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SMART FARMING IN BRAZIL: AN OVERVIEW OF TECHNOLOGY, ADOPTION AND FARMER PERCEPTION

AGRICULTURA INTELIGENTE NO BRASIL: PANORAMA DA TECNOLOGIA, ADOÇÃO E PERCEPÇÃO DO AGRICULTOR

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Abstract

At the second decade of the 21st century, the use of a new set of agricultural technologies, such as smart farming (SF), emerge among agribusiness organizations and agents. This study aims to identify the smart farming technologies used in grain production systems in Brazil and to verify the perception of the farmers regarding technical assistance for SF. A survey was conducted with farmers and 119 valid observations were collected. The study used non-probabilistic sampling, since it considered grain farmers whose farms produced more than 50% of their gross revenue in grains. Descriptive and content analysis were used to analyze the data. The results indicate that soil sampling is the main precision agriculture technology adopted by the production systems assessed, while smartphone applications to assist in agricultural management are the most used information technology. 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.

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Keywords: Future Farming, Smart Agriculture, Innovation, Technology, Internet of Things.

Resumo

Na segunda década do século 21, o uso de um novo conjunto de tecnologias agrícolas, como a agricultura inteligente, surge entre as organizações e agentes do agronegócio. Este estudo tem como objetivo identificar as tecnologias de agricultura inteligente utilizadas em sistemas de produção de grãos no Brasil e verificar a percepção de agricultores quanto à assistência técnica para agricultura inteligente. Uma *survey* foi realizada com os agricultores e 119 observações válidas foram coletadas. O estudo utilizou amostragem não probabilística, uma vez que considerou produtores de grãos cujas fazendas produziam mais de 50% de sua receita bruta em grãos. A análise descritiva e de conteúdo foi utilizada para analisar os dados. Os resultados indicam que a amostragem de solo é a principal tecnologia de agricultura de precisão adotada nos sistemas de produção avaliados, enquanto os aplicativos de *smartphone* para auxiliar no manejo agrícola são a tecnologia da informação mais utilizada. As máquinas utilizadas nos sistemas de produção de grãos estão passando por um processo de digitalização, principalmente devido ao aumento da disponibilidade de equipamentos com sensores e processos automatizados. No entanto, permanece a dúvida sobre a capacidade dos agricultores e agentes assistenciais de monitorar e aproveitar o potencial das tecnologias de agricultura inteligente nas propriedades rurais.3

Palavras-chave: Agricultura do Futuro, Agricultura Inteligente, Inovação, Tecnologia, Internet das Coisas.

Introduction

Brazilian agriculture, especially in the South of Brazil, presents an 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-tillage, which resulted in lower costs, lower environmental impacts, and increased productivity (HOFF; FREITAS; PAVINATO, 2011). In addition, the migration of farmers from the South region to new areas or frontiers of cultivation, such as the Midwest, and, more recently, to the Matopiba (enclosed by the states of Maranhão, Tocantins, Piauí, and Bahia), contributed to the diffusion of cultivation techniques and practices 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, with the green revolution, agriculture has gone from being dependent on labor to depending on chemical resources and mechanization (MAZOYER; ROUDART, 2008).

In the early 1990s, with the evolution of computer sciences and Global Positioning Systems (GPS), a transfer of knowledge spillovers occurred in agriculture. One example is Precision Agriculture (PA), which incorporates technologies from other areas, such as military sector and computer sciences. PA is defined by the Brazilian Precision Agriculture Commission (CBAP) as “an agricultural management system based on the spatial and temporal variation of the productive unit that aims at increasing economic return, sustainability and minimize its effect on the environment” (MAPA, 2012, p. 01).

The first tests and experiments with this set of technologies were carried out in the South of Brazil and was later diffused and adopted in other regions of the country. PA breaks with the traditional model for conducting production systems. The main difference between PA and the previous model is more scientific production management, working with variability of the production areas.

At 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; VERDOUW; BOGAARDT, 2017; PIVOTO et al., 2018). The main innovation or set of novelties presented by this concept 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. SF emphasizes automation of activities and smart responses, with no need for human intervention in the processes.

