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CHAPTER 9

Relationship between technological innovation infrastructure and productivity in peanut cultivation

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INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an herbaceous plant, whose seeds contain around 25% protein and 50% edible oil. The grain is considered one of the most nutritious and energetic foods, being used in the food industry as raw material to produce oil and confections (Gerico *et al.*, 2020).

In 2020, the world's largest peanut producers were China, India, Nigeria, USA, Sudan, Argentina, and Brazil, respectively, with China responsible for producing approximately 17.5 million tons. Also in 2020, the largest importers of shelled peanuts were the Netherlands, Indonesia, China, Russia, and Germany, respectively (FAO, 2023). In the same year, the volume of shelled peanut imports was approximately USD 3.3 billion, and peanut oil was almost USD 440 million in the world market, of which Brazil had a 7% and 13% share, respectively (Trade Map, 2022).

With exponential growth of 100% in the last decade, peanut production in Brazil reached almost 700 thousand tons in the 2021/22 harvest (CONAB, 2022b). This increase is due to the adoption of new technologies in the production segment, with new more adaptable, resistant, and productive cultivars, with the introduction of mechanized harvesting, and with the institutional changes that have occurred since the development of standards and production rules aimed at ensuring product health (Akram *et al.*, 2022).

The peanut crop is highly relevant to the agribusiness of the state of São Paulo, which is the largest producer in the country, being responsible for producing 561.6 thousand tons in the 2021/22 harvest, representing almost 90% of national production (CONAB, 2022a).

The main peanut-producing regions within the state of São Paulo are Alta Mogiana, where production is mainly concentrated in the municipalities of Ribeirão Preto, Dumont, Jaboticabal, and Sertãozinho; and Alta Paulista, where production is more representative in the municipalities of Tupã and Marília (Sampaio; Fredo, 2021). Additionally, it is estimated that 80% of the reformed sugarcane areas in the state are occupied by the peanut crop

(Sampaio, 2016). Therefore, the inclusion of this crop in areas of sugarcane renewal is making it increasingly competitive in the country.

Although peanut cultivation has been explored in the state of São Paulo since the 1940s, gathering more than 80 species, there is a need for more investments in infrastructure, machinery, technology, and personnel to generate innovations capable of achieving higher productivity, profitability, and competitiveness (Sampaio; Fredo, 2021).

According to Martins and Vicente (2010), the capacity to innovate and adapt to market requirements and demands depends largely on strategies, adoption, and development of new technologies. Therefore, there must be “[...] the maximization and creation of synergies among the parties involved in the production chain to meet consumer needs more efficiently and effectively, with lower costs” (Armelin; Silva; Colucci, 2016, p. 80).

Indeed, technological changes in peanut production and processing and institutional transitions are directly linked to the current production scenario of the crop, meaning they impact the production volume, product quality and competitiveness, and more effective participation in meeting domestic and foreign market demands (EMBRAPA, 2014). In this sense, Information Technology has become increasingly relevant to agribusiness, contributing to innovation in food production and food security.

Agriculture 4.0 consists of a set of integrated digital technologies (systems, applications, and machines) developed to optimize agricultural production in all its stages, from planting to harvesting (Silva *et al.*, 2019). Therefore, the combined use of precision agriculture, big data, and the internet of things can lead to greater efficiency in management and agricultural production, as these technologies have been used in the planning and control of various crops (Braun; Colangelo; Steckel, 2018); in the intelligent use of data collected through advanced technologies (Mancini; Frontoni; Zingiaretti, 2019); as well as in sustainable practices (Symeonaki; Arvanitis; Piromalis, 2020).

Agriculture 4.0 tools generate and analyze a large amount of data, integrating management and production processes and ensuring the

professionalization of activities and sustainability in production processes. They facilitate decision-making, providing cost reduction and higher productivity and profitability (Silva *et al.*, 2019). Therefore, understanding the association between the use of new technologies and the effect of this use on peanut productivity enables the establishment of scenarios that will assist in decision-making regarding the improvement of the dynamics and competitiveness of the production chain.

This chapter presents the technological infrastructure, based on Agriculture 4.0, related to machines and equipment, inputs, storage, and management used by peanut producers in the West Paulista region. Specifically, it makes an association of this infrastructure with the productivity of the said crop to verify the implication of using these technological innovation items on productivity.

The concept of technological innovation is associated with the emergence of unprecedented technologies generated in a scientific research environment that provide higher quality and productivity, an essential factor for the development of peanut production, similar to other crops and economic sectors (Sharif, 2012). In this sense, the world is becoming “dramatically more interconnected, interdependent, and competitive, where fostering innovation has emerged as the main strategy for socioeconomic prosperity” (Sharif, 2012, p. 599).

