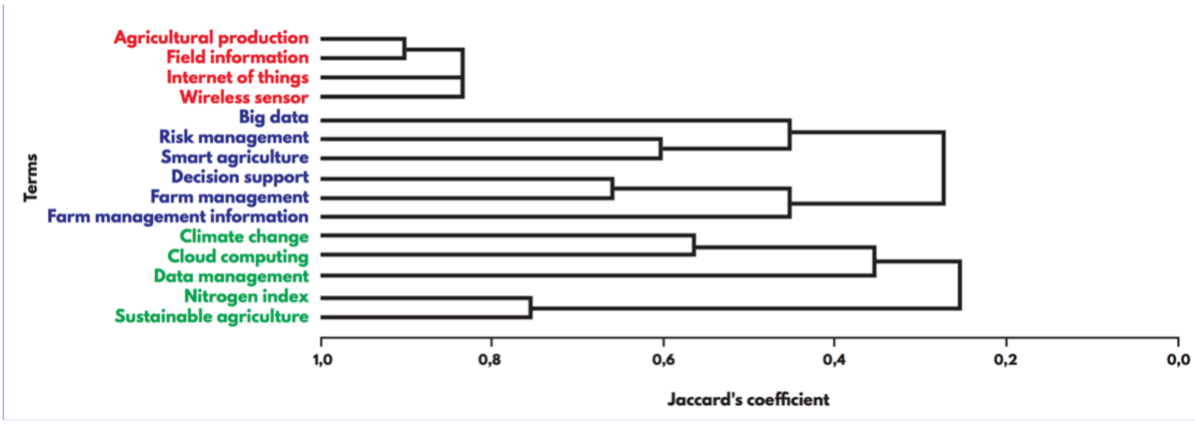
The Jaccard coefficient was used to analyze the similarity in the occurrence of the most frequent terms in the scientific literature (grouped into three clusters) (Figure 3). The Jaccard coefficient calculates the similarity of the selected terms; the closer to 1, the greater the similarity of the terms.

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].

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



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 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 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.

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APPENDIX 1. The questions that guided the interview questions

Item	Question
1	What crops 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?

CHAPTER 4: SMART FARMING IN GRAIN PRODUCTION SYSTEMS IN SOUTHERN BRAZIL: ADOPTED TECHNOLOGIES AND PERCEPTIONS REGARDING TECHNICAL ASSISTANCE[1]

Dieisson Pivoto[1], Paulo Dabdab Waquil[1], Edson Talamini[1]
[1]Universidade Federal do Rio Grande do Sul - UFRGS

ABSTRACT

At the beginning of the second decade of the 21st century, the use of a new set of applications called Smart Farming (SF) or Smart Agriculture (SA) began to emerge among agribusiness organizations and agents. This study identified the main SF technologies used in grain production systems in the South of Brazil and verified the perception of the grain farmers regarding technical assistance for SF. For this, 119 questionnaires were applied through a digital platform, at agricultural fairs and in visits to farms. The study used non-probabilistic sampling, since it considered grain farmers whose farms produced more than 50% of their gross revenue in grains. The questionnaire assessed the technologies the famers adopted, and an open question sought qualitative information regarding the producers' perception of difficulties encountered by consultants or technical assistance agents to advise the property in SF. Descriptive and content analysis were used to analyze the data. The results indicate that soil sampling is the main precision agriculture (PA) technology adopted by the production systems assessed, while smartphone apps to assist in agricultural management is the most commonly used information technology (IT). Regarding the perception of technical assistance, the farmers pointed out the low level of knowledge of the technicians and consultants regarding SF technologies as one of the main obstacles to exploring their potential. The results demonstrate a progress in the adoption of SF technologies in grain production systems in the South of Brazil. Thus, the machines used in grain production systems are undergoing a digitization process, especially due to the increase in availability of equipment with sensors and automated processes. However, the question remains about the capacity of farmers and assistance agents to monitor and take advantage of the potential of SF technologies in farms.

Keywords: Future Farming, Smart Agriculture, FMIS, Innovation.

1. INTRODUCTION

Brazilian agriculture, especially in the South of Brazil, presents a dynamic of intense innovation in grain production systems (cereals and oleaginous plants) since the mid-twentieth century. The region was the pioneer in the application of large-scale programs to improve soil fertility when soybean started being cultivated in the country, and, at the end of the 1990s, in the diffusion of no-till farming, which resulted in lower costs, lower environmental impacts and increased productivity (HOFF *et al.*, 2011). In addition, the migration of many farmers from the South to new areas or frontiers of cultivation such as the Midwest, and more recently, the

[1] This paper was formatted according with Agribusiness (ISNN: 1520-6297) authors guidelines.

MATOPIBA[2] , contributed to the diffusion of cultivation techniques and practices from the region throughout the country.

The South of Brazil has been following the global changes in agriculture. This evolution is linked to the diffusion of technologies and technical-scientific knowledge of universities and private companies that provide products and services for the agricultural sector. From the 1940s onwards, with the green revolution, agriculture went from being heavily dependent on labor, to depending on chemical resources and mechanization (MAZOYER and ROUDART, 2008). In the early 1990s, with the evolution of computer sciences and Global Positioning Systems (GPS), a transfer or effect of knowledge spillovers from other areas, to agriculture was observed.

One example is Precision Agriculture (PA), which incorporated technologies from other areas, such as military and computer sciences, and is defined by the Brazilian Precision Agriculture Commission (CBAP) as "an agricultural management system based on spatial and temporal variation of the productive unit that aims to increase economic return, sustainability and minimize its effect on the environment"(BRASIL, 2012). The first tests and experiments with this set of technologies were carried out in the South of the country and was later diffused and adopted in other regions. PA breaks with the traditional model for conducting production systems. The main difference between PA and the previous model is the more scientific production management, working with variability of the production areas.

At the beginning of the second decade of the 21st century, a new concept and set of applications emerged among agribusiness organizations and agents from computer, information and communication sciences, called Smart Farming (SF) (WOLFERT *et al*., 2017; PIVOTO *et al*., 2017). The main innovation or set of novelties this concept presented is a more intense use of the information produced by sensors that already existed in PA, and integration with other data sources, to produce results that generate new interpretations and decisions. Along the same lines, SF emphasizes automation of activities and smart responses, without the need for human intervention in the processes.

On the one hand, many technologies linked to SF are not yet innovations[3] (SCHUMPETER, 1988), because they are not available in the market or economically viable, since they are under development and being tested by companies and research institutions. On the other hand, as presented by Wolfert *et al*. (2017) and Pivoto *et al*. (2016, 2017), SF is a

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[2] Agricultural frontier region that includes the states of Maranhão, Tocantins, Piauí and Bahia.

[3] Innovation is a new service, process or product for the market or for organizations whose application is economically viable.

broad concept encompassing other areas already established in the market, such as Precision Agriculture and agriculture Information Technology (IT).

Some technologies and concepts, however, are more recent, such as “Big Data” and Robotics in Agriculture, whose use by technical consultants and farmers still causes discomfort. However, these technologies have the potential to maximize the return for farmers. It is possible to understand or imagine the dynamics for adopting and diffusing SF technologies based on the two sets of technologies (PA and IT) that are already diffused to some degree in the grain production systems of Southern Brazil.

Before analyzing the process of technology innovation and diffusion, it is necessary to understand the technologies analyzed and the level of adoption of these technologies by the farmers. Understanding the diffusion of these technologies is a way of anticipating changes in agricultural production systems in Brazil. This anticipation is useful for agents involved in agribusiness, such as public and private research companies, who can adjust their objectives, as well as agribusiness machinery and input companies that can better understand the process of technology diffusion in the context of SF.

Therefore, this study aims to identify the main SF technologies used in grain production systems in southern Brazil and to verify the perception of farmers regarding the technical assistance of companies and consultancies in SF.

2. EVOLUTION OF AGRICULTURE

At the beginning (MAZOYER and ROUDART, 2008), in the Neolithic period, agriculture was strongly dependent on nature and climatic conditions, with man learning to tame plants and animals. Due to the low amount of knowledge accumulated by society during this period, agriculture depended strongly on edaphoclimatic conditions. Currently, these rudimentary methods of agricultural production, called agriculture 1.0 (Figure 1), are still a reality for farmers in many developing countries (MAZOYER and ROUDART, 2008).

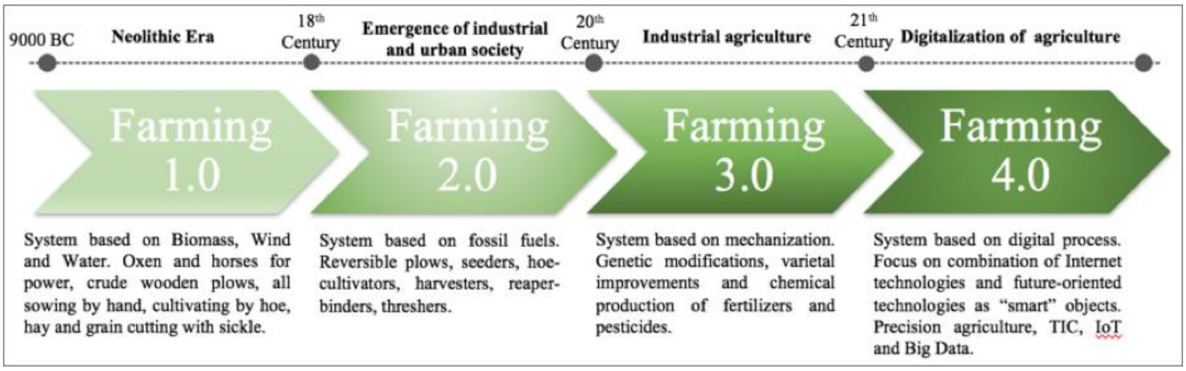

Figure 1. Evolution of agriculture and their periods.

Source: the authors.

The transition from a solar-based system (biomass, air, and water) to a fossil fuel-based system led the rise of industrial and urban society (WRIGLEY, 1988) and marked the beginning of agriculture 2.0. The energy revolution accelerated the process of agricultural change in the 18th and 19th centuries, setting the pace for a new agricultural revolution. Characterized by the development of agricultural machinery and the use of fertilizers (mineral fertilizers and new organic fertilizers), this new agricultural system made rapid progress in the early 20th century, bringing new tools (reversible plows, seeders, hoe cultivators) and harvesting equipment (harvesters) by removing, one by one, the main notsin the most time-consuming operations for the agricultural cycle (LOSCH, 2015).

One of the main disruptive aspect of agriculture 2.0 less need for manpower to carry out agricultural operations. This change led to the migration of the rural population to the urban environment. Operations that were carried out manually were now performed with machines and equipment with steam engines or internal combustion. Mechanization multiplied the capacity of human labor to carry out agricultural activities.

In 1994, the Food and Drug Administration (FDA) approved the first food completely produced with biotechnology, the FLAVRSAVR™ tomato. After this product was developed, biotechnology was diffused and expanded into large crops. In the mid-1990s, the emergence of geospatial technologies like remote sensors, geographic information systems (GIS) and GPS enabled the use of precision agricultural practices for site-specific applications of fertilizers, pesticides, irrigation and herbicides, marking the emergence of agriculture 3.0, more integrated with science.

Agriculture 4.0 or SF appears at the beginning of the 21st century, through the diffusion of Internet of Things (IoT) technologies and SF technologies (WOLFERT *et al.*, 2017; PIVOTO *et al*., 2017). If at large production scales, these technologies increase productivity and reduce costs, in small ones, in addition to this, they mainly improve the quality of food.

Recent advances in network computing enabled the development of millions of low-cost internet-connected devices, including cameras, sensors, radio frequency identification (RFID) and smartphones. This new technological paradigm could not have emerged, before because it was not economically viable (FREEMAN and PEREZ, 1988). Their use in agriculture has become economically feasible only with the significant reduction in the price of sensors and electronic equipment, due to technological advances. This dynamic is described by Freeman and Perez (1988) and by Perez (1983), who elucidate the process of consolidation of new technologies, through other economic cycles.

