FATORES DETERMINANTES DA ADOÇÃO DE TECNOLOGIAS DE AGRICULTURA DE PRECISÃO POR PRODUTORES DE GRÃOS

Determining factors in the adoption of precision agriculture technologies by grain producers

Factores determinantes en la adopción de tecnologías de agricultura de precisión por parte de los productores de granos

DOI: 10.48075/igepec.v28i1.32166

Deny Carolina Garcia
Universidade Federal da Grande Dourados

Leonardo Soares Cangirana
Universidade Federal da Grande Dourados

Ricardo Guimarães de Queiroz
Universidade Estadual de Mato Grosso do Sul

Régio Marcio Toesca Gimenes
Universidade Federal da Grande Dourados

FATORES DETERMINANTES DA ADOÇÃO DE TECNOLOGIAS DE AGRICULTURA DE PRECISÃO POR PRODUTORES DE GRÃOS

Determining factors in the adoption of precision agriculture technologies by grain producers

Factores determinantes en la adopción de tecnologías de agricultura de precisión por parte de los productores de granos

Deny Carolina Garcia[1]
Leonardo Soares Cangirana[2]
Ricardo Guimarães de Queiroz[3]
Régio Marcio Toesca Gimenes[4]

Resumo: A adoção de tecnologias de agricultura de precisão (PAT) tem contribuído significativamente para o desenvolvimento de uma agricultura mais sustentável, com maior utilização de insumos, redução de custos e aumento de produtividade. Além disso, as informações provenientes dos relatórios gerados por meio dessas tecnologias permitem que os agricultores administrem suas propriedades de forma mais eficiente. Apesar dos benefícios para a gestão da produção e utilização dos insumos, muitos agricultores ainda não utilizam tecnologias de agricultura de precisão em suas propriedades ou as utilizam apenas parcialmente. O objetivo deste estudo é investigar a percepção dos agricultores sobre o uso do PAT e determinar quais fatores influenciam a adoção do PAT. Para tanto, foram entrevistados 133 produtores de soja de diferentes estados do Brasil. A regressão logística múltipla foi utilizada para construir o modelo estimado (MA2). O nível de escolaridade, a experiência do produtor, a área plantada com milho e os órgãos governamentais como fonte de informação têm influência estatisticamente significativa na adoção do PAT.

Palavras-chave: Agricultura 4.0. Agronegócios. Fatores condicionantes. Inovação. Tecnologia.

Abstract: *The adoption of precision agriculture technologies (PAT) has contributed significantly to the development of a more sustainable agriculture with a greater use of inputs, cost reduction, and increased productivity. Also, information arising from reports generated using these technologies allows farmers to manage their property more efficiently. Despite the benefits to the management of production and use of inputs, many farmers still do not use precision agriculture technologies on their property or use them only partially. The objective of this study is to investigate the farmers' perception about the use of PAT and determine which factors influence adoption of PAT. To this end, 133 soy producers from different states of Brazil were interviewed. Multiple logistic regression was used to build the estimated model (MA2). Education level, producer experience, planted area with maize, and government agencies as a source of information have a statistically significant influence on the adoption of PAT.*

Keywords: *Agriculture 4.0. Agribusiness. Conditioning factors. Innovation. Technology.*

Resumen: *La adopción de tecnologías de agricultura de precisión (PAT) ha contribuido significativamente al desarrollo de una agricultura más sostenible con un mayor uso de insumos, reducción de costos y aumento de la productividad. Además, la información que surge de los informes generados utilizando estas tecnologías permite a los agricultores administrar sus propiedades de manera más eficiente. A pesar de los beneficios para la gestión de la producción y el uso de insumos, muchos agricultores todavía no utilizan tecnologías de agricultura de precisión en sus propiedades o las utilizan sólo parcialmente. El objetivo de este estudio es investigar la*

[1] Universidade Federal da Grande Dourados (UFGD). E-mail: denycarolina@hotmail.com
[2] Universidade Federal da Grande Dourados (UFGD). E-mail: lscangiranasoares@gmail.com
[3] Universidade Estadual de Mato Grosso do Sul (UEMS). E-mail: rgq7@yahoo.com.br
[4] Universidade Federal da Grande Dourados (UFGD). E-mail: regiogimenes@ufgd.edu.br

percepción de los agricultores sobre el uso de PAT y determinar qué factores influyen en la adopción de PAT. Para ello se entrevistó a 133 productores de soja de diferentes estados de Brasil. Se utilizó regresión logística múltiple para construir el modelo estimado (MA2). El nivel de educación, la experiencia del productor, el área plantada con maíz y las agencias gubernamentales como fuente de información tienen una influencia estadísticamente significativa en la adopción del PAT.

Palabras clave: *Agricultura 4.0. Agronegocios. Factores condicionantes. Innovación. Tecnología.*

INTRODUCTION

The adoption of new technologies in agriculture has been fundamental in contributing to the improvement of use of resources and increased productivity (WATANABE *et al.*, 2023). They allow establishing production standards (ANTOLINI, 2015), increasing labor productivity and total factor productivity and establishing links from the beginning to the end of the cycle, which exerts an important effect on the sustainability of activities (SOUZA FILHO *et al.*, 2011). As a consequence of productive efficiency, reduced costs and increased productivity reflect in economic and financial gains for rural activity (DUTRA; AREND, 2015; ANTOLINI, 2015; SOUZA FILHO *et al.*, 2011).