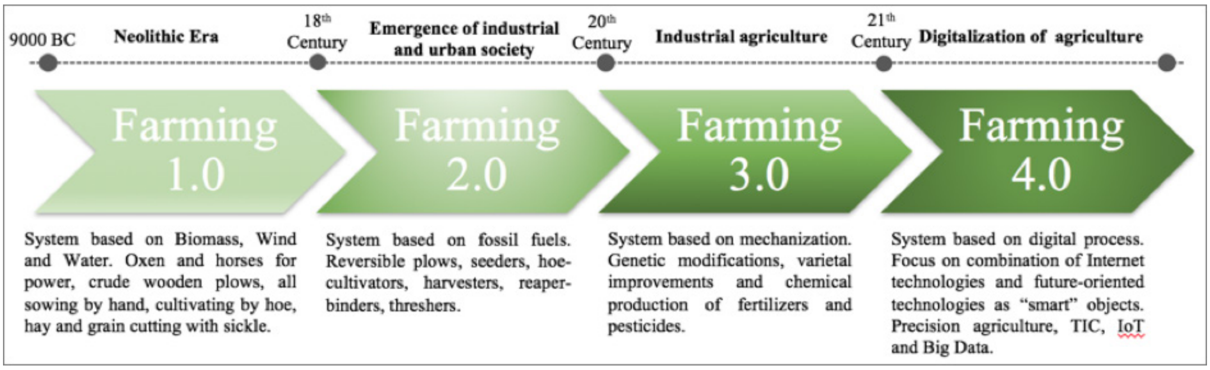
On the one hand, many technologies linked to SF are not yet innovations (SCHUMPETER. 1988), because they are not available on the market or economically viable, since they are under development, and being tested by companies and research institutions. On the other hand, SF is a broad concept encompassing areas established in the market (WOLFERT; VERDOUW; BOGAARDT, 2017; PIVOTO et al., 2018), such as precision agriculture and Information Technology (IT) in agriculture. The dynamics for adopting and diffusing SF technologies is possible to understand based on the set of technologies (PA and IT), that is diffused to some level in the grain production systems of the Brazilian South (WOLFERT; VERDOUW; BOGAARDT, 2017).

Knowledge and innovation have become important over time, because they are considered one of the main influencers for both economic growth and economic development in developing countries, such as Brazil (MELO; SANTANA; SILVA, 2019). Understanding the diffusion of these technologies is a way of anticipating changes in the patterns of agricultural production systems in Brazil. This anticipation is useful for agents involved in agribusiness, such as public and private research organizations that 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.

Evolution of Agriculture and Smart Farming Adoption

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

Figure 1: Evolution of agriculture



Source: Elaborated by authors based on the literature.

The transition from a solar-based system (biomass, air, 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, 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 not in the most time-consuming operations for the agricultural cycle (LOSCH, 2015).

One of the main disruptive aspects 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 (MAZOYER; ROUDART, 2008).

In 1994, the Food and Drug Administration (FDA) approved the first food completely produced with biotechnology, the FLAVR SAVR ™ tomato. After this product, biotechnology was widespread in large crops (MAZOYER; ROUDART, 2008). In the mid-1990s, the emergence of geospatial technologies like remote sensors, geographic information systems and GPS enabled the use of precision agricultural practices for specific applications of fertilizers, pesticides, irrigation and herbicides, marking the agriculture 3.0 more integrated with science.

Advances in network computing enable the development of low-cost internet-connected devices, including cameras, sensors, radio frequency identification, and smartphones. This new technological paradigm could not have emerged, before because it was not economically viable (FREEMAN, 1988). Their use in agriculture has become economically feasible only with reduction in the price of sensors and electronic equipment, due to technological advances. This dynamic elucidates the process of consolidation of new technologies, through other economic cycles (PEREZ, 1983; FREEMAN, 1988). SF technologies have the potential to reduce losses and waste of inputs and improve productivity, because it optimizes the allocation of resources in the productive areas, generating gains for rural farmers.

Based on this, agriculture 4.0 or SF appears at the beginning of the 21st century, through the diffusion of Internet of Things (IoT) and SF technologies (WOLFERT; VERDOUW; BOGAARDT, 2017; PIVOTO et al., 2018). If at large production scales, these technologies increase productivity, reduce costs, and mainly improve the quality of food.

It is highly dependent on scientific knowledge, with progressive insertion of knowledge, such as big data, artificial intelligence, information sciences, improving decision-making processes.

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 (KRISHNAN, 2017). Second, corporate investment in artificial intelligence increased from US$6.0 billion in 2016 to US$13.93 billion in 2017 (KRISHNAN, 2017).