Given this context, the theme addressed in this chapter aligns with the Sustainable Development Goals (SDGs) in terms of the following targets:

Target 9.5 Strengthen scientific research, improve the technological capabilities of industrial sectors in all countries, particularly developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per million people and public and private spending on research and development. Target 9.b Support domestic technology development, research, and innovation in developing countries, including ensuring a conducive policy environment for, among other things, industrial diversification and value addition to commodities (GT AGENDA 2030, 2022).

The theme and objectives of this work are interrelated with the areas of Administration, Agronomy, Statistics, Information Systems, Economics, among others. Therefore, given the multidisciplinary scope of the related areas, it is considered that the results of this research contribute to the Competitiveness of Agribusiness Systems line of the PGAD by providing important information on the advantages of using certain technologies in agricultural activities for cleaner and more sustainable production.

A form with multiple-choice questions was used as a data collection instrument. This form was applied to a random sample of 29 peanut producers from the West Paulista region (which includes the Alta Paulista region) who used conventional and conservationist systems during the second semester of 2022 (harvest 2022/23).

The surveyed producers are in the main peanut-producing municipalities of the West Paulista region, namely, Adamantina, Arco-Íris, Bastos, Getulina, Guaimbé, Herculândia, Iacri, Marília, Martinópolis, Nantes, Parapuã, Presidente Prudente, Quatá, Quintana, Rancharia, Sagres, and Tupã. The number of surveyed farmers corresponds to 20% of the total planted area in the West Paulista region, representing a significant segment of the peanut-producing region.

The form's questions concern the type of farmer (family or non-family), planted area, production destination, and peanut productivity, as well as the adoption of technological innovation items (in the 2022/23 harvest) related to:

- Machines and equipment: Self-propelled sprayer; Harvesters; Global Positioning System (GPS); Light bar; Section cut on the sprayer; Autopilot; GPS signal correction; Variable rate fertilizer; Applications using Unmanned Aerial Vehicles (Drones); and Telemetry system.
- Inputs: Annual soil analysis; Application of macrobiologicals; Integrated Pest Management (IPM); and Integrated Disease Management (IDM).
- Type of storage: Dryer; and Warehouse.

- Management: Agronomic assistance from the cooperative/reseller; Own agronomic assistance; Agribusiness-oriented applications; Business management software; Trained operators; Business management by a professional; and Quality certificate

The data obtained were analyzed using descriptive statistics (graphs and percentages), and then G independence tests were applied. The G test is a non-parametric test, similar in all aspects to the chi-square test (χ^2), used to verify the association between two qualitative variables, arranged in contingency tables or double-entry tables, specifically when the sample size is less than 40 and expected frequencies are less than '5' (Fávero; Belfiore, 2017). In this chapter, contingency tables are shown geometrically, i.e., summarized through graphs.

Non-parametric tests are recommended for formulating hypotheses about certain qualitative characteristics of a population and can be applied to qualitative data, on a nominal or ordinal scale (Fávero; Belfiore, 2017). Thus, for a significance probability obtained from the data (p-value) less than or equal to the 5% significance level established for the test, the null hypothesis H_0 of independence between the variables productivity and a given item of technological innovation was rejected, concluding that there is a significant association between the two variables analyzed (Martins, 2005).

PROFILE OF RURAL PRODUCERS, PLANTED AREA, PRODUCTION DESTINATION, AND PEANUT PRODUCTIVITY IN THE WEST PAULISTA REGION

According to the research data, 35% of the surveyed producers can be characterized as family farmers, according to Federal Law No. 11.326, of July 24, 2006 – which establishes the guidelines for Family Agriculture and Rural Family Enterprises in Brazil (Antunes, 2011; Brasil, 2006).

Sales of 83% of rural producers' production are exclusively to the domestic market. Of the remaining 17%, 7% are family farmers, with cultivation ranging from 242 to 605 hectares, who have quality certification

from the Brazilian Association of Chocolate, Peanut, and Candy Industry (ABICAB) and supply the product to domestic and international markets. The other 10% exclusively sell their products to the international market, with 3% of these producers having production of up to 1,815 hectares and 7% around 2,420 hectares. Of these 10%, about 70% of producers have quality certification.

As for export destinations, a significant portion of the peanuts produced by the surveyed producers goes to the following markets: Russia, Algeria, Ukraine, European Union (14 countries), Dubai, Morocco, and Colombia.

Additionally, about 56% of rural producers had productivity above 165.30 bags per hectare (sc/ha) in the 2022/23 harvest, i.e., above 4,132.5 kilograms per hectare (kg/ha). It is noteworthy that, in the same harvest, the average peanut productivity in the state of São Paulo was 3,848.0 kg/ha, or equivalently, 153.92 sc/ha (CONAB, 2022a), which highlights the representativeness of the West Paulista region in the state's peanut production scenario.