Among the different technological innovations in agriculture, there are PAT. Their focus is on managing the crop spatial variability carried out through a range of technologies that make it possible to reduce the use of inputs and consequently benefit the environment (CIRANI; MORAIS, 2010).

PAT allow the adoption of a production system similar to what occurs with Industry 4.0 (REIS *et al.*, 2020). They help to optimize management, cultivation and use of agricultural inputs, providing economic gains through increased productivity and efficiency. PAT also promote sustainability of agricultural production and a considerable reduction in the environmental impact of this activity (MAPA, 2013; REIS *et al.*, 2020). In addition, the use of PAT makes it possible to improve the way production is managed and provides multidimensional benefits for producers and consumers (MAPA, 2013; TAMIRAT *et al.*, 2018).

However, the adoption of such technologies in Brazilian agriculture occurs in a very heterogeneous way (OLIVEIRA; RODRIGUES, 2020; ROSSONI *et al.*, 2021), which reflects the diversity of sociocultural contexts (SOUZA FILHO *et al.*, 2011). It is possible to observe differences in the mechanization of farming, such as those between producers of different crops, such as a producer of soybeans and another of vegetables, as well as between producers who cultivate a same product (ANTOLINI, 2015).

In addition, there are inequalities in PAT adoption between the regions of Brazil (DELGADO, 2005), types of crop, and agriculture sector (family or employer) (SOUZA FILHO *et al.*, 2011). Such heterogeneity may be related to several factors, including availability of resources, access to the market, and a capacity to generate and accumulate income (BUAINAIN *et al.*, 2003).

The non-adoption of PAT may also be related to difficulties faced by farmers in understanding the tools and how to implement them in their fields (SENAR, 2021). In addition, the decision on whether or not to adopt a new technology is directly related to the advantage it is capable of generating, that is, producers expect a return in both economic terms and productivity gains, cost reduction, and environmental preservation to then decide on investing in a certain technology (ANTOLINI, 2015; THOMPSON *et al.*, 2019).

Studies on rural economics and sociology have shown several determinants of technology adoption and diffusion. The most common are property size, risk and uncertainty, human capital, form of ownership over the land (leasing, partnership, property rights), availability of credit, labor, and other inputs (SOUZA FILHO *et al.*, 2011).

The issue of the importance of technology in improving production efficiency is widely debated considering that optimizing the use of natural resources is a challenge that may cause major structural changes in farms. It is likely that, in the future, rural properties will be monitored and automated on a large scale. This technological revolution is part of an interconnected ecosystem in which technology, security, economic growth, the environment, and sustainability are intertwined (MASSRUHÁ, 2015).

To encourage the adoption of technologies in agriculture, it is important that public policies are not limited to providing affordable credit and replicating existing rural extension services. Instead, such policies need to take into account the context of vulnerability of rural producers, prioritizing basic issues such as education and technical assistance and the development of secure markets that can reduce the risks inherent to innovation (SOUZA FILHO *et al.*, 2011).

Therefore, in order to provide information that supports the understanding of public and private agents about the perception of farmers about the adoption of PAT, this study aims to identify the determining factors for the adoption of PAT by grain producers. A multiple logistic regression model was used to understand the influence of producer and farm characteristics on the adoption of PAT.

2 – LITERATURE REVIEW

PA (precision agriculture) is an "agricultural management system based on the spatial and temporal variation of the productive unit and aims to increase economic return and sustainability and minimize the negative effect on the environment" (BRASIL, 2012, p. 6). It is a comprehensive approach to farm management. It aims to increase profitability and sustainability, improve product quality, manage pests, and conserve the environment (WATANABE *et al.*, 2023; GRISSO *et al.*, 2005), in addition to contributing to food security, quality of life on the farm, and rural economic development (ROBERT, 2002).

PA techniques have been widely disseminated and used worldwide to increase crop production and improve the economic and sustainability results of the system (BONGIOVANNI; LOWENBERG-DEBOER, 2005), mainly of grain crops (BRAMLEY, 2009). This is because new technologies that have been created for agriculture allow access to differentiated information, which enables more precise observations about the existing differences in production that were previously imperceptible and neglected (PIRES *et al.*, 2004).

It is important to make it clear that one should not understand PA only as the adoption of a set of machines and technological equipment for an efficient management of production (PIRES *et al.*, 2004), but rather as a broader concept that has the management of the spatial variability of production areas as its key element (MOLIN *et al.,* 2015). Thus, for the purposes of this study, we adopted the term PAT for the set of technologies that are used to employ PA (PIRES *et al.*, 2004).

In recent years, there has been a great effort by some entities to publicize PA in Brazil. However, it cannot be stated clearly how much the adherence to these technologies has advanced. This situation stems from the fact that the way of understanding PA differs from the ideal goal and the distance from the end goal, which involves increasing the economic and environmental return of crops, which is achieved through the management of spatial variability (INAMASU *et al.*, 2011).

Although producers are increasingly willing to use new technologies (KERRY *et al.*, 2017), the diffusion of PAT is still not uniform, that is, it does not occur at the same speed and intensity among different regions and producers (SOUZA FILHO *et al.*, 2011). It is possible to observe greater technological advances in agriculture in the South, Southeast, and Midwest regions of Brazil, while in the

North and Northeast regions modernization occurs more slowly (DELGADO, 2005).