Agriculture 4.0 is highly dependent on scientific knowledge, with progressive insertion of knowledge from areas such as Big Data, artificial intelligence and other branches of information sciences, improving decision-making processes.

3. METHODOLOGICAL PROCEDURES

The adoption of SF was analyzed through research with farmers from Southern Brazil (states of Paraná, Santa Catarina and Rio Grande do Sul) (Figure 2). The main agricultural activities developed in the region are livestock production, milk production and grain production (mainly soybean, wheat and corn). Data were collected between April and December 2016 through a questionnaire. The questionnaire used was based on Souza Filho *et al.* (2011), Tey and Brindal (2012) and Pierpaolia *et al*. (2013), with suggestions from other 12 experts. The specialists who participated in the elaboration of the questionnaire are professionals linked to universities that work in areas such as Agricultural Engineering, Precision Agriculture, Crop Management, Rural Management, Agricultural Economics and professionals from companies that develop agricultural machinery and implements.

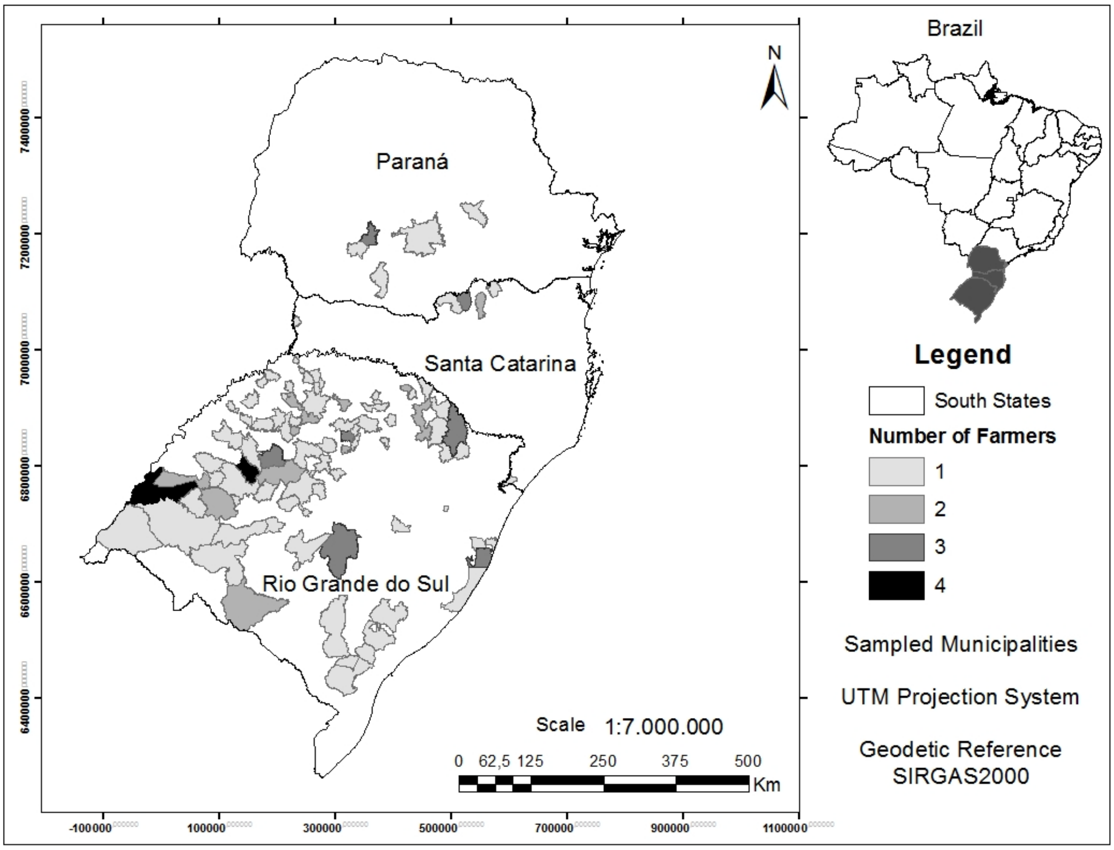

Figure 2. Location of the southern region of Brazil (South States), counties and number of producers sampled in the states of Rio Grande do Sul, Santa Catarina and Paraná

The questionnaire applied in this study was divided into sections. The first one had questions about the characteristics of producers and farms. The second section assessed the technologies adopted by famers (PA and IT). The assessment used a binary variable (yes or no), which was inserted into the database as 0 = does not adopt and 1 = adopts the technology, for both PA and IT. For PA, when the response was 1 = adopts the technology, the farmers attributed the % of the total area of the farm that used the technology. The third part had an open question related to the farmers' perception of the technical assistance in SF. The questionnaire gathered qualitative information about the difficulties encountered by the consultants or technical assistance agents to advise the farm in IT and PA.

To verify if the questions were adequate, a pilot study was applied to 32 farmers. After this procedure, some questions were eliminated, and others were adjusted. Research sampling was non-probabilistic, by convenience, since the research only focused on farmers who worked on grain production systems. To participate in this research, the famers needed to produce more than 50% of its gross revenue in grains (soybean, wheat, corn etc.).

The link to the questionnaire was sent to a list of e-mails provided by agricultural machine dealers and farmer associations. A total of 1,400 questionnaire was sent, and 160 were answered, but some were disregarded due to incomplete answers. In addition to questionnaire via the digital platform, questionnaire was also applied in agricultural fairs and visits to farmers, so that the total sample analyzed in this study was composed of 119 farmers. A descriptive analysis was performed of the percentage of adoption of PA and IT technologies. In PA technologies, the percentage of average use of each technology is presented in relation to the total area of the farmers.

The qualitative results from the third section of the questionnaire were analyzed and synthesized by dividing the answers into three constructs: knowledge, credibility and language used. These constructs reproduced some responses of the participants regarding the perception of farmers regarding technical assistance in SF.

4 RESULTS AND DISCUSSION

PA is a set of technologies to manage crop variability. The results indicate that one of the most adopted technologies by farmers using precision agriculture is georeferenced soil sampling (Table 1). 65% of the famers adopt this technology and they do it, on average, in 40.41% of the areas of their properties.

A lower percentage of farmers adopted variable rate application of fertilizers and correctives, compared to those who use georeferenced soil sampling. There is a difference of 8.66%, indicating that the farmers collect samples, but choose not to carry out the second stage, the variable rate application. It is noteworthy that these farmers apply fertilizers and correctives in a smaller area when compared to georeferenced soil sampling. Only 34.92% of the area of these producers, on average, receives the application, that is: they fulfill only part of the principle of precision agriculture.

Recent Brazilian studies found similar results, such as the one by Bernardi and Inamasu (2014), who observed adoption rates of 49% for sowing/fertilizer variable rate machines, and 38% for limestone spreaders among producers using some PA technology. In Australia, Robertson *et al.* (2012) observed a 20% growth rate in the adoption of variable rate fertilizers and correctives in the period from 2002 to 2009.

Table 1. Number of adopters, frequency of adoption of Precision Agriculture (PA) technologies and percentage of use of technologies in relation to the total area of the property

Technologies	Adops (observations)	Frequency (Adopts) (%)	Area that uses the technology (%)	Observations
Georeferenced soil sampling	76	64.96	40.41	117
Autopilot spraying	67	56.78	39.96	118
Application of fertilizers and variable rate correctives	67	56.30	34.92	119
Automatic control of sections for application of agrochemicals	62	52.54	29.75	118
Harvest maps	35	29.41	15.13	119
Autopilot	32	27.35	15.60	117
UAV's	14	11.76	3.19	119
Variable rate sowing	13	10.92	7.86	119
Telemetry	9	7.63	2.44	118

The use of autopilot sprayers was adopted by 56.78% of the producers. On average, these producers use machines equipped with autopilot to spray 39.86% of the cultivated area. So, it is possible to increase the use of this technology, even among the producers that already use it. On the other hand, the percentage of farmers that uses automatic control of sections to apply agrochemicals was lower than that of producers who use the autopilot for spraying. A study by Silva, Moraes and Molin (2011) observed that 39% of the sugarcane companies in the state of São Paulo adopt autopilot or satellite self-steering systems.

Autopilot is the most widely adopted PA tool worldwide (GEBBERS and ADAMCHUK, 2010). With the advancement of the electronic, information and communication industry, the cost of these technologies tends to drop. Add to that the investment in developing automated machines. These technologies are already available in the market, in the initial phase of tests, some already commercially, like self-propelled tractors.

The results show that only 29.41% of the farmers use harvest maps. This technology is only used in 15.13% of the cultivated area. This low percentage of use may be related to the utility attributed to the technology by the producers of southern Brazil or the lack of technical support for analysis, interpretation and technical recommendation of the data generated.

Fountas *et al*. (2005) found that North American and Danish famers found soil maps more useful than harvest maps. The usefulness and importance of the harvest maps increased with the increase in the time of collection of this information (FOUNTAS *et al*., 2005). The authors found significant and positive difference between producers with more than 5 years of use of harvest maps and the others. A study by Artuzo (2015) corroborates this result, demonstrating that the producers' perception of the viability of PA occurred only after the third year of adoption of technologies.

Variable rate sowing is still used by a small percentage of farmers (10.92%). However, it should be noted that the area that uses this technology surpassed the use of harvest maps. Telemetry is used by 7.63% of the famers. The technology allows real-time data transfer from the machine to the office and from the office to the machine. Telemetry is one of the main technologies in the process of agricultural digitization, allowing monitoring and decision making in real time. It also enables many processes to be automated, with operators distant from the location where the operation is being performed.

On the one hand, what is seen in the field is that machines and equipment are undergoing a process of digitization, especially since agricultural companies are offering products with more sensors and automated processes. On the other hand, the great question is whether the organization of farmers (management area) can monitor and take advantage of the digitization process potential. In this context, IT links agriculture 3.0 and agriculture 4.0, because through them data collection is automatically extended around farm, allowing the systematization and extraction of results that improve decision making.

It was observed that 51.26% of the farmers use software/programs in the farm, for cost management, phytosanitary management and data storage (Table 2). Similarly, 61.02% uses computers to do annual planning of farm activities. Data from the Brazilian Service of Support to Micro and Small Enterprises (SEBRAE) with farmers of the 17 most relevant chains of Brazilian agribusiness showed the use of computers by 39.5% of the sample. However, only 25.2% used digital financial control (worksheet, specific software or mobile) (SEBRAE, 2017).

Table 2. Number of adopters and frequency of adoption of Information Technology (IT) and property management.

Technology	Adopts (observations)	Frequency (Adopts %)	Observations
Do you use apps on your cell phone or smartphone to assist with agricultural management (e.g. apps to track soy quotation, identify pests, cost management)?	93	79.49	100
Do you use calculation programs or spreadsheets (Excel) for monthly cash flow control and cost management?	86	72.27	119
Do you use online or mobile banking?	82	70.09	117
Do you use software/apps for property management (cost management, people management, production management, storing property data, phytosanitary management, fleet management, land management)?	61	51.26	119
Do you use computer programs to plan annual activities?	72	61.02	118
Do you use indicators from the data stored to manage the machines and the property (for example: fuel consumption per hectare, machine hours per hectare)?	60	50.85	118

With the software it is possible to analyze data from several years/harvests, patterns of behavior and identify possibilities of improvement in production systems. This process can also be performed manually on paper; however, with limited scope. Through the digitalization of the data, the process becomes faster and there is possibility of crossing and integrating with information from other segments.

In farms that claim not to use computers for management, records are likely to be limited to annotations, which are often unorganized and cannot be retrieved quickly. Thus, the potential for examining problems through the analysis of stored information is lost (LARSON *et al.*, 2008).

Simply adopting software/programs is only one of the first steps of smart farming. Besides the use of computers and programs, smart farming is based on the use of indicators and metrics for managing the farm and the activities developed in it. The results of this study indicate that 50.28% of the farmers use indicators from the stored data. This item points to the group of producers that will find it easier to adopt technologies linked to SF, as they use scientific criteria or quantification to make decisions.

