How Communication Affects the Adoption of Digital Technologies in Soybean Production: A Survey in Brazil

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Abstract: Technology adoption has contributed to developing efficient food production throughout the history of modern agriculture. In the last decades, several technologies have positively affected yields globally, and, more recently, digital solutions are leading the way. This article presents the results of a survey carried out with 461 Brazilian soybean farmers about the use of technologies and the level of influence of mass media, social media, and interpersonal meetings on the decision to adopt new technologies. We surveyed farmers in Brazil’s top five soybean-producing states, which represent 75% of production in the world’s largest soybean producer. Spearman’s rank correlations showed an association between communication and the use of precision and digital technologies. LinkedIn had the highest positive correlation between precision and digital tools. Conferences, forums, and seminars had the highest positive correlation with the perceived benefits of using technologies on-farm. The results suggest that in-person activities still have relevance, but social media platforms, such as WhatsApp, have grown increasingly important to farmers. In addition, the correlations indicate that adopters of established technologies tend to prioritize in-person connections as a reference for their decision making. The results reinforce that superior knowledge and information are decisive in the process of adopting technologies in agriculture.

Keywords: Brazilian soybean farmers; mass media; social media; interpersonal meetings; technology adoption

1. Introduction

Over the past decade, there has been a growing public fascination with the complex connectedness of modern society. This connectedness can be found in the rapid growth of the Internet, in the ease with which global communication takes place, and in the ability of news and information, as well as epidemics and financial crises, to spread with surprising speed and intensity [1]. This rapid advancement of digital technologies is increasingly present in rural areas and has changed the way that agriculture is conducted. The increasing digitalization of the agricultural sector has become even more indispensable in the past two years due to the COVID-19 pandemic.

This digital transformation has a crucial role in agribusiness because it leads to more informed decisions, higher efficiency, and easier knowledge sharing. Some studies suggest there has been an informational revolution in the agricultural sector [2], with the adoption of digital technologies by farmers increasing for a decade. This trend will likely continue at an accelerated pace, given the increased venture capital devoted to developing these technologies [3].

The development of digital technologies is stimulated by agricultural and information technology companies, which have invested hundreds of millions of dollars in solutions...
that use data on soil types, seed variety, and climate to help farmers reduce costs and increase yields [4]. As intelligent machines and sensors grow in quantity and relevance on farms, agricultural processes become increasingly oriented by data [5].

Therefore, there is a tendency for rapid growth in generating, transferring, and storing data in agriculture along with mobile technology and data management software for the collection, generation, and dissemination of information [6]. Digital agriculture has been developing at a rapid pace, especially in countries such as the United States and Brazil, leaders in grain production in the world, as evidenced by the widespread adoption of precision agriculture over the past two decades [7,8].

Precision agriculture is a farming management concept that provides a systematic approach to managing the spatial and temporal crop and soil variability within a field to increase profitability, optimize yield and quality, and reduce costs and environmental impacts [9–11]. Precision agriculture has become mainstream in commercial agriculture production, and many agree it is “the way we farm today” [12].

Although the adoption of precision agriculture is increasing, many empirical and scientific studies have shown that the lack of ability to use these tools and the shortage of knowledge about the most appropriate technologies contribute to current farmer unease about digital technology adoption [12–14]. The use of technology varies from farmer to farmer, but the decision to invest in technology is commonly tied to the potential for increased efficiency and profitability [12]. The literature documenting determinants of adoption of precision agriculture practices is wide. Many studies have examined factors such as farmer age, farm size, the cost and complexity of technology, and level of farmer education [15,16] and their influence and relationship with the adoption rate of technologies in agriculture. However, this study presents a multidisciplinary analytical approach with the objective of investigating the influence of communication in the adoption of digital technologies in agriculture.

Based on the premise that diffusion is the process by which an innovation is communicated over time among the participants in a social system [17], this investigation concentrates on one of the main elements influencing the spread of an innovation: communication channels. In other words, the information is a determinant variable in the process of adopting innovations. Although there is a consensus that information is essential to the adoption of digital technology, there is no common understanding of which are the most efficient communication channels to influence soybean farmers’ decision making regarding new technologies.

There are several ways to disseminate information to farmers about new technologies, such as mass media (newspaper, magazine, radio, television, and website/blog), social media (WhatsApp, Facebook, YouTube, Instagram, and LinkedIn), and interpersonal meetings (field days, conferences, retailers, extension agents, peer groups, and conversations with neighbors). Various stakeholders spread relevant information, such as other farmers, technology firms, research centers, private consultants, and farmer unions [18]. The communication channel is closely related to how the information can be distributed to farmers.

Social media, for example, set a “revolutionary” context of online communication for agricultural stakeholders as it widens the scope of peer-to-peer communication, farmer-industry networking, engaging consumers, and building relationships with agribusiness and agricultural entrepreneurs [19]. Participation in social networks is important to share information and experiences between farmers and other agents of the agroindustry chain [20]. At the same time, mass media remains essential to the agriculture industry because many consumers still receive information about agriculture from sources such as newspapers and television [21]. Farmers’ initial acceptance of a mobile digital platform for farm management is shaped by social influence, which mediates the impact of performance and effort expectancy [22].

Therefore, this study aimed to measure the influence of various communication channels on Brazilian soybean farmers’ decisions on the adoption of digital technologies...
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in soybean production, which is the world leader in soybean production and exports. In the 2020/2021 season, Brazil produced a record of 14,075 million tons of soybeans, up 8.9% from last season’s record crop, according to the National Supply Company (Conab) [23]. Brazil is projected to retain its position as the largest soybean producer over the next decade, ahead of the United States and Argentina, two of the other major producers of soybeans [24].

This work aimed to gather information through an online survey with soybean farmers about the of adopting digital technologies in Brazil and the influence of communication channels, such as mass media, social media, and interpersonal meetings, on their decision. The results contribute in a practical way to increasing knowledge about the most efficient communication channels for disseminating digital agriculture technologies. In addition, this study supports new research in agricultural communication, an area still lacking data in the United States and Brazil.

2. Conceptual Framework

The acceptance and use of new technologies have been the subject of much research since the 1960s. In recent decades in academic disciplines such as psychology, communication, and sociology, numerous theoretical models have been developed to predict and explain user acceptance of information technology (IT) or information system (IS). Various theoretical perspectives inform studies on the adoption of innovations. Among the main theoretical structures to explain user acceptance is the theory of the diffusion of innovations [17]. More recently, the unified theory of acceptance and use of technology [25] includes variables of these approaches and some others. We examine the literature specifically linked to the information spread by several communication channels as a determinant variable in adopting innovations, influenced by moderators that affect technology usage, such as age, level of education, and experience.

Information plays an increasing role in controlling resources, increasing profits, and reducing risk in farming for two fundamental reasons. The first reason is the dramatic growth in knowledge and information about agricultural production’s chemical, biological, and physical processes. Second, the “food business” has become an increasingly sophisticated and complex business in contrast to producing commodities in the past [3].

The advent and adoption of digital technologies offer the profound potential to enhance the effectiveness and profitability of crop farming. Even though some digital and precision technologies have been available for some time, adoption surveys suggest continued increased rates of adoption of the various forms of these tools [26]. Communication channels are needed to adopt innovative technology for farmers [27].

In farms, for example, the most significant limitation for the use of technologies is that producers are still lacking in their ability to use information and communication technologies. Research on adoption in rural properties in European countries and the United States found that farmers’ most significant challenge to using digital technologies is the lack of ability to use these tools [14].

