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Diagnosis about the perspectives of precision applications of coffee growing technologies in municipalities of Bahia, Brazil

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ABSTRACT

Brazil is the largest coffee producer in the world and precision agriculture (PA) is essential for the efficient management of crops. However, one of the challenges is finding the best way to do it. In this sense, we sought to present in this article a diagnosis on the perspectives of Precision Agriculture technologies applicability in the production of coffee (or Precision Coffee Growing) in some municipalities in Bahia, for greater efficiency, economic and environmental sustainability. To achieve this objective, a virtual document was sent to coffee growers in the state of Bahia. The questionnaire was sent by email in 2021 and the WhatsApp application, reaching 457 producers, 34 of whom, from all productive regions of Bahia, responded. The rate of return was 7.4%, within the expected by the use of the application. Considering the return of 34 answered questionnaires, a margin of error of 14% was obtained at a reliability level of 90%. It was found that 59.3% of the respondents have a high prospect of using PA in coffee growing, 26.6% have a medium perspective and 11.1%, a low perspective. The research shows that 67.6% do not use PA in the fields and that 51.7% consider the lack of training as a major obstacle to the use of PA and other digital technologies. Thus, the conclusion is reached that there is a promising scenario in Bahia state for the application of PA in coffee growing, if there is training for the development of techniques in farming.

Key words: Precision agriculture; survey; agribusiness; rural development.

1 INTRODUCTION

Grown in Brazil since the 18th century, coffee is one of the main products consumed in the world, and over the years, it has influenced Brazilian politics and society, especially in producing regions. In the country, the Arabica (*Coffea arabica*) and conilon (*Coffea conephora*), or robusta, are the most cultivated species. Brazil is the world's largest coffee producer (2.8 million T), and its main competitors are Vietnam, Colombia, Indonesia, and Honduras.

In Brazil there are 330,000 producers, 78% of them are small manufacturers, spread across 1,900 municipalities. The total production area is 1.8 million hectares. In 2020, coffee moved more than US$5.6 billion, an increase of 10.3% compared to 2019 statistics (Campo e Negócios, 2021). National coffee production is concentrated in Minas Gerais, Espírito Santo, São Paulo, Bahia, Rondônia and Paraná, however only three of them produce more 90% of Conilon coffee: Espírito Santo, Bahia and Rondônia (Sidra/Instituto Brasileiro de Geografia e Estatística - IBGE, 2021). Used in coffee production areas in Minas Gerais, Conilon is Brazil's biggest produced (1.343 million T of Arabica and 15,848 T of Conilon coffee) and recent surveys show that Precision Coffee is still little known in the country, as in the state of Bahia (89 T of Arabica and 135 T of Conilon coffee), fourth in the ranking of national production (Ibidem/Instituto Brasileiro de Geografia e Estatística - IBGE, 2021).

In Bahia, coffee is of great importance for the state's agribusiness, where the total production area is of 114,287 hectares, of which 73,611 hectares are Arabica, and 40,676 hectares are conilon (Ibidem/Instituto Brasileiro de Geografia e Estatística - IBGE, 2021). According to Assocafé, the state has 16,000 coffee growers. In recent years, Bahia has gained prominence in Brazil for the high quality coffees (above 80 points), finalists or winners in national and global competitions. Bahia advanced in the production of quality coffee, favored by the diversity and the attributes of beans from Chapada Diamantina and Planalto da Conquista (Oliveira; Silva, 2017).

Other producing regions in Bahia follow the same path, such as the West, the new agricultural frontier for coffee production in the state, and the Extreme South, where conilon is planted, whose producers also grow coffees with high-quality specialty. In this context, we have a coffee production in Bahia that stands out in the country due to the high quality of the drink, which is also dedicated to the production of common coffee, sold on the international market.

The fifth most important item in Brazil's export basket, coffee is a product that is directly influenced by the dollar, which leaves the grower at the mercy of price fluctuations in the international market. Therefore, more and more efficiency in production is needed to ensure global competitiveness.