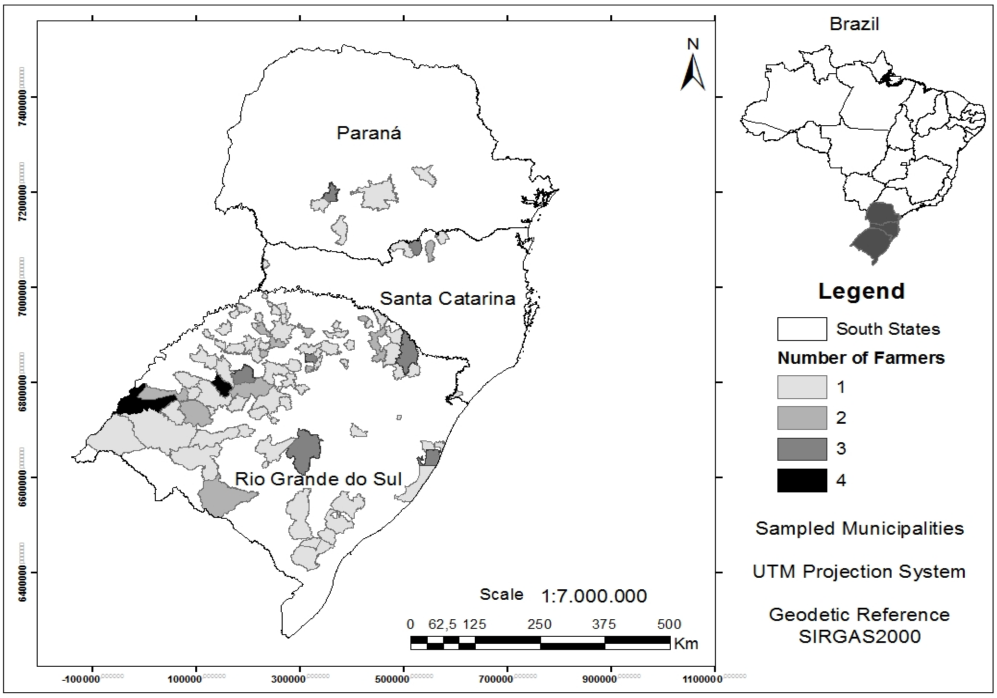
Studies with variables that influence the adoption of SF have been found in the literature (SOUZA FILHO et al., 2011; TEY; BRINDAL, 2012; PIERPAOLI, 2013; FOUNTAS et al., 2015; CARRER; SOUZA FILHO; BATALHA, 2017; WOLFERT; VERDOUW; BOGAARDT, 2017). For example, contact with technical consultants can increase the use of technologies, especially smart farming. The presence of technical assistance had a positive impact on the adoption and intensity of use of SF (CARRER; SOUZA FILHO; BATALHA, 2017). 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 (CARRER; SOUZA FILHO; BATALHA, 2017). In addition, experts can assist farmers and their employees in the proper management of new technologies. The farmers' perception about consultants in the process of adopting smart farming technology was analyzed in the empirical part of this study.

Method

This research had two approaches: (i) the quantitative measure of the SF technologies use; and (ii) the qualitative perception of farmers regarding information quality provided by consultants and technical assistants. It was conducted through a survey, with two units of analysis: (i) the farm, and (ii) the farmer responsible for decision making on the farm. Based on these units, this research was designed, and sampling established. The adoption of SF was analyzed through research with farmers in southern Brazil (states of Rio Grande do Sul, Santa Catarina e Paraná) (Figure 2).

Figure 2. South region of Brazil (and their states), cities and number of farmers sampled in the mentioned states



Source: Adapted from Silva, Moraes e Molin (2011).

The main agricultural activities produced in South region are livestock production, milk production and grain production (mainly, soybean, wheat, and corn). The questionnaire was prepared based on previous publications (SOUZA FILHO et al., 2011; TEY; BRINDAL, 2012; PIERPAOLI, 2013) in addition to the participation of 12 experts. The specialists, who participated in the elaboration of the questionnaire, are professionals that work in the following areas: agricultural engineering, precision agriculture, crop management, rural management, agricultural economics, and professionals from companies that develop agricultural machinery and implements.

The questionnaire had items about characteristics of farmers and farms; technologies adopted by farmers (PA and IT); farmers' perception of the technical assistance in SF. The last one was a qualitative information about the difficulties encountered by the consultants or technical assistance agents to advise the property in terms of PA and TI.