One of the obstacles for producers to use indicators is handling the data collected. A study by Fountas *et al.* (2005) with US and Danish producers that use PA, observed that among the main problems to handle the data are the time consumed, lack of technical and agronomic knowledge. In Brazil, companies and startups are developing apps and programs that use the data to generate program maps and exits with useful information for producers.

SF demands a rapid flow of information and, in this sense, mobile devices such as smartphones and tablets are central to the process of adopting and diffusing technologies. Many farmers use online banking via computers or cellphones, and 79.49% used these devices to assist in agricultural management, especially to get information. Among the main uses of the internet by farmers are price/supplier research (80.9%), access to financial services (58%) and purchase of inputs or goods (57.2%). (SEBRAE, 2017)

Adopting SF technologies does not guarantee a return to the farmers. These technologies demand a high level of knowledge to maximize their potential to generate results. An example is the management and planning software that requires a professional to do the analysis and return with results and recommendations.

Unlike agriculture 2.0, which was consolidated during the post-war (MAZOYER and ROUDART, 2008), and which was based on a homogeneous technological package, the principle of smart farming is to understand the variability of production and performance systems in a timely manner. For this, it demands a lot of information and knowledge. In addition to the data collected, professionals who help to give meaning and generate knowledge become important for the production process. In this context, we present the results regarding the perception of the grain farmers regarding the technical consultants in SF and their limitations to assist in the advancement of this new area.

The farmers pointed out the low level of knowledge of technicians and consultants regarding SF technologies as one of the main obstacles to using them. It was observed that the producers with the highest level of technology adoption presented the most critical answers to the lack of knowledge of the technicians. For example, one of them said that "many are not qualified. In some cases, I own more technology than the companies in the area".

Chart 1: Summary of the items raised by the participants regarding the difficulty of the technical consultants to advise in smart farming.

Item	**Answers given by participants**
Knowledge	Many are not qualified. In some cases, I own more technology than the companies in the area.
	Low overall knowledge of technologies. When the consultant does not know, this does not encourage the adoption and use of technology.
	Many agronomists have little knowledge of information technology. They have difficulty with smartphone software and apps. They lack in courses that are necessary for the current times.
Credibility	There is a need for greater credibility of companies that provide services in precision agriculture. Companies must bring numbers and examples of technologies for the farmers.
	The consultants need to be more technical and honest with the farmers.
	Machine resellers are not prepared to sell the PA and information technology services that are part of the machines and equipment. As a result, producers do not know what to do with the information. I have sensors to generate harvest map in my harvester, though I do not use them.
Language and communication	One of the main difficulties is the language used by technicians. Younger farmers understand it, but older producers have difficulty understanding.
	Standardization of language/knowledge among all users and operators.
	Agronomists have difficulty passing the information.

The results indicate that, in the perception of farmers, many technicians and consultants are not yet adapted to the new context of digital agriculture. There is still a need for technical visits and field observation by technical assistance. However, many of the recommendations and indications of management to farmers require data and information subsidies that were not available 10 years ago. For this, the consultants need to be updated with software and learn to interact with other areas of knowledge, to enable solutions and extract data results.

A second item mentioned by the farmers was related to the credibility of the companies that provide services in SF. For the participants, some resellers and service providers sell accessories and technologies or even services without having proven results or a follow-up service. An example of this situation would be harvest maps and some sensors that, after being sold by the companies, are not used for lack of an after-sales service.

For SF to advance, it is necessary that the complete cycle be adopted. What is currently seen now is only part of SF: agricultural machinery and equipment. On the other hand, resales and technical support are not prepared for a new context of agriculture, as well as the administrative and management areas in farms.

The producers also mentioned the language and communication used by the consultants. Smart farming brings new concepts and knowledge. Some farmers commented that they have difficulty understanding the language of technical assistance and some pointed out that the consultants' communication is flawed. Initiatives linked to providing training courses in this area have increased in Brazil as a response to two items highlighted by the producers, knowledge and language. Among them are the courses offered by Fatec-Pompeia in Big Data and Precision Agriculture, as well as other new courses in Brazil.

5. FINAL CONSIDERATIONS

The results demonstrate an advance in the adoption of PA and IT technologies in grain production systems in the South of Brazil. Some grain farmers are inserted in the context of SF and tend to move forward in this new paradigm. However, the number of farmers using a larger set of PA and IT technologies is still limited. This process is dynamic, as technologies become economically viable, adoption becomes possible.

The perceived utility of these technologies by the farmers may be influencing their rate of adoption and needs to be extensively studied. As verified in the perception of producers regarding technical advice, many technologies still do not have a positive and measurable result in their view. The results of this research point to the need of companies selling equipment and services to show examples and results using the set of technologies.

Another SF challenge is access to these services. In this context, companies are emerging that seek to offer innovative products and services to farmers, especially startups, who are taking advantage of the potential of Information and Communication Technologies (ICTs), electronics and all technologies inserted in the context of smart farming. However, in some regions, producers do not have the organizational culture of opening their data and seeking help with consultants, as well as or of using software.

The results of this study, new in Brazil, were reached using a sample selected by convenience. A probabilistic sample could be more reliable to extrapolate the results. Similarly, panel data would help to accompany this process of digitization of agriculture and the creation of an observatory for digital agriculture would be an important initiative by research institutes or farmers' organizations to monitor the evolution of technologies in SF.

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CHAPTER 5: FACTORS INFLUENCING THE ADOPTION OF SMART FARMING BY BRAZILIAN GRAIN FARMERS[1]

Dieisson Pivoto[1], Paulo Dabdab Waquil[1], Edson Talamini[1], Bradford Barham[2], and Cristian Rogério Foguesatto[1]

[1] Universidade Federal do Rio Grande do Sul – UFRGS [2]Universityof Wisconsin–Madison-USA

Abstract

Smart farming (SF) is a relatively new concept referring to the use of information and communication technology in farm management, focusing simultaneously on productivity, profitability, and conservation of natural resources. Given the characteristics of commodity markets, farmers usually are price-takers in grain commodity markets. Suppliers' profitability thus depends on the competent financial and productive management of goods. SF use, therefore, is a frontier in productivity gains. The aim of this paper was to identify the barriers and determining factors influencing the decisions of grain farmers regarding adopting SF technologies. For this, a sample of 119 farmers in southern Brazil was recruited. Data were analyzed through descriptive analysis, Logit and Poisson models. The results showed that some factors have increased the adoption of technologies with different intensities and in different manners. Education had the strongest influence on the adoption of georeferenced soil sampling technologies. Adoption of autopilot spraying was more dependent on the size of the farm, as was management software. The main barriers delaying the entry of Brazilian farmers into the SF context were the prices of equipment, low qualifications of rural labor, precariousness of Internet access in Brazilian rural regions, and need to input much data and information into software, which made analysis and interpretation difficult.

Key-words: Smart Agriculture, Innovation in Agriculture, FMIS, Future Farming.

1. Introduction

Brazil is one of the most important producers of the world's food supply, especially commodity grains, such as soybean, wheat, corn, and rice. In the 2015/16 growing season, Brazil produced 186.3 million tons of grains, 40% of which came from the southern region of

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the country (National Supply Company [CONAB], 2017). Brazil ranks second globally in soybean production, with 113.92 million tons in the 2016/17 season (CONAB, 2017).

Over the past few decades, Brazilian soybean yields have experienced significant increases, from 1700 kg/ha in 1979/80 to 3364.1 kg/ha in 2016/17 (CONAB, 2017). This increase in soybean productivity has occurred due to the introduction of a set of technologies in production systems, such as fertilizers, agrochemicals, new cultivars, machines, and equipment with greater operational capacity. However, the diffusion of these technologies has not been uniform throughout Brazilian territory, and the levels of technology adoption differ throughout the country (Vieira Filho, 2014).

One set of new technologies, in particular, has arisen and attracted the interest of researchers (Sorensen et al., 2010; Fountas et al., 2015) and farmers with its potential to contribute to increased productivity. Some of these technologies and information are called smart farming (SF). SF is a relatively new concept referring to information and communication technology in farm management (Wolfert et al., 2017), focusing simultaneously on productivity, profitability, and the conservation of natural resources. In general, this concept has emerged from three fields of knowledge: precision agriculture (PA), information technology (IT), and farm management information system (FMIS) (Wolfert et al., 2017). While PA takes into account only in-field variability, SF goes beyond that to base management tasks on not only location but also data, enhanced by contextual and situational awareness and triggered by real-time events (Pivoto et al., 2017; Wolfert et al., 2017).

Some indicators predict that SF will increase the availability of technologies in the coming years. First, the average price of Internet of Things (IoT) sensors for agriculture has fallen from US$1.50 in 2004 to US$0.50 in 2016 (CBINSIGHTS, 2017). These sensors provide the basis for SF because they allow collecting a lot of information and monitoring several processes in real time with precision and at low costs. Second, companies' investments in artificial intelligence are projected to rise from US$6.0 in 2016 to US$13.93 billion in 2017 (CBINSIGHTS, 2017). These data demonstrate a path of innovation in smart environments in several sectors, which could spill over to agriculture.

Given the characteristics of commodity markets, farmers usually are price-takers in grain commodity markets (Waquil et al., 2010). Suppliers' profitability thus depends on competent financial and productive management of goods. SF use, therefore, is a frontier in productivity gains. From a macroeconomic view, due to excepted challenges in food systems production in the coming decades (e.g. increased frequency and severity of climate weather events and degradation of natural resources), the adoption of SF technologies should be encouraged. In the microeconomic view of the farmer on the farm, the permanence of producers in the activity of grain production requires either productivity gains or reduced costs; therefore, they need to advance in the adoption of technologies that lead in this direction. From economic and social perspectives, if SF technologies prove to optimize results, farmers who do not adopt them will be excluded from the agricultural activity. Against this backdrop, it is important to understand farmers' behavior regarding adoption of SF technologies and the factors determining such adoption.

In the light of the foregoing, the aim of this paper is to identify the barriers and the determining factors influencing grain farmers' decisions regarding adopting SF technologies. Behind this specific research objective, there is an effort by our research group to understand a broader issue: why is Brazilian agriculture delaying entering the digital world? In a survey carried out by SEBRAE (2017), 60.5% of the farmers in Brazil did not use computers in their rural businesses. In the northern and northeastern states, the percentage of farmers that did not use computers was higher than the Brazilian average, at 78.6% and 71.0%, respectively (SEBRAE, 2017). The use of computers in rural businesses decreased as the age of the manager of the farm increased. Of Brazilian farmers, older than 55 years, less than 32% used computers.

To our knowledge, this study is the first to consider factors affecting farmers' adoption of SF in the Brazilian grain sector. The contribution of this paper is twofold: it provides empirical evidence on the role of farms' characteristics, institutional factors, information searches, and personal features in SF adoption and explains the low diffusion of SF in Brazil (Pivoto et al., 2017). The study use data collected from grain farmers in southern Brazil. This region pioneered grain production in the country, and the first cultivated areas of wheat and soybean were produced by farms in this region. Brazilian agricultural expansion occurred due to the migration of farmers from this region to Midwestern and northeastern Brazil. From this data, econometric models are created to understand the barriers and the determinants to adopting SF technology.

2. GENERAL CONCEPTS OF SMART FARMING

The concepts in SF have come from other sectors, especially industry. Scientific advances in areas such as software engineering and computer science have led to virtually ubiquitous computing, allowing the emergence of smart environment (Gubbi, 2013). Other areas, such as agriculture, then have appropriated the concept of smart environments. The industry sector, for example cars and electronics, has become one of the main area developing application for smart environments, resulting in a new, fundamental paradigm driving the shift of industrial production to industry 4.0 (Brettel et al., 2014; Lasi et al., 2014; Liao et al., 2017; Maynard, 2015).

Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies, and it includes Cyber-Physical Systems, the Internet of things, Cloud Computing and Cognitive Computing (Brettel et al., 2014; Lasi et al., 2014; Liao et al., 2017; Maynard, 2015). The term "Industry 4.0" was revived in 2011 at the Hannover Fair-Germany and in October 2012 the Working Group on Industry 4.0 presented a set of Industry 4.0 implementation recommendations to the German Federal Government (Brettel et al., 2014; Lasi et al., 2014).