The heterogeneity of Brazilian agriculture, in both the use of technology and predominant work relations, has deepened mainly from the 1960s onwards. The beginning of the process of technical modernization of agriculture, characterized by a significant change in the technical standard of the rural sector, was leveraged by the growing presence of industrial inputs and agricultural machinery (DELGADO, 2005).

Among the group of potential PAT adopters, even though economic gains and other benefits with the use of these technologies have already been identified, adoption levels have been low. Farmers who do not adopt PAT are generally producers who have been in the field of agricultural production for a longer time and who prefer to rely on their knowledge of topology (BARNES *et al.*, 2019b).

Economic constraints, although initially seeming to influence the decision to adopt an advanced technology, are not, by themselves, able to fully explain this process. To understand the motivations and obstacles to technological innovation, it is necessary to analyze each case individually (SILVA *et al.*, 2010; SOUZA FILHO *et al.*, 2011).

The adoption of PAT requires farmers to change their agricultural practices, which are often historical (KENDALL *et al.*, 2022). In this context, adoption potentially depends on the level of behavioral change required from the adopter, which may range from a disruptive change, requiring a great effort to change behavior, to an incremental evolution, offering complementary benefits to practices already adopted (HASLER *et al.*, 2017).

Since PAT is a complex set of technologies, it is necessary to take into account that the acceptance of technologies must be studied from the perspective of the adoption of innovations based on the studies of Ryan & Gross (1950) to reach a full understanding. The authors studied the acceptance of using a hybrid corn seed and were the forerunners of this type of research. The results showed an acceptance curve in the diffusion pattern and listed several determining factors, such as size of the agricultural company, education level, age, participation in the community, influence of suppliers and sellers, type of technology, and distance from the farm to the city.

In general, studies on adoption focus on the determining factors that affect an individual's decision to use or not a technology. Such factors basically refer to three primary factorial influences (internal, external, and technological), in addition to geographic region (KENDALL *et al.*, 2022).

Souza Filho *et al.* (2011) classify the factors that may influence the decision to adopt technologies into four sets according to the nature of the variables: 1) socioeconomic characteristics and condition of the producer, 2) production and rural property characteristics, 3) technology characteristics, and 4) systemic factors.

Tey & Brindal (2012) identified 34 significant factors that explain decision-making on the adoption of PA technologies and grouped them into seven categories, according to the characteristics of the studied variables. The categories are (1) socioeconomic factors, (2) agroecological factors, (3) institutional factors, (4) information sources, (5) farmer perception, (6) behavioral factors, and (7) technological factors.

For Robert (2002), the types of challenges that limit a broader adoption of technology can be classified into three groups: socioeconomic, agronomic, and technological. Socioeconomic barriers are those that mainly involve costs and lack of skills.

Agronomic challenges are related to lack of basic information, inadequate sampling and scouting procedures, absence of site-specific fertilizer recommendations, misuse of information, and lack of qualified agronomic services. Technological barriers, on the other hand, are related to the misuse of equipment (generally due to lack of operator training), difficulty in analyzing the information generated, among others (ROBERT, 2002).

The emergence of increasingly sophisticated technologies may further accentuate the heterogeneity of PA adoption, as they will likely increase the need for capital for their adoption, which may mean that only a small portion of farmers may have access to them. The lack of resources and the low level of capitalization, in this case, is still a major obstacle to adoption (BUAINAIN *et al.*, 2002).

3 – METHODOLOGICAL PROCEDURES

This study uses data from rural producers with properties located in different States of Brazil. The discussions concentrate on the variables proposed by the literature and used in recent studies on technology adoption.

The producer's profile was determined considering several variables, such as age, education level, percentage of income from rural activities, length of experience, participation in associations and cooperatives, and sources of information. In addition, the characterization of the property takes into account data such as the size of the cultivated area.

The identified dependent variable is the adoption of PAT (APAT). The term "precision agriculture technologies" was adopted in this research to represent any PA equipment. When answering that a producer is a PAT adopter, the farmer may be a user of only one technology or several of them.

The study sample consists of 133 rural producers who were invited to contribute to the study. Data collection was performed using an online self-explanatory questionnaire. Producers who contributed to the study were contacted by telephone, WhatsApp messages, or email. Also, as part of the data collection, farmers and companies in the agricultural sector were asked to contribute to publicizing and convincing their customers and partners to participate in the research. Therefore, the sample is non-probabilistic. Data were entered and stored in Microsoft Excel® and subsequently analyzed using SAS software (Statistical Analysis Software), version 9.4.

Associations between categorical variables were tested using non-parametric tests, Chi-square or Fisher's exact test. To test differences between groups, the Mann-Whitney test was applied. The variable APAT (dependent) was modeled using a multiple logistic regression model. For producers who adopt some precision agriculture technology, the APAT variable was coded as 1 (one), otherwise as 0 (zero).

Among the measured indicators, the independent variables to be incorporated into the model were suggested by the literature, by descriptive analysis, and by a correlation matrix. To select the variables to be retained from the model, first simple logistic regression models were fitted and, subsequently, the multiple logistic regression model was used. Only the variables that presented a p-value ≤ 0.20 were tested with multiple logistic regression (HOSMER; LEMESHOW, 2005). The best combination of independent variables to be incorporated into the model was selected by the stepwise method.