Several variables that influence coffee productivity can be better observed from the PA: the physical and chemical properties of the soil and the plant, the incidence of diseases and pests, the application of inputs, flowering, and fruit maturation. With this, it is possible to bring out the most efficient management of the crop (Ferraz et al., 2013).

At the academy, PA was first registered in 1929, in an experimental field bulletin from the state of Illinois (USA) by researchers Linsley and Bauer, who recommended that the rural producer applied limestone to the soil, with acidity and grid maps (Bernardi et al., 2014). Stanford (2000) says that the spatial variability has been considered for centuries by US farmers, with the observation of the terrain and levels of productivity, without, however, having made maps of these variability.

Introduced in Brazil in the late 1990 by the Brazilian Agricultural Research Corporation (Embrapa), the PA is relatively new there, but it has been increasingly advancing in the field, where technological innovations and science have made the country stop importing food, as it used to be 50 years ago, and today it is one of the main exporters in the world. Embrapa defines PA as a "managerial posture that takes into account the spatial variability of the crop in order to obtain economic and environmental return" (Bernardi et al., 2014). The growing connectivity in the rural environment, in addition to its greater integration with data from sensor systems, equipment, and smartphones have paved the way for new concepts from the so-called Agriculture 4.0 or Digital Agriculture (Bolfe et al., 2020).

In recent decades, the development of research in the agricultural sector has enabled the application of new techniques to produce high quality coffee. Among them is Precision Agriculture (PA), a rural property management model that uses technologies to manage the soil and the inputs at variable rates, with low environmental impact (Embrapa, 1997). The application of PA in the coffee crop is called Precision Coffee (Silva; Alves, 2013).

Therefore, it is necessary for coffee growers to improve production in order to be more efficient and thus remain competitive and sustainable from an economic and environmental point of view. With the tools offered by PA, it is possible to achieve these goals. However, the application of PA depends on the methodology used, which varies from region to region. Over the decades, the concept of PA has been defined by several research authors on the subject, but the key concept for understanding it can be summarized in the comprehending of spatial and temporal variability, combined with the use of different technologies in agricultural production.

Spatial variability refers to a certain moment of production, with precise data on soils, plants, the incidence of pests and diseases, or even the ripening of the fruits. With the data, it is possible to map the variability and manage the crop in an objective way, with water and inputs economy (fertilizers, fertilizers and pesticides), which makes manufacturing more efficient and with a low environmental impact. Temporal variability, in turn, refers to data from one year to another (or from one season to another) regarding the crop, which favors the preparation of comparison maps for analysis of variables (Bernardi et al., 2014).

Davis (1998) says that PA combines the new technologies, sustaining the information age with mature industrial agriculture and tries to match the amount and types of inputs to the objective needs of crops (apud Tschiedel; Ferreira, 2002, p. 160).

In fact, combining new technologies and aligning itself with the cutting-edge industrial agriculture in the information age is what has been happening in PA, which represents a great advance in terms of farm management, when compared to conventional management.

This article aims to evaluate the perspectives of Precision Agriculture technologies in Bahia state coffee farming, for greater efficiency, economic and environmental sustainability, through a virtual questionnaire with producers.

2 MATERIAL AND METHODS

The bibliographical consultation about this article pointed out that the online questionnaire is a viable option to verify the applicability perspectives of the PA in the coffee production areas of Bahia. To achieve the objectives of this article, a list of questions was organized (Table 1) and an online questionnaire was sent to coffee growers in the state, following the methodology proposed by Whipker and Akridge (2009), also used by Bernardi et al. (2014) and Borghi et al. (2016). We sought to know not only the applicability perspectives of PA in coffee production, but also the level of knowledge of farmers on the subject (methods of applicability and benefits), in addition to the demands to be met through the PA and the assessment of connectivity with the Internet.

The number of coffee producers as potential participants in this study was sought from the entities, and they replied that this was done via email or WhatsApp groups. A total of 457 active producers from these entities were informed, 30 from Assocafé, 196 from Coopmac, 90 from Cooperbac, 47 from Coopiatã, 16 from Abacafé, 48 from the Sindicato dos Produtores Rurais de Itabela and 30 from the Sindicato dos Produtores Rurais de Teixeira de Freitas. The primary data obtained for each question and its respective complete answers were consolidated in a report, later exported, and included in a spreadsheet. Subsequently, statistics were generated based on relative and absolute frequency of each of the variables associated with the survey questions.