The concept of smart environments in agriculture has emerged later than in industry, although some technologies linked to the idea of smart environments, such as PA and FMIS, have already been used in agriculture for a long time. The concept of SF can be expressed using different terminologies and definitions. Zheng et al. (2011), for example, used the concept of digital agriculture to refer to the use of digital technology to digitalize, visualize, design, monitor, and control agricultural objects and farming processes relevant to agricultural needs. According to Beecham (2014), SF emerged from the incorporation of computing and data transmission technologies into agriculture. The concept of SF or smart agriculture is broad and interacts with another set of technologies, such as PA and information management systems in agriculture, derived from FMIS.

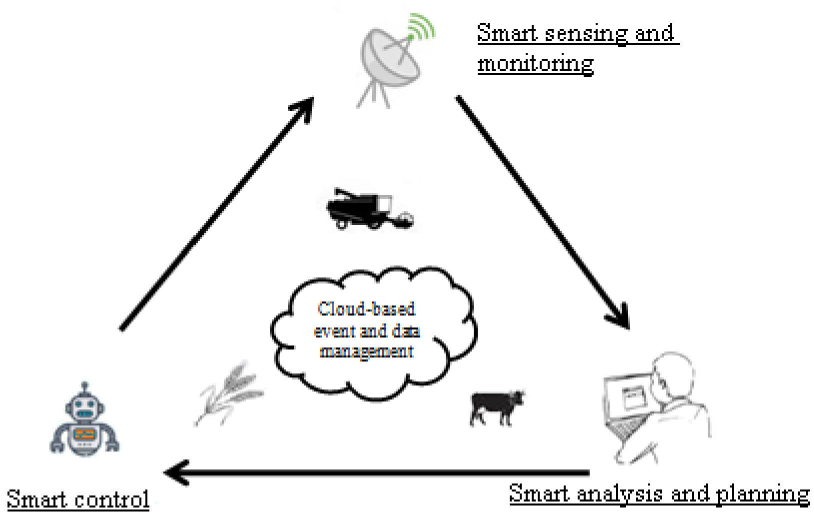
SF has similarities with the concept of industry 4.0. The basis for advances in industry 4.0 is the combination of Internet technologies and future-oriented technologies, such as “smart” objects (Brettel et al., 2014; Lasi et al., 2014; Liao et al., 2017; Maynard, 2015). The German government has labelled this emerging concept industry 4.0 (Lee, 2014), but there is no established concept in agriculture (Wolfert et al., 2017). In this study, SF refers to the use of the IoT with the objective of connecting virtually networked objects, starting with the progressive introduction of big data knowledge, artificial intelligence, and other areas of communication and information science to improve decision making and begin the process of automation in operational activities.

The greatest application and potential offered by the advance of the set of technologies connected to SF is the possibility to increase the efficiency and effectiveness of production systems and productive chains. With more sensor data, process automation, automatic controls, and algorithm decision making can reduce losses, increase the gains in processes, and improve understanding of the relationships among the variables that determine the outcomes of systems.

Besides the new areas such as Internet of things, Cloud Computing, Cognitive Computing and Big Data, two fields have contributed to the development of SF: PA and IT (Wolfert et al., 2017). A concept introduced in the early 1990 (Tey and Brindal, 2012), PA is a production system that involves crop management based on field variability and site-specific conditions (Seelan et al., 2003). Data are also collected to help farmers make guided sub-field decisions, regarding, for instance, the application of fertilizers and pesticides and the sowing density for seeds (Tey and Brindal, 2012). Overall, the set of technologies linked to PA is intended to manage crop and soil variability in a manner that increases profitability and reduces environmental impactt (Fountas et al., 2005).

As well, IT is the use of any computer, storage, networking, or other physical devices, infrastructures, and processes to create, process, store, secure or exchange any form of electronic data. IT is the basis for FMIS. The integration of IT into different sectors has made it possible for professionals in the IT industry to make changes that can also help other sectors, such as agriculture (Figure 1). The main challenge is to determine how SF will deal with uncertainty in agriculture. Unlike other sectors, the production process in agriculture is more dependent on biophysical conditions. Consequently, agriculture, especially when not practiced in a greenhouse, has more inconsistent final production results.

Figure 1**.** Concept and application of smart farming.



Source: Wolfert et al. (2017).

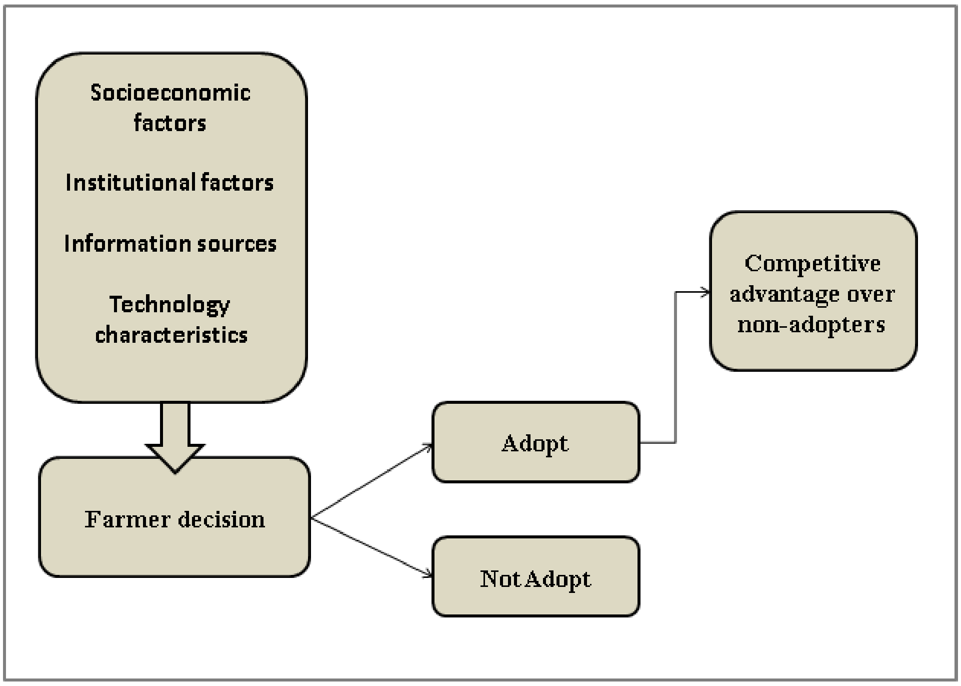
Some of the main IT devices seen in the field are smartphones, tablets, and computers. The main objectives of using such equipment in the agricultural system are to improve the decision-making process and to better plan and obtain information on and off the farm.

3. TECHNOLOGY ADOPTION

Farmers tend to adopt technologies and techniques if they can realize increased profitability (De Graaff et al., 2008; Feder et al., 1985; Jara-Rojas et al., 2012). Moreover, pioneering initiatives to adopt new technologies can generate competitive advantages for farmers compared to those who do not (non-adopters) and those who only adopt them later (Foster and Rosenzweig, 2010). It, therefore, has been observed that in agriculture, technology adoption is a process characterized by a certain level of heterogeneity (Foster and Rosenzweig, 2010).

To understand the elements that result in this heterogeneity between adopters and non-adopters, it is necessary to analyze the factors that influence the process of technology adoption. For this, we define some factors based on the studies of Pierpaolia et al. (2013), Souza Filho et al. (2011), and Tey and Brindal (2012). These studies focused mostly on famers' adoption of PA and IT, which are part of SF. Figure 2 visualize the dimensions influencing farmers' adoption of technologies (mainly SF) according Knowler and Bradshaw (2007), Souza Filho et al. (2011), Tey and Brindal (2012) and Pierpaolia et al. (2013).

Figure 2. Process of technology adoption and the dimensions influencing SF adoption.



Source: Knowler and Bradshaw (2007), Pierpaolia et al. (2013), Souza Filho et al. (2011), and Tey and Brindal (2012).

Adoption of SF has occurred in countless production chains around the world at different speeds (Fountas et al., 2015; Kaloxylus et al., 2012). Some factors may affect the likelihood of farmers adopting technologies. The most commonly analyzed dimension in the literature is the socioeconomic variables in the personal background of the farm's main decision maker. Among these personal variables, a positive relationship is expected between education and the adoption of technologies (Carrer et al., 2017; Feder et al., 1985), especially those linked to SF. Higher education levels potentially increases farmers' ability to process information, make decisions, and procure new management technologies (Carrer et al., 2017; Feder et al., 1985). Formal education, therefore, is expected to be positively related to the adoption of SF. Indeed, such results have been found in several technology adoption studies on PA and FMIS (e.g., Alvarez and Nuthall, 2006; Larson et al., 2008; Walton et al., 2008).

Within the socioeconomic dimension, some factors are linked to behavioral and perception of farmer and influence the decision process. These factors are closely related to perceptions, which are embedded within psychological aspects. Farmers' perceptions refer to their personal, subjective evaluations of innovation attributes. Among the perceived attributes suggested by Rogers (2003), one of the main authors on this topic, is the perceived relative advantage of introducing innovations to the farm. This perceived advantage passes through elements that escape economic calculation but is influenced by individuals' beliefs, previous experiences, and personality (Souza Filho et al., 2011).

Another important dimension in technology adoption is linked to the sources of information. Any technology adoption process needs information so that farmers can process the information and compare possibilities. Tey and Brindal (2012) emphasized that farmers typically source information on agricultural practices from extension services or consultants. The use of technical assistance on farms is important to provide farmers and their employees with new information (Aker et al., 2011). Farm visits by specialists reduce the risk of incorrect adoption and failure in the adoption process, increasing the likelihood of adoption (Figure 2; Alvarez and Nuthall, 2006; Dill et al., 2015).

In addition to information sources, institutional factors, such as legislation, credit access, infrastructure, and markets, can influence the adoption process, especially for SF. Access to long-term credit can be an important factor in PA (Tey and Brindal, 2012). The regional telecommunications infrastructure, especially Internet access, is one of the factors with the greatest impact on the IT adoption process.

The intrinsic elements of technology also influence the adoption process, as discussed by Aldana et al. (2011), who analyzed the adoption of package technologies in GMO

(Genetically Modified Organisms) crops. Aldana et al. (2011) identified sequential adoption patterns in which farmers adopt parts of the package before the whole package. The experience gained through the adoption of subcomponents provides information on the characteristics of the package, encouraging or discouraging its subsequent adoption (Aldana et al., 2011). This is the case of SF, which involves the progressive adoption of technologies.

4. METHODS

4.1 ANALYTICAL FRAMEWORK

A body of empirical research assumes that utility maximization influences farmers' adoption of innovations (see Carrer et al., 2017; Jara-Rojas et al., 2012, Kassie et al., 2009, 2015; Tey et al., 2014). Accordingly, we assume that adoption occurs when the expected utility of adoption (U_n) exceeds the utility of non-adoption (U_d), i.e. $U_n > U_d$. In this context, latent variables (Ui) can define the parameters of farmers' decisions (Carrer et al., 2017).

Latent variables (Ui) are the functions of a set of factors, such as socioeconomic characteristics (e.g., education and age), information sources (e.g., access to technical consultants), institutional aspects (e.g., Internet and credit access), and the technology characteristics of innovation (e.g., relative advantages of adoption) (see Figure 2). This set of factors has the potential to affect the farmer's perceptions of the expected utility of a particular technology, consequently influencing the farmer's likelihood of adopting it (Carrer et al., 2017). Mathematically, this is represented as:

$$Ui = \beta Xi + ei = 1,2, \dots, N \qquad \text{Eq. (1)}$$

where Xi is a vector of the independent variables, β is a vector of the parameters, and e is the error term. This study uses two econometrics models to analyze farmers' adoption of SF: logit regression and count data (a Poisson regression model; PRM), following Carrer et al. (2017), Isgin et al. (2008), and Jara-Rojas et al. (2012). Before running these two models, a correlation analysis is performed for the independent variables (Appendix A). Weak correlations are observed between the variables, except for X1 and X3, because farmers' age is associated with length of experience in farm work.