4 – RESULTS

Of the 133 respondents, 42 did not adopt any PAT in the 2021/22 harvest and 91 adopted at least one precision agriculture technology. The farmers interviewed are aged between 19 and 71 years, an average of 46.36 years and standard deviation (SD) of 13.54, with the majority (47.37%) belonging to the age group of 30 to 49 years, which is consistent with the share of 37.59% who already have more than 20 years of experience.

Almost half of the producers (47.36%) have complete undergraduate level and 50.76% stated that their main source of income is the rural activity. Most of these farmers participate in cooperatives (72.18%), unlike associations, whose percentage of participation by farmers is only 21.05%.

Of the variables related to producer characteristics, only age did not show a significant association with the APAT variable (p-value = 0.3954). Thus, it can be inferred that the farmer's age is not a predictor of PAT adoption. On the other hand, the producer's education level and experience time were significant (p= 0.0001 and p= 0.0027, respectively).

The descriptive analysis suggested that having a diversified income, not depending solely on agriculture, contributes to the adoption of PAT. More than half of the producers who adopt PAT (56.67%) have some activity parallel to agriculture.

Regarding the area cultivated with soybeans, more than half (55.22%) of the producers cultivate less than 1,000 hectares. Only 23.88% of the producers cultivate areas equal to or greater than 3,000 hectares. Areas cultivated with maize, with extensions below 1,000 hectares, account for 57.37% of all cultivation. Just over a quarter (27.40%) of the producers work with another crop in the off-season. Sorghum is the most cultivated off-season crop (43.24%). 74.44% of the producers interviewed are large companies, 20.30% are medium-sized, and only 5.26% are small-sized companies.

There was a significant association (p= 0.0001) between the producer size and the adoption of PAT. The greater the size of the producer, the greater the adoption of PAT. While 85.71% of small producers and 70.37% of medium producers have not adopted PAT, 82.83% of large producers have adopted some PAT.

Among the sources of information investigated, “producers' cooperative” was the only one that showed a significant association, being used by 75.82% of adopters. The means of communication “field day” (p= 0.0001), “fairs and events” (p= 0.0079), “lectures” (p= 0.0001), “television” (p= 0.0012) and “supplier websites” (p= 0.0045) were also significant in relation to the APAT variable. Other sources of information and means of communication were investigated; however, the results were not significant.

Most producers who adopted PAT (82.42%) used their own resources to purchase equipment or services (p= 0.0407). The use of government credit lines is also quite frequent, but there was no significant association (p=0.0588). Both producers who adopted PAT and those who did not avoided borrowing from producer cooperatives (p= 0.0278).

4.1 – STATISTICAL ANALYSIS – ESTIMATED MODEL

To analyze the relationship between the dependent variable (APAT) and the independent variables, multiple logistic regression was used. Chart 1 lists the explanatory variables, selected based on the associations suggested by the descriptive analysis (Fisher's exact test) suggested by the literature review.

Chart 1 – Explanatory variables (independent) retained after Fisher's exact test ($p \leq 0.2000$)

Code	Description	Code	Description
APAT	Adoption of PA techniques	Source_5_1_6	Technical assistance and rural extension
Age	Producer age	Source_5_1_7	Government Bodies
School	Education level	Communication_6_1_2	Field day
T_producer	Producer experience	Communication_6_1_5	Fairs and events
Soybean	Soybean planted area	Communication_6_1_6	Talks
Maize	Maize planted area	Communication_6_1_7	Television
Pmean_soy	Mean soybean production	Communication_6_1_8	University publications
Pmean_maize	Mean maize production	Communication_6_1_11	Supplier websites
Passociation	Product share in associations	Financ_7_1_1	Own resources
Source_5_1_2	Manufacturer's sales rep. technician	Financ_7_1_3	Government funding
Source_5_1_5	Producer cooperative	Financ_7_1_5	Producer cooperative

Source: Prepared by the authors (2023).

4.1.2 - Interpretation of the Estimated Model (MA2)

Thus, the retained model is expressed in the equation below:

$$p\hat{}=1/(1+ e\hat{}(-()-11,55 + 2,99(Escola)+ 1,12(T\_produtor)+ 0,0074(Milho)- 4,50(Órgão))$$

Where:
– if $P (Y = 1) > 0.5$ then APAT = 1 (the producer adopted some PAT);
– if $P (Y = 1) < 0.5$ then APAT = 0 (the producer has not adopted any PAT).

The result of multiple logistic regression analysis (MA2) indicated four variables that explained the adoption of PAT among the farmers in the sample, namely education level, producer experience, maize planted area, and government agencies as a source of information. It is observed that the higher the education level, the greater the chances that the producer has to adopt some PAT. A producer with higher education is up to 20 times more likely to adopt PAT (OR = 20.07) than a producer who has incomplete primary education. An increase of five years in the producer's experience increases by up to three times the chance of the producer adopting PAT. Although, in the exploratory analysis, there was no significant association ($p=0.0778$) between the variable “sources of external information: government agencies (Embrapa, Senar)” and adoption of PAT, the variable acted as a moderating factor in the model ($p=0.0023$), that is, this variable exerted an amplifying effect among the other explanatory variables and the dependent variable APAT (Table 1).

Table 1 – Odds ratio (OR) and respective confidence intervals (α= 0.05) for the variables retained in the model (MA2)

Variable	**OR**	**CI 95%**	
Education level	20.07	3.717	108.36
Producer experience	3.07	1.270	7.44
Maize planted area	1.00	1.003	1.01
Source: government agencies	0.01	0.001	0.20

Source: Prepared by the authors (2023).