A recent survey showed the difficulties of accessing and using technologies in digital agriculture in Brazil. Among more than 500 farmers interviewed, 41% responded that the lack of knowledge about the most appropriate technologies is one of the main barriers. In the same survey, 47% of the more than 200 technology companies interviewed replied that the training of farmers is the main limitation for selling their products [13]. Superior knowledge and information will enable producers to more successfully obtain the physical resources of land, labor, and capital and efficiently combine them. Thus, the role of knowledge and information for success in the farming sector and agricultural industry is more critical today than ever before [3].

One of the main theories on the adoption of innovations in societies originates from Everett Rogers and his colleagues. The professor of communication studies popularized the theory in his book Diffusion of Innovations, published in 1962 and today is in the fifth edition (2003). This theory explains how the invention and diffusion of new technologies
and ideas impact societies over time [28]. Rogers (2003) argues that diffusion is how innovation is communicated over time among the participants in a social system. This theory was critical in that it was one of the first to insert information as a determinant variable in adopting innovations.

Rogers and his colleagues argue that four main elements influence the spread of a new idea: the innovation itself, communication channels, time, and a social system. It is critical to understand the effects of these attributes as they largely influence the adoption decisions of any innovation [29]. The characteristics of the innovation will influence the rate of adoption. These characteristics include the following: (1) the relative advantage that an innovation will provide users; (2) the degree of compatibility that an innovation will have with the values and experiences of users; (3) the complexity of the innovation; (4) whether users will be able to try out the innovation prior to adoption (trialability); and (5) the degree to which users can observe others using the innovation [28].

Likewise, time is a key element that impacts diffusion. Innovations take time to diffuse throughout society, so one common goal of organizations is to decrease the amount of time this takes. A third important element impacting diffusion is the larger social system in which the diffusion takes place. The social system includes many facets, but two important considerations are the participants in society, such as opinion leaders, and the organizational structures that lead to innovation. The final element, which is the focus of this study, are the communication channels through which an innovation is diffused. Successful diffusion of any innovation depends upon the types of communication channels available. In general, there are interpersonal, mass media, and social media channels [28].

The impact of these channels varies depending on users and the social and cultural context in which diffusion is occurring. One of the most significant contributions of this theory is its explanation of diffusion stages in terms of users. These stages are based on innovators, early adopters, the early majority, the late majority, and laggards. Diffusion does not occur at a similar rate but rather resembles an “S” curve in terms of adoption [17,30]. Important to the relationship between channel and user is Rogers’ distinction between homophily and heterophily. Homophily refers to the degree of similarity that users perceive with an innovator, whereas heterophily refers to the degree of difference perceived [28]. A communication source with high degrees of homophily may generate more trust in innovation. A communication source with high degrees of heterophily may generate interest and exposure to novel ideas and technologies. The latter may be particularly impactful in the early stages of adoption.

The theory of diffusion of innovations has been widely applied across multiple disciplines. It has been particularly impactful within agricultural extension [31]. Other theoretical frameworks have been proposed to explain how adoption occurs within different groups.

Another essential theory considered in this study is the theory of acceptance and use of technology (UTAUT), which is a comprehensive synthesis of prior technology acceptance research. In the search for a more comprehensive IT acceptance model, Venkatesh et al. [25] reviewed related studies and conducted an empirical study where they synthesized several elements of the eight behavioral intention models used in previous technology acceptance contexts. The researchers then applied the UTAUT model to unify the existing theories regarding how users accept technology [25,32].

UTAUT has four essential determining components: performance expectancy, effort expectancy, social influence, and facilitating conditions. These components influence behavioral intention to use a technology and/or technology use. The underlying premise of UTAUT is that an individual’s intentions to engage in post-adaptive behavior are the best predictors of that individual’s actual post-adaptive behaviors [25]. Besides these four essential determining components, the UTAUT model contains four moderators that affect technology usage: sex, age, experience, and voluntariness of use.

Based on the main elements that influence the diffusion of innovation [17] and the essential determining components of acceptance and use of technology [25], this study
Based on the main elements that influence the diffusion of innovation and the essential determining components of acceptance and use of technology, this study aims to identify the communication channels and the precision and digital technologies most used by soybean farmers in Brazil. The main purpose of our study was to measure the influence of each communication channel on farmers’ decision making regarding these technologies. The following research questions guided the study: what are the most efficient communication channels to influence the adoption of new technology in soybean production in Brazil?

3. Materials and Methods

3.1. Data Collection

The study was conducted in Brazil’s top five soybean-producing states: Mato Grosso, Paraná, Rio Grande do Sul, Goiás and Mato Grosso do Sul. These five states represent 75%
of soybean production in Brazil, the world’s largest soybean exporter and producer [23]. The data were collected through an online questionnaire available to the farmers from 31 March to 31 May 2021. To achieve a 5% margin of error on a 95% confidence level required at least 400 fully complete questionnaires to achieve a probabilistic sample of soybean producers in the five states. Results were gathered for 461 farmers in five states, a higher response than initially expected, with a margin of error of 4.66%.

The online survey was distributed with help from the Brazilian Association of Soybean Growers (Aprosoja Brasil, Brasilia, Brazil), National Supply Company (Conab, Brasilia, Brazil), state associations of rural producers, and agricultural cooperatives. These organizations were responsible for sending the link and information to farmers. An invitation message was sent to explain the objectives to those interested in voluntarily participating in this online survey. WhatsApp (instant messaging app) was the primary distribution tool, followed by Facebook, Instagram, and e-mail lists. In some cases, the direct participant spread the survey further to other farmers, not members of those organizations as potential research participants.

3.2. Survey Instrument

To measure the influence of the communication channels on the adoption of technologies in agriculture, we designed a questionnaire survey sent to soybean farmers across the top five soybean-producing states in Brazil. The online survey was prepared in Portuguese, the Brazilian official language, and hosted on the Qualtrics virtual platform. We divided the survey into three main sections: (1) use of digital technologies, (2) influence of communication channels, and (3) demographic information.

The first section, questions one to four, asked about the precision and digital technology tools used on the farm, the decisions made by these tools, and the perceived benefits of the tools. The variables in each question were selected and adapted from the Precision Agriculture Dealership Survey conducted by CropLife magazine and the Departments of Agricultural Economics and Agronomy at Purdue University. The Purdue/CropLife survey is the longest-running, most widely used survey that chronicles the development and adoption of precision agriculture [36].

As the CropLife survey is extensive, we adapted it to cover key precision agriculture technologies in a more summary way. We chose the technologies with the highest percentages of use in the results of the 2017 and 2019 Purdue/CropLife Precision Agriculture Dealer Surveys [36,37]. In addition, we adapted the definitions from English to Portuguese to make the questions understandable to Brazilian farmers. After that, experts in precision agriculture in Brazil reviewed the choices and definitions. Finally, we did a pre-test with 10 Brazilian producers and received suggestions to improve the understanding of the questions.

The second section, questions five to seven, investigated the level of influence of mass media, social media, and interpersonal meetings on the decision to adopt a new digital technology on the farm. The variables in each question were based on Brazilian Association of Rural Marketing and Agribusiness (ABMRA, São Paulo, Brazil) reports, the most relevant study of farmers’ media habits and participation in events in Brazil. The ABMRA study considered nine social media platforms (WhatsApp, Facebook, YouTube, Messenger, Instagram, LinkedIn, Skype, Snapchat, and Twitter). We chose the top six to investigate in our study according to their results in 2017. Restrictions apply to the availability of these data. Data were obtained from ABMRA and are available from the corresponding author with the permission of the ABMRA board. The reports are not publicly available due to closed access (restricted to members and payment-based). The most recent edition surveyed more than 3000 farmers in 15 Brazilian states in 2020 [38].