4.2 ESTIMATION OF THE LOGIT REGRESSION MODEL

In most empirical studies using logit models, the observed decision for "adopt or non-adopt" is viewed as an outcome of a binary choice model (Mariano et al., 2012, Carrer et al., 2017). Thus, in this logit regression, the adoption technology decision is modeled as a binary variable, which takes the value of 1 for adopters and 0 for non-adopters:

$$yi = \begin{cases} 1\ if the farmer adopts SF \\ 0\ if the farmer does not adopt SF \end{cases}$$

The probability that the farmer adopts SF is represented as:

$$P[y_i = 1] = P(e > -X_i\beta)$$
$$= 1 - F(-X_i\beta) = F(X_i\beta) \qquad \text{Eq. (2)}$$

where F is the cumulative distribution function, and the βparameters can be estimated using maximum likelihood procedures. Models constituted by binary choices differ only in the assumption of the functional form of F. The estimation of the logit model may be employed to estimate the likelihood of the adoption of SF technologies. According to Greene (2005), it can be shown that:

$$P_i = P[y_i = 1] = \frac{e^{Xi\beta}}{1+e^{Xi\beta}} \qquad \text{Eq. (3)}$$

After obtaining the maximum likelihood estimates of *Xi* variables for the adoption of SF technologies, the following procedure is run to estimate the marginal effect of each variable. Typically, this is defined as the small effects of a unit change in *Xi* with all the other factors remaining constant. This estimation can be expressed as follow:

$$\frac{\Delta p_i}{\Delta x_i} = \frac{\partial p}{\partial xi} = ßi \frac{1}{1+e^{-(\mathrm{Xi}\beta)}} \times \frac{e^{-(\mathrm{Xi}\beta)}}{1+e^{\mathrm{Xi}\beta}} \text{Eq. (4)}$$

4.3. ESTIMATION OF THE POISSON REGRESSION MODEL

In addition to examining the adoption of a single technology, the present study is also intended to understand the determinants of adopting a SF package (Aldama et al., 2011). PRM are used to analyze the simultaneous adoption of a set of technologies. In this model, the dependent variables are the sum of four technologies (where 1 refers to the adoption of one technology, dependent variable 2 refers to the adoption of two technologies, and so on). In this model, the dependent variable (y) is the sum of the total number of SF technologies adopted by farmers. With y for the random Poisson variable, the likelihood density function can be represented as:

$P(Y = y_i|x_i) = f(y|\mu) = \frac{e^{-\mu}\mu^{y}}{y!},\ y = 0,1,2, \ldots ,\ 0 \leq \mu < \infty$Eq. (5)

where *yi* is the number of SF technologies adopted by the farmer, and *xi* are the variables that determine the adoption of SF. The expected mean parameter (λ) of this probability function is defined as:

$E(y_i|x_i = \lambda_i = \exp(x_i'\beta) + e_i$Eq. (6)

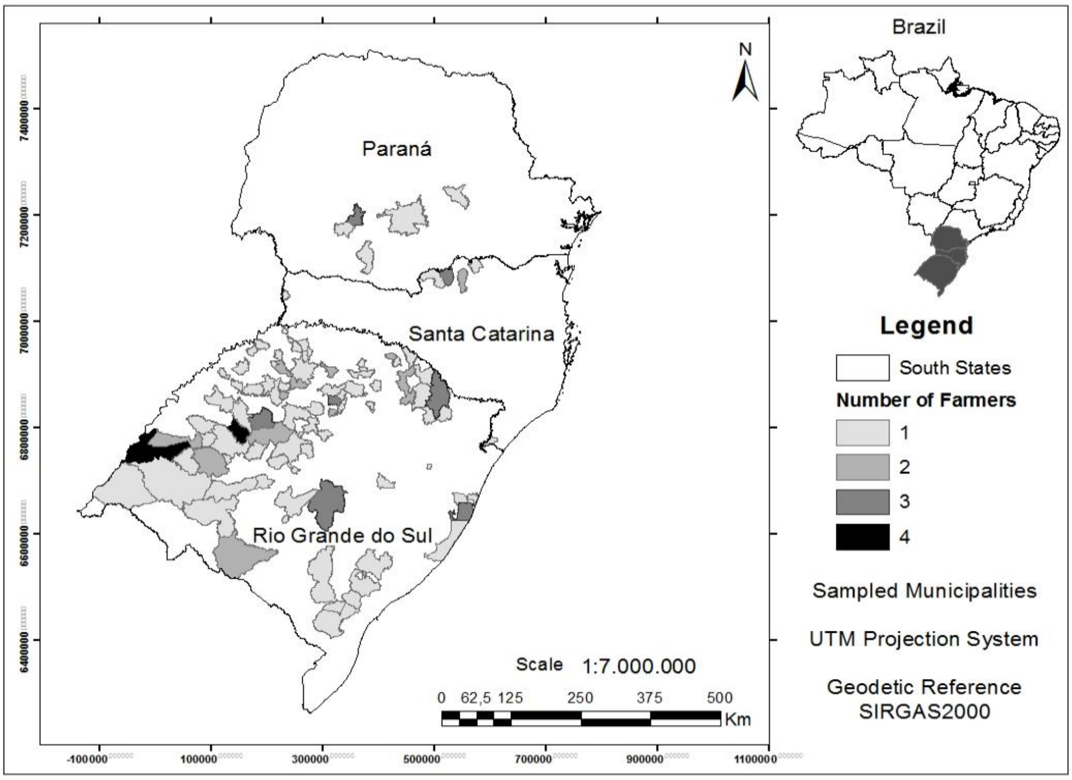
Eq. (6) represents the PRM in which the ß parameters can be estimated using maximum likelihood procedures. In particular, the following logarithmic likelihood function is maximized:

$lnL(ß) = \ln\left[\frac{e^{\lambda}\mu^{y}}{y!}\right] = -\lambda + y_i \ln(\lambda) - \ln(y_i!) = -\exp(x_i'\beta) + y_i(x_i'\beta) - \ln(y_i!)$Eq. (7)

4.4. SAMPLE, VARIABLES, AND HYPOTHESES

The data were collected in southern Brazil (Figure 3), a region that includes the states of Paraná, Santa Catarina, and Rio Grande do Sul. The main activities of these farms were livestock, milk, and grain production (primarily soybean, wheat, corn, and rice).

Figure 3. Geographic distribution of the sampled producers' cultivated lands.



The adoption of SF was analyzed by surveying farmers from April to December 2016. For this questionnaire, we defined factors based on the work of Souza Filho et al. (2011), Tey and Brindal (2012), and Pierpaolia et al. (2013) and suggestions from 12 experts (and further questions not found in the literature). The experts who participated in this study were professionals from machine companies and university professionals in areas such as agricultural engineering, PA, crop management, rural management, and agricultural economics.

The questionnaire was divided in two parts (Appendix B). The first had questions on the characteristics of farmers and farms, and the second on the barriers and factors influencing the adoption of SF technologies, called determinants. This section had two subsections: one on PA and one on IT. To measure the barriers and determinants, we used a 5-point Likert scale (1 = totally disagree to 5 = totally agree). Also, the survey had one open-ended question (the questionnaire was posted on an online platform to increase the sample for data collection). To verify the appropriateness of the questions, a pilot survey was conducted with 32 farms. Afterwards, some questions were eliminated, and others modified.

An electronic link to the questionnaire was disseminated through the e-mail lists of agricultural machinery resellers and farmers associations (*http://www.onlinesurvey.com.br/clientes/dieisson/*). In addition to online recruitment, we recruited face to face at agricultural fairs (25%) and direct application in the field (15%). To be eligible to participate in this survey, farmers had to derive more than 50% of their gross revenue from grains (e.g., soybean, wheat, and corn). We sent the questionnaire to a list with 1,400 e-mail addresses and received only 160 questionnaires. Some had incomplete answers, in addition, the other ways that were collected, so the final sample consisted of 119 farmers.

The analysis in this study focused on four SF technologies: three PA technologies (georeferenced soil sampling, automatic spray, and application of fertilizers and soil correctives at variable rates) and one variable linked to management tools, including management software (e.g., cost, people, productive, phytosanitary, and land management). These four technologies were chosen because they involved different applications and areas of development within SF, especially in grains. The first two were linked to soil sampling and application at variable rates to represent crop variability management. The third variable, auto-piloted spray, was related to farm automation (or attempts to do so). The fourth technology, IT, was related to information systematization or decision making.

Table 1 provides a description of the variables used in the econometric models for all the estimated parameters of the independent variables used in the regressions.

Table 1. Description of the variables in the econometric analysis of the determinants of smart farming adoption.

Variable	Description
Y1= Adoption of soil georeferenced sampling (y: logit model)	Dummy variable with a value of 1 if the farmer uses soil georeferenced sampling and 0 if not
Y2= Adoption of application of variable rate fertilizers and correctives (y: logit model)	Dummy variable with a value of 1 if the farmer applies variable-rate fertilizers and correctives and 0 if not
Y3=Adoption of autopilot spraying (y: logit model)	Dummy variable with a value of 1 if the farmer uses autopilot spraying and 0 if not
Y4=Adoption of management software (cost, people, productive, phytosanitary, and land management) (y: logit model)	Dummy variable with a value of 1 if the farmer software for management decisions and 0 if not
SF adoption (y: Poisson model)	Index of discrete values ranging from 0 to 4, where SF is the sum of four dummy (0,1) variables for the adoption of four SF technologies: (i) soil georeferenced sampling; (ii) application of variable-rate fertilizers and correctives; (iii) autopilot spraying; and (iv) adoption of management software (cost, people, productive, phytosanitary, and land management)
X1 Farmers' age	Years of the farmer's life (continuous).
X2 Education level	Assumes discrete values ranging from 1 to 4: (1) elementary school; (2) high school; (3) undergraduation; and (4) graduation
X3 Experience	The farmers' years of experience in agriculture (continuous)
X4 Participation in a farmers' cooperative or association	Dummy variable with a value of 1 if the farmer participated in a farmers' cooperative or association in the 2015/2016 harvest and 0 if not
X5 Participation in a group exchanging experiences with other farmers and holding technical meetings	Variable dummy with a value of 1 if the farmer participated in a group exchanging experiences with other farmers and holding technical meetings in the 2015/2016 harvest and 0 if not.
X6 Technical assistance	Variable dummy with a value of 1 if the farm received technical and management visits from specialists (e.g., agronomists and economists) in the 2015/2016 harvest and 0 if not.
X7 Frequency of consultations or technical assistance during the year	Days per year (continuous)
X8 Receptivity to technology	Assumes discrete values ranging from 1 = fully disagree to 5 = fully agree with the following statement: "In the purchase of machines and equipment, I prefer to acquire them with all the available technological options."
X9 Total area of the farm	Hectares
X10 Soybean yield	Bags per hectare (bag = 60 kg) (continuous)

The analysis of the results centers on the general characteristics of the sample. In the following section, we present the technology adoption rate at the individual level and by level of adoption. We divide the sample into three levels of adoption: low adoption (adoption of one technology), medium adoption (adoption of two or three technologies), and high adoption (adoption of four technologies). After presenting the technologies and sample characteristics, descriptive statistics related to the famers' perception of the barriers and the determinants of adoption are presented. Lastly, we discuss the application of the logit models and PRMs to analyze the influence of the variables on the decision to adopt these technologies. The model selection was based on and analysis of the estimators' significance criterion, Akaike selection, pseudo R ^ 2, and p-value of residual deviance.

5 RESULTS AND DISCUSSION

5.1 GENERAL CHARACTERISTICS OF THE SAMPLE

Table 2 provides the descriptive statistics of the variables used in the econometric analyses. Regarding farmers' educational level, 10.9% had attended or completed elementary school, 17.8% had attended or completed high school, 52.9% had attended or completed undergraduate studies, and 19.3% had attended or completed postgraduate studies. Regarding cultivated size, the sample had a mean of 1,180 ha, while half of the sample firms had less than 425 hectares. The main grains produced were soybean, wheat, corn, rice, and oat.