5 – DISCUSSION

In general, younger farmers tend to use PAT more perhaps because they are more familiar with technological innovations (BARNES, 2019a), unlike farmers over 50 who are potentially more likely not to adopt them. Roberts *et al.* (2004), Tamirat *et al.* (2018), Paudel *et al.* (2021) and Vecchio *et al.* (2020a) found similar evidence. Chances of adoption decrease after the age of 65 (BARNES *et al.*, 2019a), possibly because farmers perceive themselves to have a shorter work horizon (LAMBERT *et al.*, 2015; MILLER *et al.*, 2017).

Although age is often related to the adoption of PAT, the results of the model estimated in this study did not show a significant relationship between the variable age and the adoption of PAT. This result is similar as those found by Vecchio *et al.* (2020a), Paustian and Theuvsen (2017), and Barnes *et al.* (2019a).

As for the farmer's education level, the descriptive analysis showed a strong influence of education level on the adoption of PAT, which was confirmed in the MA2 model. The literature on the adoption of PAT presents controversial results related to this variable. For Li *et al.* (2020), Paustian and Theuvsen (2017), Barnes *et al.* (2019a) and Tamirat *et al.* (2018), there is no significant difference in the adoption of PAT in terms of the producer's educational experience. However, Vechio *et al.* (2020b) noticed a greater adoption of PAT among farmers with postgraduate degrees.

Expertise in farm management is essential for the adoption of PAT (ROBERTS *et al.*, 2004; PAUSTIAN; THEUVSEN, 2017), which is why the farmer's experience time is evaluated as a possible predictive factor for the use of new technologies. This study concludes that more experienced farmers tend to adopt PAT, especially those with more than 20 years of experience, corroborating the results of Paustian and Theuvsen (2017), Daberkow and McBride (2003) and Roberts *et al.* (2004). On the other hand, Paustian and Theuvsen (2017) reported controversial data. The authors noticed a high demand for PAT by producers with less than five years of experience.

Farmers tend to use multiple sources of information about PAT (VELANDIA *et al.*, 2010), and those who spend more time searching for information are more likely to adopt some technology (VECCHIO *et al.*, 2020a). Only the "producers' cooperative" source of information was significantly associated with the adoption of PAT in this study. The research by Blasch *et al.* (2021) identified that farmers most often turn to neighboring producers for information on PAT. However, the variable "other producers" had no significant effect in this study.

Actions such as "talks", "field day" and "event fairs" are examples of means of communication that contribute to the adoption of PAT. These channels showed significant associations in this study, as demonstrated by descriptive analysis. In addition to the aforementioned events, “television” and “supplier websites” also showed significant results. Contrary to the findings of Paudel *et al.* (2021), there was no significant relationship between the variable “university publications” and the adoption of PAT.

For most farmers who depend on farm income, the expected profitability is enough to keep them in business (SWINTON; LOWENBERG-DEBOUR, 2001). The results of this study show that farmers who count their agricultural property as their only source of income are less likely to adopt PAT. More than half of farmers who do not adopt PAT (66.67%) have virtually all of their income (more than 80%) from agriculture.

The extra income generated outside the property can be useful in providing the necessary resources for adoption (SOUZA FILHO *et al.*, 2011). Another point is that the diversification of the professional activity can better inform farmers. However, Daberkow & McBride (2003) and Paustian & Theuvsen (2017) realized that full-time agriculture generates a positive impact on the adoption of PAT.

As for the variables related to the farm characteristics, the amount of cultivated land was significant (p = 0.0001) for the adoption of PAT. Small-scale producers tend to be more cautious about investments in technology mainly due to the high cost of acquiring equipment and training (BALOGH *et al.*, 2021), while producers with larger land areas are more likely to adopt it. Most small producers (85.71%) and medium-sized producers (70.37%) who responded to this survey do not adopt PAT. Meanwhile, 82.83% of large farmers are adopters. Such results are similar as the empirical findings of Paudel *et al.* (2021), Kolady *et al.* (2020), Blasch *et al.* (2021), Paustian & Theuvsen (2017), Vecchio *et al.* (2020b), Tamirat *et al.* (2018).

Despite this, a large producer will not necessarily be a PAT adopter. Perhaps producers in large areas are already achieving optimal levels of production and profitability even without the use of precision technologies (ANTOLINI, 2015). Even owners of large areas of land, despite having wide access to knowledge about development and innovation opportunities, do not intend to adopt PAT as they understand that their adoption could result in a significant investment with inadequate return. This is even more discouraging in large properties, with high quality and homogeneous land (BALOGH *et al.*, 2021).

Farmers who cultivate smaller areas and are interested in PAT report that area size delays the return on investment and expect that the technology will become cheaper as it becomes popular; then, viability increases (BALOGH *et al.*, 2021). Cooperation and collaboration between farmers, in this case, could enable adoption (BALOGH *et al.*, 2021).

Both the size of the area planted with soybeans and maize showed a significant association (p=0.0001). However, only the variable “maize planted area” was incorporated into the MA2 model. The fact that the cultivation of off-season maize is more strongly related to the adoption of PAT may be due to the risk associated with this crop since the window for planting off-season maize is short, requiring from the producer a greater agility in harvesting of soy (which precedes it) and applying inputs. At this point, PAT present considerable benefits to adopters (ANTOLINI, 2015). This may also be related to an economy of scale and cost reduction, allowing for a better return on investment (BARNES *et al.*, 2019a).