The last section, questions nine to thirteen, comprised the information on the demographic profile of the respondents. We collected data such as the number of hectares of the planted area, age group, level of education, and participation in the agricultural cooperatives. The questionnaire also included one question asking whether the coronavirus...
pandemic has made farmers more willing to adopt digital technologies. This question was added because the data were collected in Brazil during the worst moment of the COVID-19 pandemic. During this period, many digital tools supported on-farm production by providing online advice and facilitating access to inputs and machinery services.

A self-constructed 5-point Likert scale (1 = Not at all influential, 2 = Slightly influential, 3 = Moderately influential, 4 = Very influential, 5 = Extremely influential) was used for recording the farmers responses. The scale’s reliability is validated with the help of a pilot survey of 10 respondents, and minor alterations were made in the final questionnaire.

3.3. Data Analysis

The data obtained for each question (single choice, multiple-choice, and matrix questions) were consolidated in a Qualtrics platform report, exported in CSV, and imported into a spreadsheet. The data were analyzed using descriptive statistics, Spearman rank correlation testing (ρS), and analysis of variance ANOVA. We used the Statistical Package for Social Science (SPSS), Version 18.0 for Windows to analyze data, with a minimum level of statistical significance of \( p < 0.05 \).

The Spearman rank correlation test determined the significance of correlations between different variables. Spearman correlation is recommended when data follow a non-normal distribution and for ordinal variables. The first construct, “use of digital technologies”, and its three variables were correlated with the second construct, “influence of communication channels”, and its three variables. In addition, we used the ANOVA test to identify possible differences between age groups and educational levels.

Before the analysis, the reliability of the scales used to measure the variables was investigated using Cronbach’s \( \alpha \) coefficient. A Cronbach’s \( \alpha \) coefficient higher than 0.7 indicates that the different items can be summed and that the median can be used to represent these constructs. The Cronbach’s \( \alpha \) indicated that all the scales used for precision and digital technologies (\( \alpha = 0.83 \)), making decisions (\( \alpha = 0.87 \)), perceived benefits (\( \alpha = 0.88 \)), mass media (\( \alpha = 0.78 \)), social media (\( \alpha = 0.76 \)), and interpersonal meetings (\( \alpha = 0.77 \)) were within the acceptable limit.

4. Results and Discussion

This section presents the results and discussions regarding the demographic profile, including the location, farm size, age groups, education level, and cooperative memberships of the farmers surveyed. In the sequence, we show the level of the use of precision and digital technology tools on-farm, making decisions, and the benefits. Moreover, we report and analyze the influence of mass media, social media, and interpersonal meetings on farmers’ adoption of new technology. Finally, the section presents the association between the communication channels and the adoption level of technologies in Brazil’s soybean production.

4.1. Demographic Profile

In total, 461 soybean farmers in Brazil responded to the survey within eight weeks that the survey was open, including 61.6% from the South and 38.4% from the Midwest (Figure 2). Among the top five soybean-producing states in Brazil, the number of respondents was divided by Rio Grande do Sul (39.6%), Paraná (22%), Goiás (13.8%), Mato Grosso (12.7%), and Mato Grosso do Sul (11.9%). These five states represent 75% of soybean production in Brazil [23].

Data from the last Brazilian Agricultural Census show there are 235,766 properties that plant soybeans in Brazil, including 95,394 (40.4%) located in the Rio Grande do Sul, 84,499 (35.8%) in Paraná, 7792 (3.3%) in Goiás, 7061 (3%) in Mato Grosso, and 7093 (3%) in Mato Grosso do Sul. Although the Midwestern states represent less than 10% of rural properties, Mato Grosso, Goiás, and Mato Grosso do Sul comprise 46.2% of total acreage and 45.6% of total production in the country [39]. The larger geographic area and the average size of properties in this region explain these numbers from the Brazilian Agricultural
Census. For example, in Mato Grosso, the average size of a soybean farm is 1237 hectares, while in the Rio Grande do Sul, it is just 54 hectares [40].

![Map showing soybean-producing states in Brazil]

**Figure 2.** Share of respondents in the top five soybean-producing states in Brazil.

While the decision-making capacities of the farmer are the focus, farm characteristics such as farm size also influence the adoption. The larger the farm, the greater the likelihood of adoption [15,40]. For example, large commercial farms are more likely to benefit economically from adopting precision agriculture [41]. Among the respondents in Brazil, 25.4% are farming less than 100 hectares, 25.6% from 101 to 500 hectares, 29.3% from 501 to 2000 hectares, 16.3% from 2001 to 10,000 hectares, and 3.5% more than 10,000 hectares (Figure 3).

![Pie chart showing farm size distribution]

**Figure 3.** Farm size of the Brazilian producers that participated in the survey.

The effect of age on precision agriculture adoption is unclear [42]. On the one hand, some researchers have reported that younger farmers are more likely to adopt new technologies in agriculture [43]. However, some authors have reported that older farmers correlate positively with precision agriculture adoption [44].

According to the theory of acceptance and use of technology (UTAUT) [25], which reviewed related studies and conducted an empirical study where they synthesized several
elements of the eight behavioral intention models used in previous technology acceptance contexts, four moderators affect the usage of technology: sex, age, experience, and voluntariness of use. Among the farmers who participated in the survey, 3.5% are under 25 years old, 39.7% are 25–40 years old, 35.4% are 41–55 years old, 19.7% are 56–70 years old, and 1.7% are more than 70 years old (Figure 4).

Furthermore, a higher education level is reported in the literature to positively impact precision farming adoption [16,45]. A high education level provides the knowledge and skills needed to understand the technologies, make farmers want to experiment, and enable them to adopt them [18]. In our survey, 35.1% of respondents have a postgraduate degree (MBA, master’s, or doctorate), 39.7% have a bachelor’s degree, 7.2% have not completed a bachelor’s degree, 11.9% have a high school diploma, 2.2% have not completed high school, 1.5% have middle school diploma, and 2.4% have not completed middle school (Figure 5).

Finally, among the respondents, 56% are members of a cooperative that offers technical support, and 44% are not members of any cooperative that provides technical support. A few studies estimate the role of cooperative membership in economic and/or technical efficiency [46,47]. Cooperative membership is associated with increased efficiency among farmers in the midwestern region of Brazil [48]. In another paper regarding Brazil, the authors estimate an agricultural production function and found a positive effect for the share of cooperative memberships on the gross value of production (GVP) in the south,
where there are more cooperative members [49]. In addition, the size of the cooperative can determine the degree of digitization. Cooperatives that have a greater size or volume of resources clearly present a higher level of digitization in electronic commerce and web services offered [50].