The questionnaire was sent to the entities and passed on to the coffee growers, and it was available for sending responses between January 25th and March 25th, 2021 in the platform "Google Docs". The questionnaire had 14 questions: 9 multiple-choice (it is possible to select only one option), 4 with check boxes (you can choose more than one option) and a last question, in which information was requested on the size of the production area, location and type of coffee produced (arabica or conilon).

Table 1: Questions sent to coffee producers, Bahia - Brasil (2021).

Questions
What is your level of knowledge about Precision Agriculture?
Based on your level of knowledge, what is Precision Agriculture?
Do you already use PA in your production area?
How long have you been using PA on your rural property?
Do you use any digital technology in coffee production?
In which coffee production management, Precision Agriculture and digital technologies are most important for decision making?
In your opinion, what are the main benefits of PA in coffee growing?
If you know PA, but do not use it in your production area, what is your perspective ofn the use?
Based on your level of knowledge, what are the applicability methodologies of PA in coffee?
Do you have any knowledge about the use of Geostatistics in Precision Coffee Farming?
How do you assess internet connectivity on your rural property?
For which coffee production phase would you like digital technologies to be developed?
What factors do you consider as obstacles to the use of PA and other digital technologies in coffee production?
Please inform the size of your production area, the city where the rural property is located and the type of coffee you grow.

As an acceptability parameter about the minimum number of responses, the methodology of Whipker and Akridge (2008), who in an online survey on PA considered the return rate of 9.6% acceptable, out of 2,500 searched farmers. Following the same methodology, Bernardi et al. (2014) and Borghi et al. (2016) obtained a return rate of 7% for the questionnaire, considered satisfactory for being close to the return rate of Whipker and Akridge (2008). Therefore, this article also considers a minimum rate of return of 7% as satisfactory.

The references of this paper are the publications of the Empresa Brasileira de Pesquisa Agropecuária (Embrapa) about PA (Bernardi et al., 2014), the book Cafeicultura de Precisão Silva and Alves (2013) and academic productions (articles, dissertations, and theses), published in periodicals, digital books and archives of public institutions and private.

3 RESULTS

The results of the Precision Coffee Growing Research (Bittencourt, 2021) present a brief overview of the perspectives on the application of Bahian coffee farming and serve as a means of momentary assessment of the coffee grower's perception of the subject and its demands.In total, 34 coffee producers from all producing regions in Bahia responded to the questionnaire, resulting in a return rate of 7.4%, which exceeds the minimum return rate of 7%, within the methodology used. The profile of the interviewed is vast: there are producers with a production area ranging from 1.5 hectares to 552 hectares. Of the 34 respondents, 23 produce Arabica coffee, 4 produce conilon and 7 of them did not answer what type of coffee they produce.

Interviewed who produce Arabica coffee are from the municipalities of Vitória da Conquista, Barra do Choça, Encruzilhada, Poções, Planalto, Cândido Sales, Piatã, Barra da Estiva, Ibicoara and Luís Eduardo Magalhães. Those that produce conilon are from Una, Itabela, Itamaraju, Porto Seguro and Guaratinga (Figure 1).

Considering that the sample population size of coffee farms in the municipalities is approximate and with the return of 34 answered questionnaires, a margin of error of 14% was obtained with a reliability level of 90%.

The analysis indicated that 59.3% of respondents said that the prospect of using PA in coffee growing is high, 26.6% have medium perspective and another 11.1% have low perspective; 67.6% do not use PA in farming, but 32.4% already use the technique. There were 41.2% who know the PA and 38.2% that have only heard about it.

4 DISCUSSION

The use of PA in Brazil has occurred in practically all types of agricultural production and in cattle raising. In annual crops, such as grains and fibers, PA is much more advanced, with the use of cutting-edge technologies, than in perennial ones, such as coffee (Silva; Alves, 2013). But academic research carried out in coffee production areas in Minas Gerais, Espírito Santo and Bahia indicate that PA can bring good results for coffee production – in the production of arabica and conilon.