CONCLUSIONS

PAT have been introduced with the aim of increasing productivity, promoting an efficient use of inputs, and contributing to the environment and food security. Many countries have invested in research to understand how the process of adopting these technologies takes place, so that they can serve the most diverse agricultural business models. The objective of this study was to identify the conditioning factors for the adoption of PAT by soybean and corn producers, taking as a first step the characterization of the rural producer, the farm, and the sources of information used.

The adjustment of the multiple logistic regression model (MA2) showed that the adoption of PAT can be explained by four variables: education level, experience time, maize planting area, and government agencies. The results of the adjusted model allow us to infer that the adoption of PAT is, in some way, related to the profile of the farmer. Although age does not seem to be a predictor of adoption, the tendency is for younger farmers to be more likely to adopt PAT. This is possibly because they have a greater affinity with technologies in general and because they belong to a generation with greater access to undergraduate and specialization courses.

The relevance of maize planting area for the adoption of PA may indicate that the cultivation of maize in the off-season generates a probable gain in scale, in addition to helping to dilute the costs with the technology. However, this theme was not investigated in depth here. Studies on the relevance of the crop adopted in the off-season for the adoption of PA may be interesting to better understand the influence of this variable on the adoption of PA.

It is important to point out that the PAT investigated here were analyzed from a generalist perspective. Farmers were asked about the use of PAT without having been classified by groups according to type, such as intensive information technologies and embedded knowledge, or other sets.

Due to costs, time limit, and issues related to the coordination of collecting information in the field, this research used data from a non-probabilistic sample. Therefore, the results of this study cannot be generalized. It is recommended that other studies be carried out using random samples to fill this gap.

REFERENCES

ANTOLINI, L. S. Condicionantes de adoção de agricultura de precisão por produtores de grãos. 2015. 106 p**. Dissertação** (Mestrado em Ciências) – USP - Universidade de São Paulo, Ribeirão Preto, 2015. Disponível em: https://www.teses.usp.br/teses/disponiveis/96/96132/tde-22022016-170917/publico/LeonardoSAntolini_Original.pdf . Acesso em: 04 nov. 2022.

BALOGH, P.; BAI, A.; CZIBERE, I.; KOVÁCH, I.; FODOR, L.; BUJDOS, Á.; SULYOK, D.; GABNAI, Z.; BIRKNER, Z. Economic and social barriers of precision farming in Hungary. **Agronomy**, v. 11, n. 6, 2021. https://doi.org/10.3390/agronomy11061112

BARNES, A. P.; SOTO, I.; EORY, V.; BECK, B.; BALAFOUTIS, A.; SÁNCHEZ, B.; VANGEYTE, J.; FOUNTAS, S.; VAN Der WAL, T.; GÓMEZ-BARBERO, M. Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. **Land Use Policy**, v. 80, p. 163-174, 2019a. https://doi.org/10.1016/j.landusepol.2018.10.004

BARNES, A. P.; SOTO, I.; EORY, V.; BECK, B.; BALAFOUTIS, A. T.; SÁNCHEZ, B.; VANGEYTE, J.; FOUNTAS, S.; VAN Der WAL, T.; GÓMEZ-BARBERO, M. Influencing incentives for precision agricultural technologies within European arable farming systems. **Environmental Science and Policy**, v. *93*, p. 66-74, 2019b. https://doi.org/10.1016/j.envsci.2018.12.014

BLASCH, J.; VUOLO, F.; ESSL, L.; VAN Der KROON, B. Drivers and barriers influencing the willingness to adopt technologies for variable rate application of fertiliser in lower Austria. **Agronomy**, v. 11, n. 10, 2021. https://doi.org/10.3390/agronomy11101965

BONGIOVANNI, R.; LOWENBERG-DeBOER, J. Precision agriculture in Argentina. In: ***3 Simpósio Internacional de Agricultura de Precisão,*** pp. 16-18, 2005. https://www.cnpms.embrapa.br/siap2005/palestras/SIAP3_Palestra_Bongiovanni_e_LDB.pdf

BRAMLEY, R. G. Lessons from nearly 20 years of precision agriculture research, development, and adoption as a guide to its appropriate application. **Crop and Pasture Science**, v. 60, n. 3, p. 197-217, 2009. https://doi.org/10.1071/CP08304

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento (2012). Portaria nº 852 - Art. 1º Criar a comissão brasileira de agricultura de precisão – CBAP. **Diário Oficial da República Federativa do Brasil**, Brasília-DF, 1(184). https://www.cnpt.embrapa.br/biblio/do/p_do42.htm

BUAINAIN, A. M.; SOUZA FILHO, H. M.; SILVEIRA, J. D. Agricultura familiar e condicionantes da adoção de tecnologias agrícolas. **Inovação nas tradições da agricultura familiar**. Brasília, CNPq/Paralelo, 2002.

BUAINAIN, A. M.; SILVEIRA, J. M.; MAGALHÃES, M. M.; ARTES, R.; SOUZA FILHO, H. M. Estudo de avaliação de impactos do programa Cédula da Terra. **Unpublished Report**. Ministry of Agrarian Development, Brasília, Brasil, 2003.