To verify if the questions were adequate, a test was applied to 32 farmers in the South region. After this procedure, some questions were eliminated, and others were adjusted. Research sampling was non-probabilistic, by convenience, since the research focused on farmers who worked with grain production systems. To participate in this research, the farmers needed to produce more than 50% of its gross revenue in grains.

The questionnaire was applied in the online format. It was sent to e-mails provided by agricultural machine dealers and farmer associations. In addition to questionnaire via the digital platform, the 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. The sample presented a mediated property of 400 hectares, with a minimum of 20 hectares and a maximum of 20,000 hectares, with an average of 1,164 hectares.

Descriptive analysis was performed of adoption of PA and IT technologies. In case of 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 were analyzed through content analysis.

Results and Discussion

Descriptive Analysis

Precision agriculture 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). For instance, 64.96% of the farmers adopt this technology and, on average, they use it in 40.41% of the areas of their properties.

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

Technology	Frequency (Adopts, %)	Area that uses the technology (%)
Georeferenced soil sampling	64.96	40.41
Autopilot spraying	56.78	39.96
Application of fertilizers and variable rate correctives	56.30	34.92
Automatic control of sections for application of agrochemicals	52.54	29.75
Harvest maps	29.41	15.13
Autopilot	27.35	15.60
Drones and vants	11.76	3.19
Variable rate sowing	10.92	7.86
Telemetry	7.63	2.44

Source: Research data.

Based on Table 1, a lower percentage of farmers adopted variable rate fertilizers and correctives, compared to those who use georeferenced soil sampling. There is a difference of 8.66%, indicating that the farmers harvest, but choose not to carry out the second stage, the variable rate application. These farmers apply fertilizers and correctives in a smaller area when compared to georeferenced soil sampling. On average, 34.92 % of the area of the farmers receive the application, that is, they fulfill part of the principle of precision agriculture.

A Brazilian study found similar results (BERNARDI; INAMASU, 2014), which observed adoption rates of 49.00% for sowing/fertilizer machines, and 38.00% for fertilizer/limestone spreaders among farmers using PA technology. In Australia, there was a growth rate of 20.00% in the adoption of variable rate fertilizers and correctives in the period from 2002 to 2009 (ROBERTSON, 2012).

The use of autopilot sprayers was adopted by 56.78% of the farmers (Table 1). On average, these farmers use machines equipped with autopilot to spray 39.96% of the cultivated area. It is possible to increase the use of this technology, even among the farmers 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 farmers who use the autopilot for spraying. A study observes that 39.00% of the sugarcane plants in the state of São Paulo adopt automatic pilots or satellite self-steering systems (SILVA; MORAES; MOLIN, 2011).

Autopilot is the most widely adopted PA tool worldwide (GEBBERS; 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 on the market, in the initial phase of tests, some already commercially, like automated tractors (LARSON et al., 2008). The results show that 29.41% of the sampled farmers use harvest maps. This technology is used in 15.13% of the cultivated area. This percentage of use may be related to the utility attributed to the technology by the farmers of Southern Brazil or the lack of technical support for analysis, interpretation and technical recommendation of the generated data.

Our results show that variable rate sowing is used by 10.92% of farmers, and telemetry is used by 7.63% of farmers. Technology allows online data transfer from the machine to the office and from the office to the machine. Telemetry is one of the main technologies of the agricultural digitization process, allowing monitoring and decision-making in real time. It also enables many processes to be automated, with operators far from the location where the operation is being performed.

Machines and equipment are undergoing a process of digitization, especially since agricultural companies are offering products with more sensors and automated processes. However, the big question is whether the organization of farmers (management area) can monitor and take advantage of the digitization process potential. IT links agriculture 3.0 and 4.0, because through them data collection is automatically extended around property, allowing the systematization and extraction of results that improve decision-making.

Considering Table 2, we highlights that 51.26% of the sampled farmers use software/programs in the property, for cost management, phytosanitary management, and data storage (Table 2). Similarly, 61.02% uses computers to do annual planning of property activities.

Table 2. Number of adopters and frequency of adoption of IT and property management

Technology	**Frequency (adopts, %)**
Do you use apps on your smartphone to assist with agricultural management (*e.g.* to track soy quotation, identify pests, cost management)?	79.49
Do you use calculation programs or spreadsheets for monthly cash flow control and cost management?	72.27
Do you use digital banking?	70.09
Do you use software/apps for property management (cost management, people management, production management, storing property data, phytosanitary management, fleet management, land management)?	51.26
Do you use computer programs to plan annual activities?	61.02
Do you use indicators from the data stored to manage the machines and the property (*e.g.* fuel consumption per hectare, machine hours per hectare)?	50.85

Source: Research data.