Despite the low relative use of PA, which was expected, there is a strong tendency for the technique to be used, also following the research by McKinsey & Company (2020) about "The mind of the Brazilian farmer in the digital age", according to which the technology has been used mainly in commercialization, through the WhatsApp application.

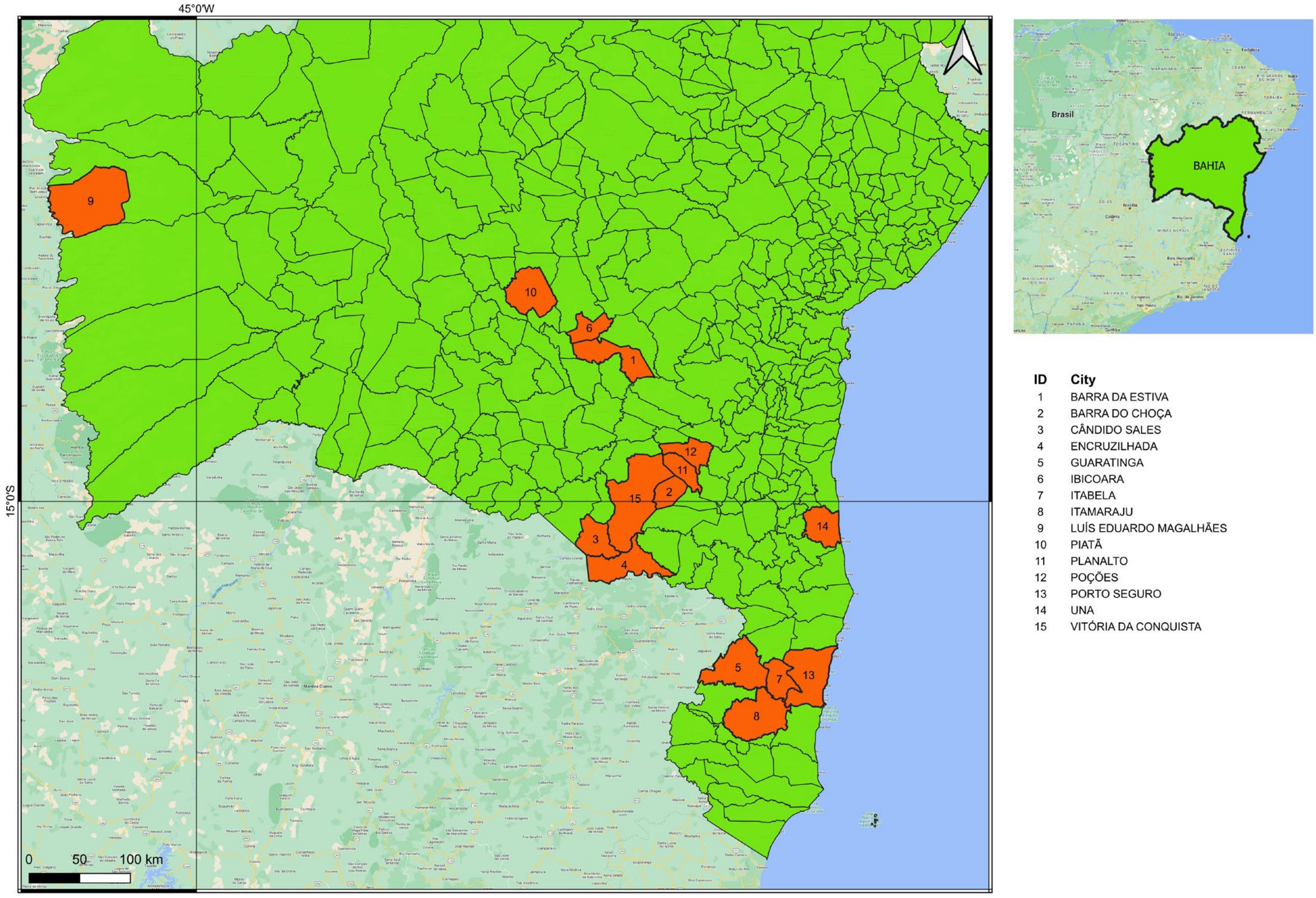

Figure 1: State of Bahia, with emphasis on the municipalities from the survey respondents.