4.2. Technologies Adoption On-Farm, Decisions, and Benefits

The survey asked about the level of the use of precision and digital technology tools on-farm on a 5-point scale (1 = Never use, 2 = Rarely use, 3 = Sometimes use, 4 = Often use, 5 = Always use). Respondents also indicated the level of influence of digital technology and precision tools on-farm on making decisions and on the benefits (1 = Not at all influential, 2 = Slightly influential, 3 = Moderately influential, 4 = Very influential, 5 = Extremely influential). Table 1 shows the average regarding each question:

Table 1. Level of the use of the technologies on-farm and level of their influence in making decisions and in the benefits.

| Precision and Digital Technologies                           | Means |
|---------------------------------------------------------------|-------|
| Guidance/autosteer                                           | 3.56  |
| Satellite/drone imagery                                      | 2.99  |
| Yield monitors                                               | 2.92  |
| Telematic systems                                            | 2.11  |
| Wired or wireless sensor networks                            | 2.10  |
| Electronic records/mapping for traceability                  | 2.09  |
| Spot spray systems                                           | 1.98  |
| Soil EC mapping                                              | 1.50  |

| Decisions                                                     | Means |
|---------------------------------------------------------------|-------|
| Nitrogen, phosphorus, potassium (NPK) fertilization and liming applications | 3.64  |
| Overall hybrid/variety selection                              | 3.49  |
| Overall crop planting rates                                   | 3.44  |
| Planting date decision                                        | 3.35  |
| Pesticide selection (herbicides, insecticides or fungicides) | 3.26  |
| Cropping sequence/rotation decisions                         | 3.12  |
| Variable seeding rate                                         | 2.38  |
| Irrigation decisions                                          | 2.02  |

| Benefits                                                      | Means |
|---------------------------------------------------------------|-------|
| Increased crop productivity/yields                            | 3.70  |
| Cost reductions                                              | 3.63  |
| Labor efficiencies                                           | 3.57  |
| Autosteer (less fatigue/stress)                               | 3.54  |
| Time savings (paper filing to digital)                        | 3.51  |
| Purchase of inputs                                           | 3.38  |
| Lower environmental impact                                    | 3.34  |
| Marketing choices                                            | 3.31  |

Regarding the use of precision and digital technology tools on-farm, guidance/autosteer has the highest adoption rate, according to the survey. This technology was the only one that reached a mean of over 3 points among the tools used on-farm by Brazilian soybean farmers. Autosteer has many benefits, including less operator fatigue, more time focused on the operating equipment, and less waste of applied inputs [37]. The long-used global navigation satellite system (GNSS) technology has stood out since the beginning of the implementation of precision agriculture, has supported an increasing range of activities, and has generated countless benefits in rural areas [13].

Satellite/drone imagery and yield monitors make up the next technology group with the highest rates of farmer adoption, with averages close to 3 points. The development of new remote sensors in satellites and drones for agriculture has significantly enhanced the potential in recent years [51,52]. Similar to GNSS, yield monitors have been widely
available for combines since the early 1990s, the beginning of precision agriculture. Precision agriculture can provide an overwhelming amount of data from yield monitors, soil sampling, machine operations, and inputs applied to various portions of fields [37].

The next grouping is telematic systems, wired or wireless sensor networks, and electronic records/mapping for traceability, with means of just over 2 points on a 5-point scale. Precision agriculture and information technologies (soil and yield maps and variable rate input applications) allow farmers to optimize their production practices [26].

With a mean of less than 2 points, the final group comprises spot spray systems and soil EC mapping. These technologies are newer and unproven in their capabilities when compared to the more established ones. One of the challenges in quantifying the economic benefits of precision and digital technology adoption is that farmers lack tools and methods that enable comprehensive analysis [12].

The perceived ease of use, described as users’ belief that technology will require little effort, is a relevant factor in the process of acceptance and use of innovations [32]. This has a relationship with complexity or the degree to which an innovation is considered as difficult to understand and use. A higher degree of complexity, such as newer and unproven technologies, renders an equally higher degree of difficulty in understanding and using any given innovation. Complexity thus becomes negatively related to an innovation adoption decision [17].

In relation to precision and digital tools in making decisions, nitrogen, phosphorus, potassium (NPK) fertilization, and liming applications have the greatest influence among the respondents. One of the benefits of precision agriculture is applying nutrients where they are most profitable based on soil test results and yield data analysis. Agricultural retailers’ willingness and ability to provide variable rate application of various fertilizers has grown over time but follows an adoption path similar to that of GNSS-based soil sampling [53].

The next grouping comprises the overall hybrid/variety selection, overall crop planting rates, planting date decision, pesticide selection (herbicides, insecticides, or fungicides), and cropping sequence/rotation decisions. These kinds of decisions, with means between 3.49 and 3.12 among the respondents, involve crop management according to field variability and site-specific conditions. Decisions that are better than those that would be made with conventional agricultural practices have the potential to boost the efficient use of resources, reduce input costs, and minimize environmental degradation. At the same time, they improve yield and crop quality [42].

With means below 2.5, the final group is decisions regarding variable seeding rate and irrigation. It may also be associated with the smaller number of farmers using these technologies in relation to the other groups of technologies evaluated. For example, the center pivot system occupied 1.6 million hectares in Brazil in 2020, according to data from the Brazilian Agricultural Research Corporation (Embrapa). In the same year, soybeans alone occupied 36 million hectares in Brazil, according to data from the National Supply Company (Conab). The future expansion of irrigated agriculture in Brazil will depend on economic incentives, water availability, and water conservation practices.

An abundance of studies evaluating the adoption rates of precision agriculture technologies in Brazil, the United States, Australia, and Europe have been conducted, including several in recent years. Although results among these studies vary, adoption rates have generally increased over the last two decades. On the other hand, adoption has lagged behind what many researchers expected, with overall adoption rates rarely overcoming 50% of farms [13,26,31,54–56]. One of the reasons is that farmers are heterogeneous in their perceptions of precision farming technologies’ benefits [7].

The benefits obtained through the adoption and use of precision and digital technologies for farmers’ production processes was another aspect raised in the survey. Increased crop productivity/yields had the highest level of influence among the respondents, followed by cost reductions and labor efficiencies. All of the eight benefits in this question, including autosteering (less fatigue/stress), time savings (paper filing to digital), purchase of
inputs, lower environmental impact, and marketing choices, had means of over three on a 5-point scale.

We know that the use of technology varies from farmer to farmer, but the decision to invest in technology is commonly tied to the potential for increased efficiency and profitability [12]. It is important to note that farmers are heterogeneous in their perceptions of precision farming technologies, and their perceptions are also affected by the technologies they use [7]. Even so, our results suggest that farmers have a significant perception of the benefits provided by the use of technologies in soybean production in Brazil, especially regarding the increase in efficiency and profitability.

4.3. Communication Channels to Spread Information

Soybean farmers in Brazil also were asked to report on the level of influence of mass media, social media, and interpersonal meetings on their decision to adopt precision and digital technology on a 5-point scale (1 = Not at all influential, 2 = Slightly influential, 3 = Moderately influential, 4 = Very influential, 5 = Extremely influential). Table 2 shows the means regarding each question:

Table 2. Level of influence of mass media, social media, and interpersonal meetings in farmers’ decision.

| Mass Media                      | Means |
|---------------------------------|-------|
| Website and blog                | 3.38  |
| Subscription television         | 2.41  |
| Radio                           | 2.17  |
| Open television                 | 2.15  |
| Magazine                        | 2.11  |
| Newspaper                       | 1.75  |

| Social Media                    | Means |
|---------------------------------|-------|
| WhatsApp                        | 3.65  |
| YouTube                         | 3.17  |
| Instagram                       | 2.61  |
| Facebook                        | 2.40  |
| LinkedIn                        | 2.03  |
| Messenger                       | 1.71  |

| Interpersonal Meetings          | Means |
|---------------------------------|-------|
| Field days                      | 3.87  |
| Conferences, forums, and seminars | 3.86 |
| Extension agents                | 3.63  |
| Conversation with neighbors     | 3.62  |
| Peer groups (formal or informal)| 3.42  |
| Retailers                       | 3.20  |

In relation to the mass media group, the results show a difference between the channels. For example, websites and blogs had an average of 3.38, and newspapers had a mean of 1.75. The results are in line with the rapid growth of the Internet, the ease with which global communication takes place, and the ability of news and information to spread with surprising speed and intensity [1]. Meanwhile, newspapers have been trying to make the transition from print to digital for almost two decades in Brazil, but most are struggling with this transformation, as shown by the 1.75 mean rating for newspapers in Table 2.