Table 2. Descriptive statistics of the variables in the econometric analyses.

Variable	Mean	SD[1]	Minimum	Maximum
X1 Farmers' age	41.31	13.60	20	70
X2 Educational level	2.81	0.88	1	4
X3 Experience	21.48	13.18	3	53
X4 Participation in a farmers' cooperative or associations	0.74	0.44	0	1
X5 Participation in a group exchanging experiences with other farmers and holding technical meetings	0.77	0.42	0	1
X6 Technical assistance	0.37	0.49	0	1
X7 Frequency of consultation or technical assistance during the year	173.85	158.39	0	365
X8 Receptivity to technology	3.47	1.08	0	5
X9 Total area of the farm	1,180.709	2,348.82	10	20,000
X10 Soybean yield	59.72	11.06	35	82

1 Standard Deviation

Table 3 shows the frequency of the adoption of the technologies analyzed in the present study. The most-used technology was soil georeferenced sampling. It was observed that not all farmers who adopted georeferenced soil sampling applied variable-rate fertilizers and soil correctives, with a difference of 8.66%. More than half of the sampled used autopilot spraying. Molin (2017) found similar adoption rates in the midwestern Brazil, Matopiba[2], and southern Brazil, with 60% of grain farmers using autopilot spraying. Unlike this work focused on spraying, Molin (2017) found that autopilot spraying was used for several applications.

Table 3. Adoption of smart farm technologies by grain farmers in southern Brazil.

Technology	Adopters	Frequency (Adopters)	Observations[1]
Soil georeferenced sampling	76	64.96%	117
Application of variable-rate fertilizers and correctives	67	56.30%	119
Autopilot spraying	67	56.78%	118
Uses management software (cost, people, productive, phytosanitary and land management)	60	50.85%	118
Non-adopters	16	13.45%	119
Adoption of one technology (low level)	22	18.49%	119
Adoption of two technologies (medium level)	25	21.01%	119
Adoption of three technologies (medium level)	25	21.01%	119
Adoption of four technologies (high level)	31	26.05%	119

[1] Some technologies had no respondents.

The same level of adoption was observed in the use of software for cost, people, and crop management by half of the farmers sampled. This data demonstrated farmers familiar with computers and software will have less difficulty making their farms connected and smarter and making better decisions about activity automation when more SF technology becomes commercially available.

After the presentation of the adoption rate for individual technologies in Table 3, the aggregate adoption of technologies was displayed, with different levels of adoption by farmers. It was seen that 13.45% of the sample did not adopt any analyzed technology. These farmers cannot be included in the context of SF and may find it difficult to introduce.

[2]This Brazilian agricultural border region with a great growth in crops, including soybean, cotton, and corn, is formed by the states of Maranhão, Tocantins, Piauí, and Bahia.

We can see that 18.49% of the farmers adopted only one technology. These farms presented a low level of technology adoption. It is important to explore the factors lying behind this low level of technology adoption because this low level might not be restricted to SF technologies but extend to technology in general, limiting these farmers' competitive capacity.

Farmers with a medium level of technology adoption accounted for 42.02% of the sample. These farmers were more familiar with the detailed, georeferenced IT and crop management. At the same time, the producers with high levels of SF technology adoption made up 26.05% of the sample. These farmers experienced the conditions of working in agriculture in which information was digital, decision making was aided by stored information for variables over several years, and the processes were automated with less human interference.

5.2 DETERMINANTS OF THE ADOPTION OF SMART FARMING

As discussed, PA was one of the most established areas in SF. The PA determinants are presented in Table 4. The most important aspect in the farmers' perceptions of adopting PA was "*seeking yield increases*." Molin (2017) found similar reasons among farmers who adopted PA technologies and techniques, as 69% of the respondents reported increased productivity as a main reason for adoption. Additionally, Batte and Arnholt (2003) found that profitability was the biggest motivating factor in using PA tools.

Table 4. Determinants to the adoption of precision agriculture in farmers' perceptions.

Variables	**Mean**	**SD[1]**
Seeking yield increases	4.77	0.63
Need to increase knowledge and information about areas of growth	4.59	0.72
Need to increase the quality of farm operations executed by employees	4.47	0.75
Reduce farm costs	4.30	0.97
Reduce the application of inputs, such as fertilizers and agrochemicals	4.17	1.05
Need to monitor agricultural operations in the field	3.96	1.16
Need to make work more comfortable for rural laborers	3.88	1.12

[1] Standard deviation

Often, farmers did not make economic optimum calculations; instead, they preferred to maximize the output of grain production. Technologies that had the best effect on productivity increase tended to have greater acceptance among the farmers. This finding may have implications for policies to mitigate climate change and to make agriculture sustainable. Technologies that were environmentally less aggressive but affected negatively farmers' productivity of farmers tended not to be adopted.

The variable “*need to make work more comfortable for rural laborer*” appeared to have the lowest score among all the questions. It was observed that concern for rural laborers was not yet a factor valued by farmers; however, farmers have been worried about shortages of rural labor, especially in southern, southeastern, and midwestern Brazil (Arns, 2016). This shortage of labor has led to increased labor prices for rural workers, especially more qualified workers (Arns, 2016). This could be another motivating element for SF adoption to increase the efficiency and the results generated by existing labor while applying more technology on the farm.

The determinants for adopting IT are presented in Table 5. The most important reason to adopt IT in the farmers’ view was the “*need to improve farm management*.” Farmers had increasingly available data and information to manage but also difficulty accessing, handling, and gaining knowledge from such data (Fountas et al., 2015).

It was observed that much data stored and generated were not used due to a lack of methodologies or companies with data analysis services, despite the growing number of companies and startups in the sector. Lamb, Frazier, and Adams (2008) argued that, in many cases, farmers’ ability to collect data has exceeded their ability to understand and apply this data in a meaningful way. In the Lamb, Frazier, and Adams’ (2008) view, developers, not users, have stifled the adoption of PA technologies.

The second most important factor for the adoption of software was related to the “*need to improve farm control costs*.” Many of the applications and products sold in the market are intended to meet this demand. This was one of the first uses of IT and software in rural areas (Nudal and Alvares, 2006).

Another variable with a high score was the “*need to storage information about soil and climate crop management*.” This showed that producers were beginning to take an interest in using information to extract more knowledge of previous harvests. This concern might have emerged due to climatic impacts and greater yield fluctuations and greater climatic variability.

Table 5. Determinants of the adoption of IT tools in farmers' perceptions.

Variables	Mean	SD[1]
Need to improve farm management	4.51	0.72
Need to improve farm control costs	4.42	0.73
Need to store information about soil and climate crop management	4.12	0.90
Need to pass on up-to-date property information to agronomists and consultants	3.57	1.32
Need to handle too much information, data, and documents daily	3.45	1.17

[1] Standard Deviation

It was observed that the item "*need to pass on up-to-date farm information to agronomists and consultants*" was not yet an important reason in the farmers' perceptions. This was because data-sharing technologies are still in early stages. The same happened with the "*need to handle too much information, data, and documents daily*", that was the last determinant score in farm view to adopting IT technologies.

5.3 BARRIERS TO THE ADOPTION OF START FARMING

As in the previous sections, the barriers to adoption are divided into two parts: PA and IT. The variable "*high initial investments*" was the main barrier in the farmers' view. Some PA technologies had higher financial value for acquisition. Also, some services for which outsourcing had to be contracted, such as georeferenced soil analysis and variable-rate application, required a high investment, which had to be amortized over several years to become economically viable to farmers. When analyzing this investment in a timely manner for a single agricultural year, these technologies became quite costly.

Table 6. Barriers to the adoption of precision agriculture in farmers' perceptions.

Variables	Mean	SD[1]
High initial investments	4.21	1.08
Lack of a skilled workforce	3.40	1.41
Farmworkers' difficulties handling computers and technologies in machines and equipment	3.31	1.38
Uncertain outcomes (advantages) in adoption	2.70	1.27
Neighboring producers and consultants' negative opinions on precision agriculture	2.09	1.15
Adoption of precision agriculture leading to routine changes in agricultural operations in which the farmers have no interest	1.81	1.22
No knowledge of precision agriculture tools	1.67	1.08

[1] Standard Deviation

The second most important barrier in the farmers' perceptions was the "*lack of a skilled workforce*. Many of the respondents demonstrated through the variables analyzed that their employees did not have the knowledge or skills to make use of the new technologies being adopted in rural areas. This has been a very important topic in the economic literature. Beyond the present capacity, it is important that individuals have the capacity to absorb and assimilate knowledge, termed by Cohen and Levital (1990) as absorptive capacity. Many farmers and managers of rural enterprises have opposed the acquisition of equipment and machinery with a higher level of technology for the farm. This has sometimes occurred because the employees have not been able to handle or will not make the use of the technology acquired, preferring basic versions of equipment or machines.

In Brazil, a low level of education has been observed in the rural population, especially in regions far from urban centers (IBGE, 2006). The population older than 40 years, for example, has had less contact with technologies, such as computers. The variable in the third position reflected this finding: "*Farmworkers have difficulties in handling computers and technologies in machines and equipment*." The shift to more data- and information-intensive, digital agriculture has presented the challenge of including the rural labor force to become its effective diffusion.

Information related to PA technologies was widespread among sampled farmers. The variable "*no knowledge of PA tools*" had the lowest value among all. As Rogers (2003) reported, access to information is the first item in the technology adoption process. What might be happening in regard to PA then is a lack of sophisticated information about the technology.

The first barrier to the adoption of IT in the farmers' view (Table 7) was the "*need to collect and insert data manually in many programs/software*." Unlike PA, in which the producer does not mind changing routines for adoption, farmers perceived manual data insertion as an important limitation in the adoption of management software. This limitation was beyond the focus of the farmers; that is, they were activities and processes that farmers and employees of farms were not accustomed to monitoring and controlling, as was done in industrial areas.

Table 7. Barriers to the adoption of information technology (IT) in the farmers' perceptions.

Variables	Mean	SD[1]
Internet connection in the property	3.18	1.59
Need to collect and insert data manually in many programs/software	3.17	1.31
Lengthy time needed to learn the technologies	2.66	1.31
Concern that property information is sent to businesses or government agencies	2.16	1.33
No knowledge of the information tools and technologies that could help in property management	1.97	1.28
Not seeing a return from adopting information technologies in farms	1.76	1.13

[1] Standard deviation

Similarly, the variable "*lengthy time needed to learn the technologies*" had the second highest value. Farmers had low interest in using time for administrative and control activities. Generally, they tended to spend more energy on productive and operational activities. As firms grew, there was a need for more tools and process control, leading to the creation of departments on farms. Carrer et al. (2017) noted that as citrus growers had to manage larger areas, the demand for IT, especially computers, increased due to the greater complexity of management.

Davis (1989) defined perceived ease of use, another aspect influencing the intention to adopt IT, as the belief that using a particular technology is free of physical and mental effort. According to Davis (1989), a potential user who perceives a technology as easy to use is more likely to perceive it as useful and adopt it. This view, added to the high value attributed by farmers to the barrier "need to collect and insert data manually in many programs/software," shows that the ease of use of IT, especially software and applications, needs to be improved by companies that sell and market products, as well as academia, which emphasizes the importance use of management tools.

The variable "*not seeing a return from adopting IT in farms*" had the lowest value. In the farmers' perceptions, there were returns from adopting IT, but other factors limited the adoption process.

5.4 FACTORS INFLUENCING THE ADOPTION OF TECHNOLOGIES

Table 8 presents the results of the logit and Poisson econometric models. In addition to the estimated parameters, the marginal effects of each independent variable on the dependent variable of the models are also presented. These effects show the variation in the dependent variable in response to small variations in the independent variable, *ceteris paribus*.

Farmers' education level (X2) had a statistically significant, positive effect on the likelihood of adoption of soil georeferenced sampling (Y1). The estimated marginal effect for this variable indicated that the likelihood of adoption of Y1 increased by 23% among grain farmers with postgraduate degrees, *ceteris paribus*. A similar effect from education was found by Carrer et al. (2017) in computer adoption by citrus farmers, with an 20% increased likelihood of adoption. Farmers with more education and more familiarity with scientific methodologies were more willing to employ these techniques in their farms.