This survey indicated that 39.9% of the producers claim to know methodologies for applying PA in coffee production; 35% know about the application of the Geostatistics method, but 54.5% are not aware of the use of Geostatistics and 36.4% have only heard about the subject.

Of those who use PA in coffee production, 63.3% have been using it for between 1 to 5 years, 27.3% for less than 1 year and 9.1% for more than 1 year. There are 62.1% of respondents who thought that PA is more important in soil management and 55.2% thought PA is more important in harvesting, anothers 27.6% claimed that it's important in irrigation; 48.4% do not use digital technologies in the field.

Researchers like Sott et al. (2020) show that the solution to sustainable agriculture is using precision and digital agriculture technologies. Through a bibliometric analysis of performance and network on the use of PA technologies in the coffee sector, they found that the Internet, Machine Learning and Geostatistics are the technologies most used by researchers in the coffee sector.

However, following the example of the research carried out with coffee growers in the state of Bahia in this article, Sott et al. (2020) emphasize that more attention needs to be given to methodologies for implementing PA techniques on farms, and that researchers need to establish technological integration between farmers, intermediaries, and customers to improve communication, logistics and environmental sustainability.

Thus, "the development of models and systems capable of synthesizing the organization needs to adapt processes and implement new technologies is a gap and a fundamental pillar for the transformation of traditional farms into smart farms" (Sott et al., 2020).

However, the efficient use of the technique requires methods that can better characterize the variability of physical and chemical attributes of the soil and the coffee tree, and thus provide reliable data on productivity, which is the final activity of coffee growing and interferes with the entire property management.

Several methods and concepts are used in the applicability of PA in coffee growing, such as Geostatistics, sampling grids, semivariogram, Moran Local (IML) and Global (IMG) indices, kriging, isoline maps, Information Systems modeling Geographics (SIGs), among others. Each method and concepts are used at the same time as technologies that allow better interpretation of collected data. And just like the methods, technologies and their utilities must be in tune with the reality of each productive area.

One of the methods that have been most used by researchers and in various types of experiments is the analysis and interpretation of data through Geostatistics, based on two concepts: semivariogram and kriging. The semivariogram has the role of describing the structure of spatial variability and kriging predicts unmeasured values, without bias and with minimal variance (Silva; Alves, 2013).

Geostatistical analysis allows spatially organizing data according to the similarity between georeferenced neighbors (Silva; Alves, 2013). Geostatistics was used by Silva et al. (2020) in experiments on nutritional balance and its relationship with productivity in a Conilon coffee farm in Espírito Santo state. The research used a sample grid of 100 points, each point liked to one plant.

Silva et al. (2020) evaluated that the use of a Geostatistics tools allied to the Nutricional Balance Index (NBI) resulted in a better understanding of the relationship between nutritional and non-nutritional variables in Conilon coffee productivity.

The use of Geostatistics in precision coffee farming has been improved, with the proposal of more efficient methods, with regard to the quality of sampling grids. This is very important for choosing the sampling grid that best fits one or a set of variables.

In their study, in which the structure and magnitude of spatial dependence were characterized by semivariogram, Ferraz et al. (2017) applied validation techniques as a basis to create a network quality assessment index and develop an indicator that points to the best sampling grid, in an experiment on the Brejão farm, Minas Gerais state, Brazil.

Twenty sampling grids were developed and compared, applied to four soil variables sampled in georeferenced locations. An accuracy index (AI), an precision index (PI) and the optimal grid indicator (OGI) were developed and proposed to characterize the magnitude of the spatial variability of the four soil chemical properties in all soil sampling grids except for SCC at pH 7 on grid 20. It was also observed that the soil variables had a spatial dependence structure, allowing the validation parameters to be obtained. Sampling grid 5 was the best evaluated for presenting 3 points per hectare in a square grid. In addition, the difference between sampling grids and soil variables was verified. The survey results showed that the choice of a sampling grid is critical for a good performance in the application of precision agricultural techniques to the coffee crop Ferraz et al. (2017).