This movement from newspaper to the website is also shown in the latest Brazilian Association of Rural Marketing and Agribusiness reports, the most relevant study of Brazil’s farmers’ media habits. From 2013 to 2020, newspapers’ share among communication channels used by Brazilian farmers declined from 42% to 27%. At the same time, the Internet increased almost two-fold, from 39% to 74%. Due to a weakened newspaper industry and reduced resources, an accurate understanding of consumer demand for digital news products is more important than ever [57].
Still, regarding the mass media group, subscription television had the second-highest level of influence among the respondents in our survey (M = 2.41). The result can be understood by the specialized content offered by this communication channel. Considered a market niche, the agribusiness lost many spaces in open television programming in recent years in Brazil. Therefore, the subscription television with exclusive channels to the farmers earned relevance to farmers.

The next group comprises radio, open television, and magazine, with very similar averages in the survey. It is interesting to note that radio keeps relevant to farmers, despite the proliferation of new media. This can be explained by the radio’s immediacy and by its accessibility. For example, the radio can be accessed in cars, trucks, and Ag machines or cell phones virtually anywhere. In addition, the radio usually brings local news that interests the producer, such as weather forecasts. The radio’s relevance is also shown in the last Brazilian Association of Rural Marketing and Agribusiness study, where 71% of farmers answered that they listen to the radio in 2020, practically the same percentage as in 2013 [38].

In relation to the social media group, WhatsApp stands out in the survey as the most influential in soybean farmers’ decision making, with a 3.65 average. WhatsApp is a cross-platform online instant messaging service for mobile devices. As of 2021, WhatsApp is the most popular mobile messenger app worldwide with approximately two billion monthly active users, outranking Facebook Messenger at 1.3 billion and WeChat at 1.2 billion users. Following Facebook and YouTube, it is the third most popular social network globally, according to the 2021 Statista Dossier about WhatsApp [58].

WhatsApp has become the primary and fastest daily communication tool for farms in Brazil. For example, 76% of farmers use WhatsApp to do business, according to a study by the Brazilian Association of Rural Marketing and Agribusiness conducted in 2020 during the pandemic. According to the same study, the use of WhatsApp among farmers grew along with the increase in the number of smartphones used by 94% of farmers in Brazil, compared to just 61% four years ago [38].

The mobile messaging app enables users to share texts, images, videos, and voice messages and supports video calling. Our survey, for example, was delivered to farmers in Brazil over two months through WhatsApp. The questionnaire link was distributed mainly in farmers’ groups on the platform, which allows up to 256 members in the same group. The app creates alternate communities of mutual interests, enabling farmers to receive relevant information during their workday. The lockdown and social distancing experienced in 2020 and 2021 created a situation where WhatsApp became even more important to farmers in communicating with workers, suppliers, and extension agents.

Still, regarding the social media group, YouTube had the second-highest average among the respondents in our survey, with an average of 3.17. While many social media proved to be ephemeral, YouTube continues to expand rapidly and has become the second most visited website globally [59]. According to data from Statista, the number of YouTube viewers amounted to 1.86 billion in 2021, up from 1.47 billion in 2017. Visual media can provide a valuable source of information for farmers.

In the Brazilian Association of Rural Marketing and Agribusiness study, YouTube almost tripled its importance from 2017 to 2020, based on usage rates among farmers increasing from 24% to 70% [38]. Farmers typically use the platform for seeking information related to agricultural innovations, upcoming technologies, and specialized skills. The live streaming service is also popular among producers, especially with younger Internet users.

The next grouping comprises Instagram and Facebook, both with very similar means in the survey. Instagram started as a photo-sharing platform in 2010, growing in popularity to attract a large crowd of followers, which led to its creative use by bloggers and marketers. Today, Instagram has moved from photo sharing to video sharing and live streaming [60]. Similar to YouTube, Instagram live gained relevance with the pandemic. This scenario led to the surge of live events with guests remotely located, which was unthinkable before COVID-19.
In addition, Instagram is the main platform used by digital influencers and digital media content creators who use their media platforms to influence audience behavior. The wave of influencers in Brazilian agriculture, formed by producers, agronomists, communicators, and other professionals, began to gain strength in the last five years. Therefore, there is still no data to measure the real impact on companies investing in influencers as marketing tools. Instagram appeals more to the younger generation than other social media platforms, making it more popular among the youth than Facebook, which remains widespread among older generations [60].

The final group that had the lowest means within the social media group was LinkedIn and Messenger. LinkedIn is a social networking site for business professionals. Perhaps because of that, it has a lower mean in comparison to other channels. With an estimated 645 million self-reported users, according to data from Statista 2021, LinkedIn is becoming more relevant for the business as marketers are increasingly using the platform for marketing purposes. By placing sponsored posts or other advertising formats on LinkedIn, marketers can successfully target expert audiences, such as farmers.

In relation to the interpersonal meeting group, there was a slight variation in survey results. All of the eight channels in this question, including field days, conferences, forums and seminars, extension agents, retailers, peer groups, and conversations with neighbors, had means of over 3 on a 5-point scale. The two channels with the highest means were field days and conferences, forums, and seminars. These kinds of events typically provide educational opportunities for producers seeking knowledge in crop production, farm management, land use, and other issues. Besides that, these are opportunities to share information and experiences between farmers and other agents of the agroindustry chain.

The second group was extension agents and conversations with neighbors. Connections and visits with farms by specialists, for example, help in the dissemination of innovative technologies. Agricultural extension services can affect technology acceptance because of the delivery of consultancy and education services [61,62]. With respect to influence from neighbors, a typical model assumes that farmers learn by observing others’ experimentation [63]. Farmer-to-farmer knowledge sharing is an important source of information. However, social learning breaks down if unobserved or imperfectly observed; individual characteristics are important determinants of neighbors’ outcomes [64].

Despite being the last group, peer groups (formal or informal) and retailers have a mean of over 3 points. Peer groups are vital as they facilitate the sharing of local knowledge that is context-sensitive and makes intuitive, practical sense. The relative impact of the peer group may be explained by increased levels of homophily, which generates trust in innovations [28]. Economists increasingly appreciate the critical role that social networks play in mediating the diffusion of agricultural innovations. However, this literature remains underdeveloped.

4.4. Relationship between the Adoption of Technologies and Communication Channels

Spearman’s correlation test was applied to measure the strength of the association between the communication channels and the level of adoption of technologies in soybean production in Brazil. The results depict a positive correlation between eight precision and digital technologies and several mass media, social media, and interpersonal meetings. In Table 3, we chose to discuss just the three communication channels with the highest correlation coefficients.