The independent variable of receptivity to the technology (X8) had a significant, positive effect on the adoption of the application of variable-rate fertilizers and soil correctives

(Y2). The more open to new technologies farmers were, as measured by proxy, the higher their likelihood of adopting the application of variable-rate fertilizers and correctives was.

Regarding autopilot spraying technology (Y3), the variable in the model with significance at 5% was size of the total farm area (X9). This variable had a positive effect, and the probability of adopting this technology increased by 0.02390% for each additional hectare and by 23.90% for every 1,000 hectares. Previous technologies had a feature of allowing companies to provide outsourced services to producers, making the technology available to smaller areas. However, the autopilot spray was available on equipment that required a minimum area for application and did not match the market for service delivery. Consequently, the farm size factor had greater influence on adoption of autopilot spray.

Table 8. Results of the logit and Poisson models: Determinants of adoption of smart farming by grain farmers.

		Logit				**Poisson**
Variable (Independents)	**(Dependents)**	SoilGeoreferencedSampling**(Y1)**	Application of variable-rate fertilizers and correctives **(Y2)**	Autopilotspraying **(Y3)**	Use management software (cost, people, productive, phytosanitary and land management) **(Y4)**	**Y (1,2,3,4)**
Intercept	ß	-7.796	2.568867	-5.910893	-3.7334064	-1505
	P Value					
	Marginal effect					
Farmers' age **(X1)**	ß		0.017531	0.054787*		
	Marginal effect		0.0040986	0.0035087		
Educationlevel**(X2)**	ß	1.791*	0.068537	0.515525	0.4111382	203
	Marginal effect	0.234	0.0160238	0.0330156	0.10274	0.56069342
Years of agricultural experience **(X3)**	ß		-0.022784			
	Marginal effect		-0.0053268			
Participation in a farmers' cooperative or association **(X4)**	ß	-2.719	-0.578132	-0.832157		-283.5
	Marginal effect	-0,259	-0.1287857	-0.0454089		-0.83487
Participation in a group exchanging experiences with other farmers and holding technical meetings **(X5)**	ß		-0.536820		0.57603	413.9
	Marginal effect		-0.1197834		0.14244	0.95015561
Has consultant or contracted technical assistance **(X6)**	ß		0.412198	1.260364		
	Marginal effect		0.0950065	0.0749804		
Frequency of consultant or technical assistance during the year **(X7)**	ß	-0.011				-1,271
	Marginal effect	-0.001				0.00351006
Receptivity to technology (In the purchase of machines and equipment, I prefer to acquire them with all the technological options available) **(X8)**	ß	1.161	0.831981**			268,9*
	Marginal effect	0.152	0.1945154			0.74274
Total area of the farm **(X9)**	ß	0.00048		0.003733**	0.00102**	0.09626
	Marginal effect	0.00006		0.0002390	0.00025	0.00027
Productivity of soybean (sacks per hectare) **(X10)**	ß	0.0510066	0.009756	0.020620	0.01909	13,3100
	Marginal effect	0.00667	0.0022809	0.0013206	0.00478	0.03675
P value residual deviance		0.69277	0.06856647	0.834939	0.11547	0.98450
R^2 McFadden		0.88586	0.5137886	0.6716018	0.48147	0.53216

*** Sig at 10% ** Sig at 5% *** Sig at 1**

The fourth technology analyzed, management software, was one of the main elements driving the emergence of SF. Regarding adoption of software for productive, technical, and financial management of the farm (Y4), it was observed that the main influencer in the adoption of this technology was farm size. Larger producers demanded more information tools to meet the greater complexity and demand for farm organization, whereas small and medium farmers still did not have a high demand for this control and performed it in an informal and tacit manner.

Adrian et al. (2005) observed that the profile of adopters of PA technologies was an educated farmer who owned a larger farm with good soil quality and aimed to implement more productive agricultural practice to face growing competitive pressures. Adrian et al. (2005) argued that producers with higher confidence levels, larger farms, and more education had greater intention to adopt PA technologies than producers with lower levels of each of these variables.

When analyzing technologies in an aggregate way through the Poisson model, it was observed only one variable was significant: receptivity to technology (X8). A possible explanation of this result is that attitude (individuals' beliefs) can explain behavior (Ajzen and Fishbein, 1977). Farmers more open to technologies were more likely to adopt all four technologies or a form closer to the SF concept.

However, there was no strict pattern in farmers' profile, especially in terms of socioeconomic characteristics, to explain the adoption of SF technologies as a package. It was observed that some technologies are starting to be adopted by smaller farms. Adoption of some technologies requires more years of education and knowledge of how technology works (e.g., Y1 *soil georeferenced sampling*). Others demand more scale, represented by higher acreage, which could be solved by means of a market of services that meets the demands of farmers. Broadly speaking, SF requires producers open and receptive to this concept of agriculture.

6. FINAL CONSIDERATIONS

The aim of this paper was to analyze the determinant factors and the barriers in grain farmers' decisions regarding the adoption of SF technologies. More broadly than this specific research question, we have attempted to understand why Brazilian agriculture is delaying entering the digital world.

We have noted that the main drivers of adopting SF were increased productivity, better process quality, reduced costs, and greater knowledge of cultivated areas. From a practical point of view, companies that offer solutions along these lines could increase their market share. Similarly, some factors increased the adoption of technologies in different intensities and manners. Education had the strongest effect on the adoption of georeferenced soil sampling technologies. Adoption of autopilot spraying pilot and management software was more dependent on the size of the area. From a practical point of view, due to the high fixed costs of these technologies, adoption could be done through collectives of farmers and service providers, as has occurred in PA in Brazil.

The main barriers delaying Brazilian farmers' SF entry were the prices of equipment, low qualifications of rural labor, precariousness of Internet access in Brazilian rural regions and need to input much data and information into software, which made analysis and interpretation difficult. Some limitations required institutional elements, such as better telecommunication infrastructure in rural areas and improved access to the Internet, critical to the diffusion of SF. Without high-quality, high-speed Internet access, many SF capabilities could not be widely implemented in agriculture. Other limitations, such as need to input much data and information into software, required more investment and development from companies. We observed numerous startups in Brazil exploring this opportunity.

It is suggested that future studies focus on the constructs and new research questions that emerged from this work and use and deepen more specific scales. One possible direction is research on farmers' behavior. This could be investigated with farmers from Midwestern Brazil to control for farm size, another variable affecting SF adoption. This study has made the first efforts to work not with a single SF technology but with a set of technologies forming SF. Future research could be based on the ideas and results generated in this study.

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APPENDIX A: CORRELATION MATRIX OF INDEPENDENT VARIABLES

	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*	*X8*	*X9*	*X10*
X1	1									
X2	-0.321	1								
X3	0.852	-0.447	1							
X4	0.154	0.037	0.139	1						
X5	0.169	-0.050	0.091	0.141	1					
X6	0.167	0.156	0.018	0.034	0.395	1				
X7	0.058	0.247	0.092	-0.104	-0.198	0.143	1			
X8	-0.137	0.214	-0.125	0.037	-0.031	0.127	0.395	1		
X9	0.023	0.168	-0.037	-0.119	0.136	0.330	0.366	0.177	1	
X10	0.054	0.033	0.048	0.109	0.024	-0.101	-0.095	0.032	-0.228	1

CHAPTER 6. ADDITIONAL CONSIDERATIONS

The present thesis has analyzed the innovation process in the context of SF, from the production of scientific knowledge to the diffusion phase of these new technologies in agriculture. Through scientific literature analysis we could observe that the production of knowledge in SF has been increasing in recent years, especially in technology development. It is possible to note a concentration of this production of knowledge in countries as China, the United States, South Korea, Germany and Japan. This process is associated with the investment in science and technology in these countries, and it may indicate which of them will be leaders in providing technologies, even with a small area of arable land, such as South Korea and Japan.

Through discussion and analysis, based on the evolutionary economy and the techno-economic paradigm which are used to analyze technological revolutions, we can infer that SF technologies are in the process of gestation and emergence. There is intense scientific development in technologies such as IoT and in intelligent environments, as well as a strong effect on “spill over” from other industries to agriculture. In the following years, innovations available to the SF market will probably grow significantly if it follows the curve pattern of a technological revolution.

When we observe the market of SF products, especially the Brazilian one, we can notice that it is at the initial stage of development, in which several agents are seeking business opportunities in this sector. The two areas with the highest consolidation within the SF concept are AP and IT, although the adoption of these two sets of technologies by farmers still presents a possibility of significant increase in the area. We can see an initial concern of organizations in agribusiness, such as suppliers, machines and implements, farmers, purchasing companies to more effectively use data collected and stored to produce knowledge, mainly applied to the prediction and prescription of events in farming. This area will expand in the coming years, since it may provide services, which can bring positive results to farmers.

Considering the two most consolidated areas in SF, AP e IT, we analyzed the adoption of technology in grain farms in southern Brazil. The main factors for adopting SF were: a) productivity increase, b) better quality in the process, c) costs reduction and d) better knowledge of farming areas. Similarly, some factors have increased the adoption of technologies in different intensities and manners. Education had the strongest impact on the adoption of geo-referenced soil sampling technologies. The size of the area influenced on the adoption of automatic pilot for spraying and software management.

The results of this thesis indicate that a higher level of schooling tends to increase the probability of adopting these technologies. In the macroeconomic view, the results reinforce that investments in education are important for the diffusion of smart farming in Brazil. As for the improvement on decision-making of owners and managers, regarding acquisition and investment in these technologies, and employees who work on farms.

The main barriers that hinder the entry of Brazilian farmers into SF are equipment prices, low qualification of rural work, precariousness of internet access in Brazilian rural regions and the need to insert a lot of data and information into software, which hampers analysis and interpretation. Concerning the barriers, different strategies can be adopted to minimize them. For instance, with the consolidation of technologies and larger market available, equipment prices tend to reduce. In the institutional view, to provide special lines of credit can increase the diffusion of these technologies. INOVAGRO is an example of this. It is a rural credit line to finance technological innovation on farms, operated by BNDES, which could be expanded to include technologies linked to SF, and thus, encourage the development and production of technologies in this area by national companies.

Qualification of rural labor force is another item that deserves attention, both by the State, as well as by organizations that represent farmers. The rural environment has gone from an abundance of work force to a scenario of scarcity. Furthermore, with new electronic equipment and machines, there is a demand for higher qualification and higher educational level. Technical courses and extension programs can fulfill this skill and specialization gap for rural labor. Organizations that represent farmers, mainly the National Confederation of Agriculture (CNA), are trying to provide rural labor training courses and skills for farmers.

Another focus of the analysis is related to the ability of technical advisers to assist farmers in SF. The results show that, farmers claim that a large number of technicians and consultants are not yet adapted to digital farming. This demonstrates the need for continual training of technicians, such as agronomists, farming engineers to update their knowledge on scientific methods and technologies. In North America, especially, universities with a strong extension system provide this updating for consultants and extensionists.

The results of this study, unpublished in the Brazilian context, came from convenience sampling and we highlight that a probabilistic sampling could bring more confidence to extrapolate the results. Electronic platforms and fairs sampling is another biased element, as it tends to select farmers with a higher degree in technology adoption. A random sample in a fieldwork could eliminate this bias; however, operational costs to accomplish this research would be high.

Smart farming technologies open a vast field of applications that raise other research foci. Regarding future researches, panel data with historical series could present the evolution of technology adoption over the years, thus improving the knowledge of the diffusion process of technologies. The discussion of data protection is another important debate. To whom do data produced by a machine belong? If this information has a price, could farmers sell his crop data? Another research topic concerns the openness of farmers to share his farm data and his degree of pre-availability to adopt technologies. We did not aim to study intrinsic questions to farmers' behavior in this paper. A study based on behavioral economy, trying to measure subjective characteristics of farmers, could broaden the understanding of determinant factors in the adoption of SF.