In another study also made in Minas Gerais, in an area of 22 hectares, Ferraz et al. (2015) showed the benefits of PA of inputs in coffee growing, when comparing the management of conventional sampling with the management of grid sampling (spatial variability).

Phosphorus and potassium contents were measured, as well as the application recommendations, based on standard samples and a 64-point grid, whose data were analyzed using geostatistical techniques. By this method, it was possible to characterize the spatial variability and the dosage of P2O5 and K2O in the grid surveyed area.

For phosphorus, the dosage, following the pattern, was 1,158 kg, while that recommended with spatial variability was 1,128 kg, a reduction of 25.7% in relation to the conventional sampling. For potassium, the recommended application would be 4,125 kg, and for grid sampling, 4,666 kg – an increase of 11.6% compared to standard sampling.

It is observed, therefore, that sampling in PA will not always suggest a reduction in inputs, but rather indicate more precisely what the real nutritional need of the soil is, which results in efficiency on the management of inputs.

Figueiredo et al. (2018) used geostatistical tools in precision coffee farming to assess the spatial correlations between the chlorophyll index (CI) and the contents on the NPK leaf. In data collection, a portable sensor was used to measure the CI in the coffee leaves. The evaluation method proved to be efficient for N, with moderate spatial correlation with the CI, but it showed low correlation with the K. As for the P, the correlation was varied in the samples collected.

Other studies on precision coffee farming, also carried out in Minas Gerais by Zanella et al. (2020), using geostatistical tools, show that it is possible to obtain data on the variability of soil compaction in the crop. For this, the spatial distribution of soil penetration resistance (SPR) was evaluated, with the positions in the coffee rows and the soil depth ranges as variables, using a penetrometer in the depth range from 0 to 0.40 m. It was found that the soil on the tractor track had high compaction, which can harm the crop.

In a research on the spatial variability in the productivity of fertigated coffee and plant nutrients in soil saturation extracts, Jorge et al. (2019) used geostatistics to build a spatial variability model representing the physical attributes of the soil, finding that yield and soil chemistry varied across the study site. Thus, they concluded that maps generated from geostatistics can be useful tools for soil management in fertigated coffee plantations.

In terms of challenges and new demands, the study showed that internet connection is rated as median by 41.2% and good/great by 23.5%; also 23.5% point it as low and 11.8% have no connection. Regarding technological innovations, 74.2% of the respondents would like digital technologies to be developed to use in harvesting, 58.1% would like the digital technologies in the application of fertilizers and 54.8% to improve the management of rural properties. The demands on the use of technologies in coffee harvesting, pointed out in this article, are shown in other studies, especially in areas above 25 hectares, such as the 2021/2022 Coffee Crop Survey (Confederação

Nacional da Agricultura - CNA, 2022). In Bahia, a research on Precision Coffee Growing has already been initiated by the Post-Graduate Program in Agronomy at the State University of Southwest Bahia (UESB), without, however, consulting coffee growers about the prospects for applying the AP.

Finally, 51.7% answered that they consider the lack of training as an obstacle to the use of PA and other digital technologies in coffee production. Education for farm management through precision agriculture and digital technologies is something that already occurs in several areas of grain production in Brazil (Silva; Alves, 2013).

However, in coffee farming, as the research shows, this is an important demand that needs to be met, mainly from an educational point of view, since both coffee producers and rural workers need educational training to use the tools, many of which are which can be accessed and downloaded for free over the internet.

Studies show that, in general, initiatives have been promoted in developed countries since the 1980s for the adoption of precision agriculture, especially in developing countries such as Brazil. According to Pivoto et al. (2019), the main barriers to the advancement of precision and digital agriculture in Brazil are the precariousness of Internet access in rural Brazil and the low qualification of the workforce in rural Brazil. The researchers point out that a solution to solve some of these problems would be training and capacity building through farmers' associations.

A similar reality occurs in other South American countries, according to research carried out by Puntel et al. (2022) which sought to quantify the adoption of existing digital agriculture (DA) technologies, identify limitations to DA adoption, and summarize existing metrics to compare the benefits of DA.