LinkedIn had the highest positive correlation with seven precision and digital technologies among eight analyzed technologies (Table 3). This result can be questioned because the social media for business professionals had a low mean (2.03 points) among the farmers that indicated the level of influence in their decision making to adopt new technology on the farm. Indeed, the low mean showed that fewer farmers use this channel, but still, LinkedIn may have the highest association with producers using these technologies. In other words, farmers who responded that LinkedIn influences decision making tend to be the ones with the highest levels of on-farm technology adoption.
Table 3. Relationship between use of precision and digital technologies and communication channels.

| Precision and Digital Technologies | Communication Channels                                      | Spearman’s Rank Correlation Coefficient (\(\rho_S\)) |
|-----------------------------------|-------------------------------------------------------------|-----------------------------------------------------|
| Guidance/Autosteer                | 1st Conversation with neighbors                             | 0.209 **                                            |
|                                   | 2nd Conferences, forums, and seminars                      | 0.120 **                                            |
|                                   | 3rd Field days                                             | 0.096 **                                            |
| Yield monitors                    | 1st LinkedIn                                               | 0.178 **                                            |
|                                   | 2nd Conversation with neighbors                            | 0.170 **                                            |
|                                   | 3rd Subscription television                                | 0.145 **                                            |
| Satellite/drone imagery           | 1st LinkedIn                                               | 0.253 **                                            |
|                                   | 2nd Conferences, forums, and seminars                      | 0.246 **                                            |
|                                   | 3rd Instagram                                              | 0.226 **                                            |
| Soil EC mapping                   | 1st LinkedIn                                               | 0.228 **                                            |
|                                   | 2nd Instagram                                              | 0.183 **                                            |
|                                   | 3rd Messenger                                              | 0.182 **                                            |
| Wired or wireless sensor networks | 1st LinkedIn                                               | 0.261 **                                            |
|                                   | 2nd Instagram                                              | 0.208 **                                            |
|                                   | 3rd Conferences, forums, and seminars                      | 0.183 **                                            |
| Electronic records/mapping for traceability | 1st LinkedIn                                           | 0.224 **                                            |
|                                   | 2nd Instagram                                              | 0.180 **                                            |
|                                   | 3rd Conferences, forums, and seminars                      | 0.148 **                                            |
| Spot spray systems                | 1st LinkedIn                                               | 0.221 **                                            |
|                                   | 2nd Subscription television                                | 0.189 **                                            |
|                                   | 3rd WhatsApp                                               | 0.151 **                                            |
| Telematic systems                 | 1st LinkedIn                                               | 0.246 **                                            |
|                                   | 2nd Instagram                                              | 0.186 **                                            |
|                                   | 3rd Peer groups (formal or informal)                       | 0.135 **                                            |

**Correlation is significant at the 0.01 level (2-tailed).

In addition, the level of education of respondents may have influenced the results around LinkedIn. Among the farmers surveyed, 34.9% have a graduate degree (MBA, master’s, or doctorate), 40.2% have a bachelor’s degree, and 24.9% have less than a bachelor’s degree. The results of the one-way ANOVA showed a significant difference among the three-level education groups regarding the use of LinkedIn at the 95% confidence level (\(F = 15.260; df = 2450; p < 0.001\)). Among farmers that have a graduate degree, for example, LinkedIn had a mean of 3.38. Meanwhile, among farmers that have a bachelor’s degree, the mean was 1.88, and among farmers with less than a bachelor’s degree, the mean was 1.66 (Table 4). People with higher levels of education are more likely to be LinkedIn users than those with lower levels of education, according to the Social Media Use in 2021 report conducted by Pew Research Center in the United States.

Table 4. Level education and use of LinkedIn using one-way analysis ANOVA.

|                        | N   | Mean | Std. Deviation |
|------------------------|-----|------|----------------|
| Less than a bachelor’s degree | 113 | 1.66 | 1.057          |
| Bachelor’s degree      | 182 | 1.88 | 1.186          |
| Graduate degree        | 158 | 2.46 | 1.461          |
| Total                  | 453 | 2.03 | 1.300          |
The only technology that had no positive association with LinkedIn was the guidance/autosteer ($\rho_S = 0.059; p > 0.05$). In this case, the three highest correlation were with conversation with neighbors ($\rho_S = 0.209; p < 0.001$), conferences, forums, and seminars ($\rho = 0.120; p < 0.05$), and field days ($\rho_S = 0.096; p < 0.05$). The results suggest an association among adopters of this long-used technology, present since the beginning of the implementation of precision agriculture, with interpersonal meetings.

These connections typically prioritize in-person activities based on trust, such as relations with other farmers and learning from specialists who participate in technical events promoted by rural associations or agroindustry. One of the essential determining components of the UTAUT theory, for example, is social influence, the extent to which consumers perceive that important others (e.g., family and friends) believe they should use a particular technology [65]. This is confirmed through the concept of homophily within the diffusion of innovations.

In second place, behind LinkedIn, Instagram also showed a positive association with the use of wired or wireless sensor networks ($\rho_S = 0.208; p < 0.001$), telematic systems ($\rho_S = 0.186; p < 0.001$), soil EC mapping ($\rho_S = 0.183; p < 0.001$), and electronic records/mapping for traceability ($\rho_S = 0.180; p < 0.001$). These technologies are newer and unproven in their capabilities compared to the more established ones, such as guidance/autosteer and yield monitors.

This result suggests an association among adopters of emergent technologies with Instagram, the most popular social media platform among youth. For example, among the farmers who participated in the survey, 43.3% were under 40 years of age or younger. The results of the one-way ANOVA showed a significant difference among the three ages groups regarding the use of Instagram at the 95% confidence level ($F = 21.694; \text{df} = 2454; p < 0.001$). Among farmers under 41 years of age, for example, Instagram had a mean of 3.02. Meanwhile, among farmers from 41 to 55 years old, the mean was 2.50, and among producers more than 56 years old, the mean was 1.98 (Table 5). Farmers’ age appears as a significant factor in quantitative or econometric approaches to testing the effects of different variables on the adoption of digital technologies on the farm [66,67].

| Age groups          | N    | Mean | Std. Deviation |
|---------------------|------|------|----------------|
| Under 41 years      | 198  | 3.02 | 1.342          |
| From 41 to 55 years | 161  | 2.50 | 1.309          |
| More than 55 years  | 98   | 1.98 | 1.201          |
| Total               | 457  | 2.61 | 1.359          |

Subscription television was the only mass media listed among the three communication channels with the highest correlation coefficient in relation to precision and digital technologies. It positively associated spot spray systems ($\rho_S = 0.189; p < 0.001$) and yield monitors ($\rho_S = 0.145; p < 0.05$). The exclusive channels offered by subscription television, some specializing in agriculture, are relevant to farmers since the agribusiness lost many spaces in open television programming in recent years in Brazil.