CIRANI, C. B. S.; MORAES, M. A. F. D. D. Inovação na indústria sucroalcooleira paulista: os determinantes da adoção das tecnologias de agricultura de precisão. **Revista de Economia e Sociologia Rural**, v. 48, p. 543-565, 2010.

DABERKOW, S. G.; McBRIDE, W. D. Farm and operator characteristics affecting the awareness and adoption of precision agriculture technologies in the US. **Precision Agriculture**, v. 4, p. 163-177, 2003.

DELGADO, G. C. (2005). **A questão agrária no Brasil**, 1950-2003. Questão social e políticas sociais no Brasil contemporâneo. Brasília: IPEA, 51-90. https://edisciplinas.usp.br/pluginfile.php/126539/mod_resource/content/2/Guilherme%20%20Delgado%20Quest%C3%A3o%20Agr%C3%A1ria.pdf

DUTRA, J. A. A.; AREND, S. C. Tecnologia da informação e desenvolvimento agrícola regional: estudo de caso em Balsas/MA. **Informe GEPEC**, v. 19, n. 2, p. 23-40, 2015.

GRISSO, R. D.; ALLEY, M. M.; McCLELLAN, P.; BRANN, D. E.; DONOHUE, S. J. Precision farming. A comprehensive approach. **Virginia Tech**. p. 442-500, 2005. https://vtechworks.lib.vt.edu/bitstream/handle/10919/51373/442-500.pdf?sequence=1&isAllowed=y

HASLER, K.; OLFS, H. W.; OMTA, O.; BRÖRING, S. Drivers for the adoption of different eco-innovation types in the fertilizer sector: a review. **Sustainability**, v. *9, n.* 12, 2017. https://doi.org/10.3390/su9122216

HOSMER JR, D. W.; LEMESHOW, S.; STURDIVANT, R. X. Applied logistic regression. **John Wiley & Sons**, v. 398, 2013.

INAMASU, R. Y.; BERNARDI, A. D. C.; NAIME, J. D. M.; QUEIROS, L. R.; de RESENDE, A. V.; VILELA, M. D. F.; BASSOI, L. H.; PEREZ, N. B.; FRAGALLE, E. P. **Estratégia de implantação, gestão e funcionamento da rede agricultura de precisão**. 2011.

KENDALL, H.; CLARK, B.; LI, W.; JIN, S.; JONES, G. D.; CHEN, J.; TAYLOR, J.; LI, Z.; FREWER, L. J. Precision agriculture technology adoption: a qualitative study of small-scale commercial "family farms" located in the North China Plain. **Precision Agriculture**, v. 1, n. 33, 2022. https://doi.org/10.1007/s11119-021-09839-2

KERRY, R.; INGRAM, B. R.; NAVARRO, F.; ORTIZ, B. V.; SCULLY, B. T. Determining corn aflatoxin risk within counties in Southern Georgia, USA using remotely sensed data. **Advances in Animal Biosciences**, v. 8, n. 2, p. 640-644, 2017. https://doi.org/10.1017/S2040470017000565

KOLADY, D. E.; VAN Der SLUIS, E.; UDDIN, M. M.; DEUTZ, A. P. Determinants of adoption and adoption intensity of precision agriculture technologies: evidence from South Dakota. **Precision Agriculture**, v. 22, p. 689-710, 2021.

LAMBERT, D. M.; PAUDEL, K. P.; LARSON, J. A. Bundled adoption of precision agriculture technologies by cotton producers. **Journal of agricultural and Resource Economics**, p. 325-345, 2015.

LI, W.; CLARK, B.; TAYLOR, J. A.; KENDALL, H.; JONES, G.; LI, Z.; JIN, S.; ZHAO, C.; YANG, G.; SHUAI, C.; CHENG, X.; CHEN, J.; YANG, H.; FREWER, L. J. A hybrid modelling approach to understanding adoption of precision agriculture technologies in Chinese cropping systems. **Computers and Electronics in Agriculture**, v. 172, 2020. https://doi.org/10.1016/j.compag.2020.105305

MAPA – Ministério da Agricultura, Pecuária e Abastecimento. Agricultura de precisão. **Boletim Técnico**. Brasilia: MAPA/ACE, 33ª ed., 36. 2013.

MASSRUHÁ, S. M. F. S. O papel na agricultura. **AgroANALYSIS**, v. *35, n.* 9, p. 29-31, 2015.

MILLER, N. J.; GRIFFIN, T. W.; BERGTOLD, J.; CIAMPITTI, I. A; SHARDA, A. Farmers' adoption path of precision agriculture technology. **Advances in Animal**

Biosciences, v. *8, n.* 2, p. 708-712, 2017. https://doi.org/10.1017/S2040470017000528

MOLIN, J. P.; AMARAL, L. R.; COLAÇO, A. F. **Agricultura de precisão**. São Paulo: Oficina de Textos, 2015. 224 p.

OLIVEIRA, T. J. A.; RODRIGUES, W. Vulnerabilidade e o desenvolvimento das regiões do agronegócio no Brasil (2007/2017). **Informe GEPEC**, v. 24, n. 2, p. 232–248, 2020. DOI: 10.48075/igepec.v24i2.25044

PAUDEL, K. P.; MISHRA, A. K.; PANDIT, M.; SEGARRA, E. Event dependence and heterogeneity in the adoption of precision farming technologies: A case of US cotton production. **Computers and Electronics in Agriculture**, v. 181, 2021.