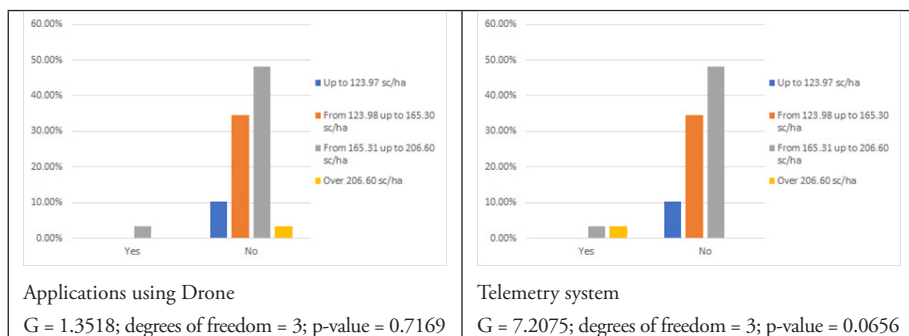
RELATIONSHIP BETWEEN TECHNOLOGICAL INNOVATION INFRASTRUCTURE AND PEANUT PRODUCTIVITY

As for technological innovation infrastructure, Figure 1 shows the existing structure in terms of machines and equipment used by rural producers in peanut production.

It is observed that all surveyed producers have harvesters (Figure 1.b), and a significant percentage of producers have self-propelled sprayers (Figure 1.a), use GPS (Figure 1.c), and cut sections on the sprayer (Figure 1.e). A less significant percentage use autopilot (Figure 1.f) and GPS signal correction (Figure 1.g). On the other hand, most producers do not apply variable rate fertilizer (Figure 1.h) or use drones (Figure 1.i) for such applications, nor do they use a telemetry system (Figure 1.j) or light bar (Figure 1.d).

Figure 1 – Machines and equipment used by rural producers versus productivity (sc/ha)





Source: Prepared by the authors from the research data (2022). *Significant at 5%, indicating that the variables are associated.

The Global Positioning System or GPS is the equipment used for navigation, communication, measurement, and area delimitation, providing a reduction in the risk of losses. As for the autopilot systems in tractors, harvesters, and other agricultural machines, these work through an antenna installed on the machines' roofs that receive satellite signals from the GPS, allowing the vehicle to be guided automatically, without operator interference (Silva *et al.*, 2019). Unmanned Aerial Vehicles or drones are instruments that can be used to analyze areas, check for pest or disease attacks, and investigate planting failures. Telemetry, in turn, is a system that collects and shares data about machines, equipment, and vehicles remotely, monitoring routes, fuel consumption, and refueling, among other purposes (Silva *et al.*, 2019). The light bar is the equipment used to guide a vehicle in adjacent strips to obtain more precision and uniformity in the distribution of soil amendments and fertilizers. Variable rate fertilizer application is a resource that allows the application of different fertilizer rates in each part of the soil, according to its characteristics and planned yield (Armelin; Silva; Colucci, 2016).

Figure 1 also shows the p-values of the G tests applied to verify the independence between each of the machines and equipment items used (or not) by rural producers and productivity. It was observed that no item is significantly associated with productivity, according to statistical tests. Indeed, the data show that the Agriculture 4.0 infrastructure in terms

of machines and equipment in the West Paulista region is still incipient among the surveyed producers.

In this sense, Silva, Oliveira, and Loureiro Junior (2019) emphasized that there is little investment in research on the use of technologies in peanut cultivation, including regarding the mechanized harvesting process compared to other crops. However, technologies have significant potential for improving the harvesting process of this crop, highlighting the use of autopilot, yield mapping, telemetry, and computer vision.

Figure 2 shows the second group of technological adoption items related to inputs, which can be used to improve the soil and combat the main pests and diseases affecting peanut production, with “black spot” (which appears associated with other diseases) and the “redneck caterpillar” pest being the most observed in the West Paulista region. Regarding weeds, there is a higher incidence of “indigo” and “morning glory” in this region.