We also applied Spearman’s correlation to measure the association between communication channels and the use of technologies on-farm in making decisions. Although the results depict a positive correlation between the decision making and mass media, social media, and interpersonal meetings, we did not identify a clear pattern in the associations. Again, we chose to discuss just the three communication channels with the highest correlation coefficients (Table 6).
Table 6. Relationship between decisions and communication channels.

| Making Decisions                                                                 | Communication Channels                                           | Spearman’s Rank Correlation Coefficient (ρS) |
|---------------------------------------------------------------------------------|------------------------------------------------------------------|---------------------------------------------|
| Nitrogen, phosphorus, potassium (NPK) fertilization and liming applications    | 1st Conferences, forums, and seminars                           | 0.284 **                                   |
|                                                                                  | 2nd Peer groups (formal or informal)                             | 0.247 **                                   |
|                                                                                  | 3rd Field days                                                  | 0.244 **                                   |
| Overall hybrid/variety selection                                                | 1st Field days and WhatsApp                                     | 0.263 **                                   |
|                                                                                  | 2nd Conferences, forums, and seminars                           | 0.260 **                                   |
|                                                                                  | 3rd Website and blog                                            | 0.238 **                                   |
| Overall crop planting rates                                                     | 1st WhatsApp                                                    | 0.230 **                                   |
|                                                                                  | 2nd Field days                                                  | 0.218 **                                   |
|                                                                                  | 3rd Website and blog                                            | 0.186 **                                   |
| Variable seeding rate                                                           | 1st LinkedIn                                                    | 0.209 **                                   |
|                                                                                  | 2nd Retailers                                                   | 0.205 **                                   |
|                                                                                  | 3rd Subscription television                                    | 0.175 **                                   |
| Planting date decision                                                          | 1st Field days                                                  | 0.229 **                                   |
|                                                                                  | 2nd Subscription television                                    | 0.217 **                                   |
|                                                                                  | 3rd Radio                                                       | 0.215 **                                   |
| Pesticide selection (herbicides, insecticides or fungicides)                    | 1st WhatsApp                                                    | 0.270 **                                   |
|                                                                                  | 2nd Field days                                                  | 0.260 **                                   |
|                                                                                  | 3rd Subscription television                                    | 0.234 **                                   |
| Cropping sequence/rotation decisions                                            | 1st WhatsApp                                                    | 0.244 **                                   |
|                                                                                  | 2nd Subscription television                                    | 0.238 **                                   |
|                                                                                  | 3rd Conferences, forums, and seminars                           | 0.234 **                                   |
| Irrigation                                                                       | 1st LinkedIn                                                    | 0.220 **                                   |
|                                                                                  | 2nd Magazines                                                   | 0.213 **                                   |
|                                                                                  | 3rd Radio                                                       | 0.190 **                                   |

** Correlation is significant at the 0.01 level (2-tailed).

For each kind of decision, a different group of communication channels had a positive correlation. For example, regarding nitrogen, phosphorus, potassium (NPK) fertilization and liming applications, conferences, forums and seminars (ρS = 0.284; p < 0.001), peer groups (ρS = 0.247; p < 0.001) and field days (ρS = 0.244; p < 0.001) had the three highest correlation coefficients. In this case, all of them related to interpersonal meetings. The results reinforce the idea that adopters of established decisions regarding precision agriculture tend to prioritize in-person connections.

On the other hand, the overall hybrid/variety selection decision had WhatsApp (ρS = 0.263; p < 0.001) and field days (ρS = 0.263; p < 0.001) with the highest correlation coefficients. Both communication channels had the highest association also with overall crop planting rates and pesticide selection (herbicides, insecticides, or fungicides). The result suggests that in-person activities still have relevance for soybean farmers in Brazil, but social media, such as WhatsApp, has been growing in importance to farmers. The app is used daily in rural areas to send and receive messages among coworkers, retailers, suppliers, associations, extension agents, and other farmers. These connections are essential to help farmers in several kinds of decision making.

Within the mass media group, subscription television showed a positive correlation with four types of decisions: cropping sequence/rotation decisions (ρS = 0.238; p < 0.001), pesticide selection (ρS = 0.234; p < 0.001), planting date decision (ρS = 0.217; p < 0.001), and variable seeding rate (ρS = 0.175; p < 0.001). Moreover, website and blog positively correlated with overall hybrid/variety selection (ρS = 0.238; p < 0.001) and overall crop planting rates (ρS = 0.186; p < 0.001). All these decisions require particular knowledge.
in precision agriculture, typically spread by specialized channels, such as subscription television and website.

The radio appears for the first time with a positive correlation with planting date decision ($\rho_S = 0.215; p < 0.001$) and irrigation decisions ($\rho_S = 0.190; p < 0.001$). Although this channel had the third-highest mean among mass media in the survey, it did not prove to be significantly associated with the use of technologies. Perhaps radio is used much more for everyday issues, such as weather and traffic, than for specific topics, such as technology adoption.

We also applied Spearman’s correlation to measure the association between communication channels and the perceived benefits of using technologies on-farm. The results depict a positive correlation between eight perceived benefits and several mass media, social media, and interpersonal meetings. We chose to discuss just the three communication channels with the highest correlation coefficients (Table 7).

**Table 7.** Relationship between benefits and communication channels.

| Perceived Benefits                  | Communication Channels                                      | Spearman’s Rank Correlation Coefficient ($\rho_S$) |
|-------------------------------------|-------------------------------------------------------------|--------------------------------------------------|
| Increased crop productivity/yields  | 1st Field days and Conferences, forums, and seminars         | 0.312 **                                         |
|                                     | 2nd Website and blog                                       | 0.274 **                                         |
|                                     | 3rd WhatsApp                                               | 0.240 **                                         |
| Cost reductions                     | 1st Conferences, forums, and seminars                      | 0.344 **                                         |
|                                     | 2nd Field days                                             | 0.280 **                                         |
|                                     | 3rd WhatsApp                                               | 0.245 **                                         |
| Purchase of inputs                  | 1st WhatsApp                                               | 0.262 **                                         |
|                                     | 2nd Conferences, forums, and seminars                      | 0.260 **                                         |
|                                     | 3rd Website and blog                                       | 0.244 **                                         |
| Marketing choices                   | 1st WhatsApp                                               | 0.311 **                                         |
|                                     | 2nd Conferences, forums, and seminars                      | 0.227 **                                         |
|                                     | 3rd Conferences, forums, and seminars                      | 0.204 **                                         |
| Time savings (paper filing to digital) | 1st Conferences, forums, and seminars                   | 0.343 **                                         |
|                                     | 2nd Website and blog                                       | 0.269 **                                         |
|                                     | 3rd Field days                                             | 0.249 **                                         |
| Labor efficiencies                  | 1st Conferences, forums, and seminars                      | 0.351 **                                         |
|                                     | 2nd Field days                                             | 0.270 **                                         |
|                                     | 3rd Extension agents                                       | 0.260 **                                         |
| Lower environmental impact          | 1st Conferences, forums, and seminars                      | 0.340 **                                         |
|                                     | 2nd Field days                                             | 0.279 **                                         |
|                                     | 3rd Extension agents                                       | 0.269 **                                         |
| Autosteer (less fatigue/stress)     | 1st Conferences, forums, and seminars                      | 0.240 **                                         |
|                                     | 2nd Conversation with neighbors                             | 0.231 **                                         |
|                                     | 3rd Instagram                                              | 0.184 **                                         |

**Correlation is significant at the 0.01 level (2-tailed).**

Conferences, forums, and seminars had the highest positive correlation with six perceived benefits of using technologies on-farm, among eight ones analyzed in the study (Table 7). The educational role played by these events can help to understand the result.
Understanding the value of technology is increasingly important in an environment of narrow crop margins when deploying technologies to optimize returns is critical, especially around agricultural commodities, such as soybeans [12].

In relation to increased crop productivity/yields, for example, conferences, forums, and seminars had a similar positive correlation as field days ($\rho_S = 0.312; p < 0.001$). Regarding cost reductions, conferences ($\rho_S = 0.344; p < 0.001$) and field days ($\rho_S = 0.280; p < 0.001$) also had the highest association in the study. Both channels prioritize the interaction and collaboration between farmers and researchers to promote innovation and knowledge exchange, increasing yields. The increased productivity is one of the most relevant drivers of the significant increase in Brazilian agricultural production and exportable surpluses in the 21st [68,69].