PAUSTIAN, M.; THEUVSEN, L. Adoption of precision agriculture technologies by German crop farmers. **Precision Agriculture**, v. 18, p. 701-716, 2017.

PIRES, J. L. F.; CUNHA, G. R.; PASINATO, A.; FRANÇA, S.; RAMBO, L. **Discutindo agricultura de precisão** – aspectos gerais, 2004. https://www.infoteca.cnptia.embrapa.br/bitstream/doc/852495/1/pd042.pdf

REIS, Â. V. D.; MEDEIROS, F. A.; FERREIRA, M. F.; MACHADO, R. L. T.; ROMANO, L. N.; MARINI, V. K.; FRANCETTO, T. R.; MACHADO, A. L. T. Tendências tecnológicas no cenário da agricultura digital e seus impactos nas práticas de desenvolvimento de máquinas agrícolas. **Revista Ciência Agronômica**, v. 51, 2020.

ROBERT, P. C. Precision agriculture: a challenge for crop nutrition management. In **Progress in Plant Nutrition**: Plenary Lectures of the XIV International Plant Nutrition Colloquium: Food security and sustainability of agro-ecosystems through basic and applied research, p. 143-149,. Springer Netherlands, 2002.

ROBERTS, R. K.; ENGLISH, B. C.; LARSON, J. A.; COCHRAN, R. L.; GOODMAN, W. R.; LARKIN, S. L.; MARRA, M. C.; MARTIN, S. W.; SHURLEY, W. D.; REEVES, J. M. Adoption of site-specific information and variable-rate technologies in cotton precision farming. **Journal of Agricultural and Applied Economics**, v. 36, n. 1, p. 143-158, 2004.

ROSSONI, R. A.; MORAES, M. L. de; CATTELAN, R. O perfil da modernização da agricultura do Paraná: uma análise de cluster. **Informe GEPEC**, v. 25, p. 29-45, 2021.

RYAN, B.; GROSS, N. (2017). **Acceptance and diffusion of hybrid corn seed in two Iowa communities**. Research Bulletin. Ames: Iowa.

SENAR- Serviço Nacional de Aprendizagem Rural. **Agricultura de Precisão**. 2021. https://www.cnabrasil.org.br/projetos-e-programas/agricultura-de-precis%C3%A3o

SILVA, C. L. da; ZERBATO, C. C.; ROCHA JR, W. F. Agricultura Familiar e Desenvolvimento Paranaense entre 1996 e 2006. **Informe GEPEC**, v. 14, n. 2, p. 39–59, 2010. DOI: 10.48075/igepec.v14i2.3825.

SOUZA FILHO, H. M.; BUAINAIN, A. M.; da SILVEIRA, J. M. F. J.; VINHOLIS, M. D. M. B. Condicionantes da adoção de inovações tecnológicas na agricultura. **Cadernos de Ciência & Tecnologia**, v. 28, n. 1, p. 223-255, 2011.

SWINTON, SCOTT M.; LOWENBERG-DEBOER, J. Global adoption of precision agriculture technologies: who, when and why? In: Proceedings of the 3rd European conference on precision agriculture. **Citeseer**, p. 557-562, 2001.

TAMIRAT, T. W.; PEDERSEN, S. M.; LIND, K. M. Farm and operator characteristics affecting adoption of precision agriculture in Denmark and Germany. **Acta Agriculturae Scandinavica**, *Section B—Soil & Plant Science*, v. 68, n. 4, p. 349-357, 2018. https://doi.org/10.1080/09064710.2017.1402949

TEY, Y. S.; BRINDAL, M. Factors influencing the adoption of precision agricultural techologies: a review for policy implications. **Precision agriculture**, v. 13, p. 713-730, 2012. https://doi.org/10.1007/s11119-012-9273-6

THOMPSON, N. M.; BIR, C.; WIDMAR, D. A.; MINTERT, J. R. Farmer perceptions of precision agriculture technology benefits. **Journal of Agricultural and Applied Economics**, v. 51, n. 1, p. 142-163, 2019. https://doi.org/10.1017/aae.2018.27

VECCHIO, Y.; AGNUSDEI, G. P.; MIGLIETTA, P. P.; CAPITANIO, F. Adoption of precision farming tools: the case of Italian farmers. **International Journal of Environmental Research and Public Health**, v. 17, n. 3, p. 869, 2020. https://doi.org/10.3390/ijerph17030869

VECCHIO, Y.; DE ROSA, M.; ADINOLFI, F.; BARTOLI, L.; MASI, M. Adoption of precision farming tools: a context-related analysis. **Land Use Policy**, v. 94, 2020a. https://doi.org/10.1016/j.landusepol.2020a.104481

VELANDIA, M.; LAMBERT, D. M.; JENKINS, A.; ROBERTS, R. K.; LARSON, J. A.; ENGLISH, B.; MARTIN, S. W. Precision farming information sources used by cotton farmers and implications for extension. **The Journal of Extension**, v. *48, n.* 5, 2010. https://tigerprints.clemson.edu/joe/vol48/iss5/20

WATANABE, F. A. C.; LEITÃO, F. O.; GUARNIERI, P.; SALIM, O. O. Alinhamento das práticas da produção de soja com a economia circular: um estudo multicasos. **Informe GEPEC**, v. 27, n. 1, p. 123-141, 2023. DOI: 10.48075/igepec.v27i1.29260.

Recebido em 01/11/2023.
Aceito em 22/02/2024.