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 cannot be retrieved quickly. Thus, the potential for examining problems through the analysis of stored information is lost (FOUNTAS et al., 2005). Simply adopting software/programs is an important step of smart farming. Besides the use of computers and programs, smart farming is based on the use of indicators and metrics for managing the property and the activities developed in it. Our study indicates that 50.85 of the farmers use indicators from the stored data. This item points to the group of farmers 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 farmers to use indicators is handling the data collected. A study developed with U.S. and Danish farmers that use PA observes that among the main problems to handle the data are the consumed time, lack of technical assistance, and agronomic knowledge (FOUNTAS et al., 2005). In Brazil, companies and startups are developing apps and programs that use the data to generate program maps and outputs (PIVOTO et al., 2019) with useful information for farmers, such as Elysios (ELYSIOS, 2021), Solinftec (SOLINFTEC, 2021), and Aegro (AEGRO, 2021).

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. In our research, many farmers use digital banking, that is, 70.09% used these devices to assist in agricultural management. Among the main uses of the internet by farmers are price/supplier research, access to financial services, and purchase of inputs or goods.

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; 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, in the following subsection, the perception of the grain farmers regarding the technical consultants in SF and their limitations to assist in the advancement of this new area.

Qualitative Analysis

The qualitative question captured the perception of farmers about the quality of information provided by consultants and technical assistants. It sought to understand the difficulties that consultants or technical assistance (agronomists) present to guide the farmers in information technology and precision agriculture. In this context, 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 farmers with the highest level of technology adoption presented the most critical answers to the lack of knowledge of the technicians.

The results indicate that, in the perception of farmers, some 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, recommendations and indications of management to farmers require data and information subsidies that were not available ten years ago. For this, consultants need to update with software and to interact with other areas of knowledge to enable solutions and extract data results. The excerpts taken from the transcripts reflect this:

> "When the consultant does not know, it does not encourage me to adopt and use technology" (*Farmer 32*).

> "Some agronomists have little knowledge of information technology. They have difficulty with smartphone software and apps. They lack the necessary courses for the current times" (*Farmer 57*).

A second item mentioned by the farmers was the credibility of the companies that provide services in SF. On the one hand, one respondent mentioned that:

> "There is a need for greater credibility of companies that provide services in precision agriculture. Companies must bring numbers and examples of technologies for farmers" (*Farmer 11*).

Meanwhile, for the respondents, some resellers and service providers sell accessories and technologies or even services with no having proven results or a follow-up service. An example would be harvest maps and some sensors that, after being sold by the companies, are not used for lack of an after-sales service. A respondent signaled:

> "Machine resellers are not prepared to sell the PA and IT services that are part of the machines and equipment. As a result, farmers 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" (*Farmer 22*).

For SF to advance, the complete cycle needs to be adopted. Currently, only a part of this is seen: agricultural machinery and equipment. In some cases, resales and technical support are not prepared for this new context of agriculture, as well as the administrative and management areas in farms.

The farmers also mentioned the language and communication used by the consultants. Smart farming brings new concepts and knowledge. Farmers commented that they have difficulty to understanding the language of technical assistance and some pointed out that the consultants' communication is flawed. This can be seen in the excerpts below:

> "One of the main difficulties is the language used by technicians. Younger farmers understand it, but older farmers have difficulty understanding" (*Farmer 85*).

> "Standardization of language/knowledge among all users and operators. They have difficulty passing the information" (*Farmer 101*).

Initiatives linked to providing training courses in this area have increased in Brazil, as a response to two items highlighted by the farmers, knowledge and language (CNA, 2020).

Final Remarks

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, the adoption becomes possible.

The perceived utility of these technologies by the farmers may be influencing their rate of adoption and needs to be studied. As verified in the perception of farmers regarding technical advice, many technologies still do not have a measurable result in their point of view. Our results point to the need of companies selling equipment and services to show examples and results using the set of and especially, having an after sales service that meets customer expectations.

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, electronics, and others technologies inserted in the context of smart farming. However, in some regions, farmers do not have an organizational culture of consulting their data, using software and asking for help from consultants.

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, which we suggest for future studies. Similarly, panel data would help to accompany this process of digitization of agriculture, and a 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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