Still, regarding conferences, forums, and seminars, the highest association was with labor efficiencies ($\rho_S = 0.351; p < 0.001$) and time savings ($\rho_S = 0.343; p < 0.001$). Brazilian agriculture underwent a quick process of technical and structural change. In recent decades, the trend toward a reduction in the use of labor has been consolidated, and an increase in farm machinery capital sock [70]. In the case of soybeans, the production organization model and the available technological package have evolved to favor gains in scale and increased the capital-labor ratio, which also contributes to growing per capita income in agriculture, reducing the number of workers.

Conferences, forums, and seminars also had a positive correlation with lower environmental impact ($\rho_S = 0.340; p < 0.001$). Soybean production and its supply chain are highly dependent on inputs such as land, fertilizer, fuel, machines, pesticides, and electricity. In recent decades, the expansion of this crop in Brazil has generated concerns about its environmental impacts [71]. Currently, the pressure to adopt digital technology on the farm emanating from end-use consumers also is mounting. One motivation for that pressure is the desire for more sustainable cropping systems. It is necessary to produce more food with less natural resources and inputs. Therefore, conferences, forums, and seminars have become increasingly important to exchange knowledge that results in soybean production with less environmental impact.

Among the perceived benefits correlated with communication channels, WhatsApp had the highest association with marketing choices ($\rho_S = 0.311; p < 0.001$) and purchase of inputs ($\rho_S = 0.262; p < 0.001$). We expected this result due to the increase in this mobile messaging app for these kinds of activities, especially during the pandemic. The lockdown and social distancing created a situation where WhatsApp became even more important to farmers in communicating with suppliers (to buy the agricultural inputs) and with traders and cooperatives (to sell the soybean production). It is important to highlight that, unlike Instagram, the results of the one-way ANOVA test did not show a significant difference among the three age groups in the use of WhatsApp ($F = 0.256; df = 2455; p > 0.05$). In other words, the behavior regarding the use of WhatsApp does not change according to the age of the interviewed producers.

Among the mass media, website and blog were the channels that showed the highest association with perceived benefits, such as increased crop productivity ($\rho_S = 0.274; p < 0.001$), purchase of inputs ($\rho_S = 0.244; p < 0.001$), marketing choices ($\rho_S = 0.227; p < 0.001$), and time savings ($\rho_S = 0.269; p < 0.001$). The result is in line with the answers from respondents that indicated websites and blogs as the most influential mass media in their decision to adopt precision and digital technology on-farm. In this channel, as an example, soybean farmers can find information regarding machinery, seeds, chemicals, management, and innovations in general.

4.5. Impacts of the COVID-19 Pandemic

It is important to highlight that data were collected in Brazil during the worst moment of the COVID-19 pandemic. During this period, many digital tools supported on-farm production by providing online advice and facilitating access to inputs and machinery services. The pandemic crisis can push the digital revolution in the agricultural industry with
can make the correct decision in time and improve the productivity of yield [72].

Digital advancement is increasingly present in rural areas and has become indispensable for work and personal relationships because of the SARS-CoV2 virus. The use of digital solutions among farmers increased in Brazil in 2020 because of the pandemic. This highlights the use of the Internet to search for information related to field activities, according to results from Embrapa’s study [13].

Could the pandemic thus accelerate a digital revolution in agriculture? The results of the survey carried out in Brazil show that it can. Among the respondents, 65.7% answered that the pandemic made them more willing to adopt digital technologies. So, we can affirm that after COVID-19, agricultural digitalization will lead to a transformation in farming over the coming years.

5. Conclusions and Limitations

This study presents valuable information to better understand how mass media, social media, and interpersonal meetings affect the decision for the adoption of digital technologies in soybean production in Brazil. The results revealed the communication channels and the precision and digital technologies most used by soybean farmers in Brazil, as well as the influence of each one on farmers’ decision making.

In addition, the study has presented a new multidisciplinary analytical approach to investigate the influence of communication in the adoption of digital technologies in soybean production. Based on the main elements that influence the diffusion of innovation [17] and the essential determining components of acceptance and use of technology [25], the results presented here advance our understanding of the role of communication in the adoption of innovations in agriculture in general.

Based on the survey data of 461 soybean farmers in Brazil’s top five soybean-producing states, the analysis showed a significant difference between the use of precision and digital technology tools on-farm. The long-used technologies that stand out, such as guidance/autosteer, had levels of use higher than newer technologies that remain unproven in their capabilities, such as soil EC mapping. The results reinforce that superior knowledge and information are decisive in the process of adopting technologies in agriculture [3].

Results also showed a significant difference between the level of the use of communication channels by soybean farmers as well as the heterogeneity in the farmers’ adoption and perceptions of precision technologies [7]. Websites and blogs had the highest average among mass media, while newspapers had the lowest mean, which is in line with the rapid growth of the Internet. LinkedIn stands out in the survey as the most influential in soybean farmers’ decision making among social media groups such as WhatsApp and Instagram.

The two channels with the highest means were field days and conferences, forums, and seminars among the interpersonal meeting group. These kinds of events typically provide educational opportunities for producers seeking knowledge in crop production and farm management. The results suggest that in-person activities still have relevance, but social media has grown important to farmers. In addition, the study suggests that adopters of established decisions regarding precision agriculture tend to prioritize in-person connections. In contrast, adopters of emergent technologies tend to prefer social media.

At the same time, this study provides a glance at farmers’ behavior during the COVID-19 pandemic in Brazil. The country had, by far, the highest overall death toll in Latin America and the second highest in the world after the United States. The findings indicated that the pandemic accelerated a digital revolution in agriculture, with farmers more willing to adopt new technologies.

The results are helpful for agricultural companies by offering essential insights into current farmers’ behavior regarding the adoption of new technologies. The study can help examine the strategies for the generation and dissemination of information about digital technologies on soybean production and then contribute in a practical way to increase knowledge about the best use of communication channels. The study’s findings are also
crucial for the farmers themselves and other stakeholders because they can build closer relationships to improve the adoption of innovations rapidly growing around the globe. Based on this research, it can be suggested that agricultural companies, farmers, policymakers, and stakeholders focus on the vital role of communication in disseminating new technologies. Superior knowledge based on information is the first step toward spreading all-new technology in agriculture. If information about a new product does not reach the farmer clearly and accurately, it is less likely to be adopted.

However, when interpreting these results, it is crucial to remember that they are contingent upon our sample, representing 461 soybean farmers in Brazil’s top five soybean-producing states. Therefore, caution should be exercised when extrapolating or generalizing the results presented here to all soybean farmers in Brazil. Another limitation is data collection, which was carried out entirely online due to the pandemic period in Brazil. So, the results may have a bias influenced by the profile of online respondents, who are usually more adept at innovations.

In addition, the presented study did not evaluate the causal relationship between the use of technologies and the level of influence of communication channels. Future research could fill this gap, which in turn could be expanded to a deeper analysis of Brazilian soybean farmers’ behavior regarding technologies adoption in Brazil and the influence of communication channels.

As a recommendation for future research, we suggest the opportunity to reproduce this study in other relevant countries in soybean production, such as the United States and Argentina. The reproduction of this research in these countries would make it possible to compare data from players leading the adoption of technologies in agriculture globally. In addition, we suggest adding new social media in future studies, such as TikTok, a video-sharing social media app launched in 2017 and consolidated in its global audience nowadays with millions of new users.

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