Puntel et al. (2022) found that the level of DA adoption was led by Brazil and Argentina, followed by Uruguay and, to a lesser extent, by Chile and that GPS guidance systems, mapping tools, mobile applications and remote sensing are the technologies of most adopted DA.

Other findings by Puntel et al. (2022) are that the cost of technology, lack of training, limited number of service providers and unclear communication of DA benefits are the most reported limitations for DA adoption.

Therefore, the researchers suggest the need for an DA educational curriculum that meets the demand for professional skills such as data processing, analysis, and interpretation. In addition, they propose a set of economic, social, and environmental metrics to support future research and outreach efforts to better communicate the benefits of DA. Regional efforts such as Projeto Agro 4.0 are needed to standardize surveys and metrics to quantify adoption and identify constraint (Puntel et al., 2022.).

The training of new professionals is even necessary so that the sector throughout the country can follow the evolutions resulting from precision and digital agriculture, very important not only for improving productivity, but also for economic and environmental sustainability, in the face of climate change, which affects agricultural production around the world.

The relatively low use of Precision Coffee Growing presents itself as the main problem pointed out by this article, whose objective is to verify the applicability perspectives of PA in the coffee production areas of Bahia. It is hypothesized that this low use is due to the lack of information about the application methodologies and benefits that this management technique generates in the rural property. The other hypothesis for the lowered use of Precision Coffee Farming would be the lack of knowledge, from the producers, about methods of using digital technologies and their benefits.

Bolfe and Massruhá (2020, p. 34) emphasize that "the process of digital transformation in rural properties is no longer an option; it is an essential way to make Brazilian agriculture more competitive and with greater added value". But this path of no return still depends on public and private investments in science, means of accessing digital technologies, as well as infrastructure, but, above all, training professionals and rural producers to use PA technologies. It is believed that the results of this work will serve as an incentive to coffee growers in Bahia to use Precision Coffee Growing. The study could also be important for companies that develop digital technologies.

The network of knowledge and technologies in machines and equipment, as well as computer programs (softwares) and mobile devices (applications installed on smartphones and tablets) works in harmony with the PA (Bernardi et al., 2014). Silva and Alves (2013) also note that management based on PA includes making decisions aimed at a sustainable agricultural activity from an economic and environmental point of view. Thus, the priority of agricultural management must be the search for balance in economic development, environmental quality, and income and wealth distribution. Benefits of PA are summarized in two points: the environmental and the economic.

Environmental benefits are related to optimizing the use of inputs and decision-making to reduce the impact of these inputs on natural resources. These benefits can be related to reducing the application rate of a phytosanitary product to control pests in a sandy soil, building a terrace to reduce erosion or determining the water quality of a river and its possible sources of contamination. Economic benefits are those that result in higher financial returns or cost-saving operations. This cost reduction may be related to the operational performance of a tractor in cultivation operations, planting or reduction in the application of inputs in the crop (Silva; Alves, 2013).

5 CONCLUSIONS

As seen in the research results, there is great perspective in the applicability of PA in Bahia's coffee, which is already being done by some producers. The research confirms part of the hypotheses raised, such as lack of knowledge about methodologies for applying PA techniques.

Most respondent growers know the benefits of PA and digital technologies, but they lack the skills to use it and need better internet connection, which is a national problem.

Good perspectives on the use of PA are something that should be reflected by both the public and private sectors, which should also seek ways to solve bottlenecks, such as the lack of training of coffee growers and the dissemination of knowledge about the methodologies for applying such techniques in rural areas.

It is important to highlight that other researches on the subject are underway in Bahia and other states in the country, aimed at improving PA methodologies in coffee production.

We believe that, in view of the exposed, the state of Bahia has a very favorable scenario for the advancement of PA in coffee production and the development of a more efficient, competitive, and sustainable coffee production.

6 AUTHORS' CONTRIBUTION

RBF wrote the manuscript and performed the sample research, ELB wrote the manuscript, performed the statistical analysis, reviewed and approved the final version of the work.

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