APPENDIX A – QUESTIONNAIRE

This is a research of the Center for Studies and Research in Agribusiness (CEPAN) of the Federal University of Rio Grande do Sul (UFRGS), aiming to analyze the use of Smart Farming (Information Technologies and Precision Agriculture) tools in farm. If you are the owner, partner or manager of a farm whose main activity is the production of grains (soy, corn, wheat, beans, rice, among others), your participation is very important. So please, answer this questionnaire, paying attention to the questions. The questionnaire can be answered by any owner, partner or manager who works with grain production, even if they do not use precision agriculture or information technologies on their property. If you are a grain producer, your answer is important to our research. The answers and information provided will not be used for tax purposes; their use is restricted to the research. Your name will be kept confidential, and you do not need to provide it, if you prefer.

Dieisson Pivoto – Ph.D student in Agribusiness – Federal University of Rio Grande do Sul

Below are some statements regarding the use of technologies in your farm. Please indicate your degree of agreement to each of them, using the scale of agreement with a range of 1 to 5, where 1 = Totally Disagree and 5 = Totally Agree.

Adopted technologies

1. When purchasing machines and equipment, I prefer to get them with all the available technology-options, even if I need to pay more for this.	1	2	3	4	5
2. In general, I am among the first in my group of agricultural producers to acquire new technology or equipment new in the market.	1	2	3	4	5
3. I use new technology-intensive products when launched, even though they have not been used by other produce	1	2	3	4	5

Answer the questions connected tothe technologies used in your property

Precision Agriculture (PA)	**I use it**		**% of area that use it**
1. Georeferenced soil samples	Yes	No	
2. Use of variable-rate fertilizers/correctives	Yes	No	
3. Variable-rate seeding	Yes	No	
4.Autopilot for spraying	Yes	No	
5.Autopilot for sowing	Yes	No	
6. Light bar	Yes	No	
7.Harvesting maps	Yes	No	
8. Automatic control of sections in the application of agrochemicals and fertilizers	Yes	No	
9. Use of UAV or drones to generate vegetation maps or for crop management	Yes	No	
10. Vegetation sensors	Yes	No	
11. Telemetry for Remote Data Transmission	Yes	No	
12. Other. Specify which:	Yes	No	
13. Do you monitor the agricultural operations (sowing, harvesting, agrochemicals) in real-time via cellphone or computer through sensors in machines and equipment, intervening when they are not adequate?	Yes	No	

Determinants for Adopting Precision Agriculture

When answering the questions in the next item, consider yourself as a precision agricultural producer, if you use at least one (1) of the technologies described below.

Precision agriculture: Georeferenced soil sample, use of variable-rate inputs or seeds, autopilot or light bar for spraying, sowing or harvesting, use of harvest maps, automatic control of sections in the application of agrochemicals and fertilizers, use of UAV or drones for generating vegetation maps or with other purposes, use of vegetation sensors and telemetry for remote data transmission. **For example**: For the purposes of this research, if you use autopilot you are already considered a precision agriculture user.

Next, indicate the main determinants (what made you use this technology) for adopting Precision Agriculture on your property, where 1 (Totally disagree) and 5 (Totally agree).

1. Need to make the work more comfortable for rural laborers.	1	2	3	4	5
2. Need to improve the quality of the agricultural operations carried out by the staff.	1	2	3	4	5
3. Reducing costs in agricultural production.	1	2	3	4	5
4. Reducing the application of inputs like fertilizers and agrochemicals.	1	2	3	4	5
5. Need/pursuit of increased productivity.	1	2	3	4	5
6. Seeking better agricultural management of the property.	1	2	3	4	5
7. Need for greater knowledge and information on the areas cultivated by my property.	1	2	3	4	5
8. Need to monitor agricultural operations in the field.	1	2	3	4	5
9. Other. Specify which:	1	2	3	4	5

Limitations for Adopting Precision Agriculture

Indicate the main limitations**(what made you not use this technology)** for adopting Precision Agriculture on your property, where 1 (Totally disagree) and 5 (Totally agree).

1. High initial investments.	1	2	3	4	5
2. Uncertain outcomes (advantages) of the adoption	1	2	3	4	5
3. Property employees have difficulty handling computers and technologies in machines and equipment.	1	2	3	4	5
4. Lack of skilled workforce.	1	2	3	4	5
5. I do not know the precision agriculture tools.	1	2	3	4	5
6. I heard negative opinions about Precision Agriculture from neighboring producers and consultants.	1	2	3	4	5
7. Precision agriculture leads to routine changes in agricultural operations, which I have no interest in carrying out.	1	2	3	4	5
8. Other. Specify which:	1	2	3	4	5

Information Technologies

1. Do you use software/apps for property management (cost management, people management, production management, storing property data, phytosanitary management, fleet management, land management)?	Yes	No
2. Do you use online or mobile banking?	Yes	No
3. Do you use apps on your cell phone or smartphone to assist with agricultural management (e.g. apps to track soy quotation, identify pests, cost management)?	Yes	No
4. Do you use calculation programs or spreadsheets (Excel) for monthly cash flow control and cost management?	Yes	No
5. Do you use computer programs to plan annual activities?	Yes	No
6. Do you use indicators from the data stored to manage the machines and the property (for example: fuel consumption per hectare, machine hours per hectare)?	Yes	No
7. Other. Specify which:	Yes	No

Determinants for using information technologies

To answer the following questions, consider the following information technologies: cost management software/apps, spreadsheets for operation control (e.g.: Excel), people management software/apps, fleet control software, production and operational management software, cellphone apps for agricultural activities management, cellphone apps for monitoring price quotation or the weather, among other software and apps used in agricultural activities. If you use at least one (1) of them, consider yourself as an information technology user. Next, indicate the main determinants for using information technologies in your property, where 1 (Totally disagree) and 5 (Totally agree).

1. Improved cost control.	1	2	3	4	5
2. Too much information, data, and documents I need to handle daily.	1	2	3	4	5
3. Need to store information, such as climate, soil, and treatment given to the crop, to be used later.	1	2	3	4	5
4. Need to improve property management.	1	2	3	4	5
5. Need to give up-to-date property information to agronomists and consultants.	1	2	3	4	5
6. Other. Specify which:	1	2	3	4	5

Limitations for adopting Information Technologies

Indicate the main limitations for using Information Technologies in your property, where 1 (Totally disagree) and 5 (Totally agree).

1. Internet connection in the property.	1	2	3	4	5
2. Too much time needed to learn to use the technologies.	1	2	3	4	5
3. Need to collect and insert data manually in many apps/software.	1	2	3	4	5
4. I do not know the tools and information technologies that could help to manage the property.	1	2	3	4	5
5. I cannot see a positive outcome from adopting information technologies in my property.	1	2	3	4	5
6. I am concerned that information on the property will be sent to companies or to government agencies	1	2	3	4	5
7. Other. Specifywhich:	1	2	3	4	5

Degree of influence on the adoption of Precision Agriculture and Information Technologies

Indicate the degree of influence the items below have in your decision to adopt **Precision Agriculture or Information Technologies** in your farm. For this, assign **1 (low influence) to 5 (high influence) for each item.**

1. Companies and stores that sell these equipment.	1	2	3	4	5
2. Neighbors.	1	2	3	4	5
3. Children.	1	2	3	4	5
4. Cooperatives and associations.	1	2	3	4	5
5. Consultants and technical assistance (e.g.: agronomists).	1	2	3	4	5
6. Agricultural trade fairs and exhibitions.	1	2	3	4	5
7. Other. Specify which:	1	2	3	4	5

Which difficulties the consultants or technical assistance (agronomists) present to advise the property regarding information technologies and precision agriculture?________________________________

Farmer characteristics:

1. Age:
2. Gender: ( ) Male ( ) Female
3. Education:
( ) Elementary School ( ) High School ( ) Higher Education. Area:
( )Post-graduation. Area:
4. How long have you worked in agriculture?
5.Did your parents also work in agriculture?( ) Yes ( ) No
6.Do you work with anything else besides agriculture? ( )Yes ( ) No
7. How much does this activity represent in your total income (in %)?
8. Do you have partners in your agricultural activities? ( )Yes ( ) No
9.Do you manage your property? ( )Yes ( ) No
10. Are there other managers below you in your property? ( )Yes ( ) No
11. Do you have children? ( ) No ( ) Yes. How many:
12. Do any of your children intend to continue working with agriculture? ( )Yes ( ) No
13. In what county do you live?
14. Characteristics of the farm:
14.1 Farm size (ha)?
14.2 Own area (ha)?
14.3 Effectively explored area (ha)?
14.4 How many direct (hired) employees do you have in the property?
15 Do you participate in any cooperatives or associations? ( )Yes ( ) No
16. Are you part of any group to exchange experiences with other producers, meetings and technical meetings? ( ) No ( ) Yes. Which?
17. Do you have a consultant or hired technical assistance?
18. Approximate annual gross revenue of the property (R$)?
19. Annual net revenue of farm?
20. Do you plan to expand your business in the next 5 years (cultivated area, investments in machinery and equipment, soil improvement)? ( ) Yes ( ) No

Crop	Cultivated area (ha)	What does it represent in revenue (%)	Average production in bags (ha) (last harvest)
Soy			
Corn			
Wheat			
Oats			
Rice			
Other. Specific which:			
Livestock activity	Explored area	Representation in revenue (%)	-
Cattle			-

If possible, fill in the information below to receive the research results. (It is not mandatory to provide this information). Name: Phone number: Email

APPENDIX: B - ACCEPTED FOR PUBLICATION

Ref: IPA_2016_80_R3
Title: SCIENTIFIC DEVELOPMENT OF SMART FARMING TECHNOLOGIES AND THEIR APPLICATION IN BRAZIL
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Dear Professor PIVOTO,

I am pleased to inform you that your paper has been accepted for publication. My own comments as well as any reviewer comments are appended to the end of this letter. Now that your manuscript has been accepted for publication it will proceed to copy-editing and production.

Thank you for submitting your work to Information Processing in Agriculture. We hope you consider us again for future submissions.

Kind regards,

XiangyunGuo
Editorial Office
Information Processing in Agriculture

Comments from the editors and reviewers:

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APPENDIX: C–FIRST PAGE OF PAPER PUBLISHIDED.

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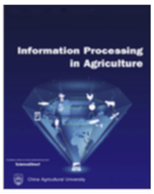

Scientific development of smart farming technologies and their application in Brazil

Dieisson Pivoto [a,*], *Paulo Dabdab Waquil* [b], *Edson Talamini* [b], *Caroline Pauletto Spanhol Finocchio* [c], *Vitor Francisco Dalla Corte* [d], *Giana de Vargas Mores* [e]

[a] *Universidade Federal do Rio Grande do Sul, Center for Studies and Research in Agribusiness, 7712 Bento Gonçalves Avenue, Agronomy District, Porto Alegre, State of Rio Grande do Sul, Brazil*

[b] *Universidade Federal do Rio Grande do Sul, Department of Economics and Foreign Affairs and Center for Studies and Research in Agribusiness, 7712 Bento Gonçalves Avenue, Agronomy District, Porto Alegre, State of Rio Grande do Sul, Brazil*

[c] *Universidade Federal do Rio Grande do Sul, 7712 Bento Gonçalves Avenue, Agronomy District, Porto Alegre, State of Rio Grande do Sul 33086-586, Brazil*

[d] *Meridional University – IMED, Business School, 304 Senador Pinheiro Street, Rodrigues District, Passo Fundo, State of Rio Grande do Sul 99070-220, Brazil*

[e] *Universidade Federal do Rio Grande do Sul, Universidade Comunitária da Região de Chapecó, 7712 Bento Gonçalves Avenue, Agronomy District, Porto Alegre, State of Rio Grande do Sul 33086-586, Brazil*

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A B S T R A C T

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

* Corresponding author.
E-mail addresses: dieissonpivoto@gmail.com (D. Pivoto), waquil@ufrgs.br (P.D. Waquil), edson.talamini@ufrgs.br (E. Talamini), caroline.spanhol@ufms.br (C.P.S. Finocchio), vitor.corte@imed.edu.br (V.F. Dalla Corte), gimores@gmail.com (G. de Vargas Mores).
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