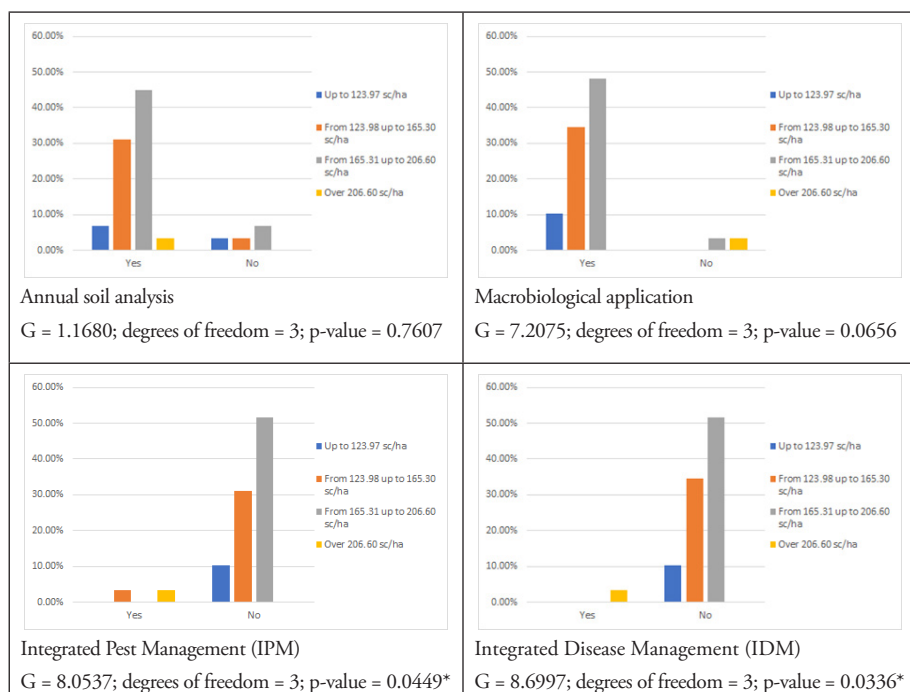
It is found that most surveyed producers take care of the soil, with more than 90% of them conducting annual soil analysis (Figure 2.a) and investing in microbiological application (Figure 2.b), which is a pest and disease management procedure that uses living organisms (natural enemies) to control them. However, IPM and IDM have much less adherence among peanut producers in this region (Figures 2.c and 2.d).

As for the p-values of the G tests applied to verify the independence between each of the input items used (or not) by rural producers and productivity, Figures 2.c and 2.d indicate that two of them are significantly associated with productivity, namely, IPM and IDM. According to the data, about 80% of producers do not practice IPM or IDM but are concentrated in the two central productivity ranges (between 123.98 sc/ha and 206.60 sc/ha). However, producers who practice IPM and IDM are in the highest productivity range, above 206.60 sc/ha.

Integrated Pest and Disease Management is a control procedure that aims to preserve natural mortality factors through the integrated use of combat techniques selected based on economic, ecological, and sociological parameters. Thus, by effectively combating existing pests and diseases in the crop, this type of management leads to reduced use of

agricultural pesticides and, consequently, production costs, contributing to environmental balance and increased productivity and profitability of the crop (Norlia *et al.*, 2018).

Figure 2 – Inputs used by rural producers versus productivity (sc/ha)



Source: Prepared by the authors from the research data (2022). *Significant at 5%, indicating that the variables are associated.

Figure 3 provides information on the types of storage used by surveyed producers after peanut harvesting. Such care is essential for maintaining the product, which requires specific conditions for drying, conditioning, transportation, and storage to avoid contamination by Aflatoxin, heavy metals, and other pathogens (Yang *et al.*, 2020).

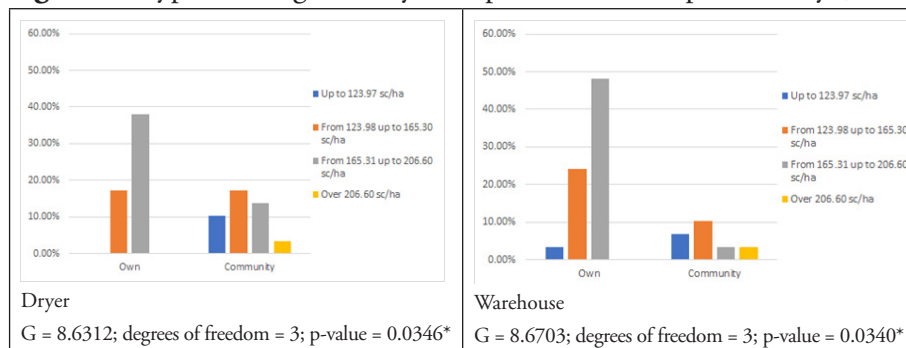
Notably, investments in technology and drying and storage equipment with humidity control enable the producer to have greater control over the procedures and lower risk of contamination by contact

with peanuts from other sources, in addition to strategic positioning with reduced external logistical costs, increased efficiency in logistical flow, and lower risk of product deterioration (Batalha, 2007; Norlia *et al.*, 2018).

According to Figure 3, all surveyed producers use dryers and warehouses for peanut maintenance, with over half of rural producers using their own dryers (Figure 3.a) and nearly 75% having their own warehouses (Figure 3.b). Additionally, the p-values of the G tests applied to verify the independence between each type of storage used (or not) by rural producers and productivity show that both (type of dryer and type of warehouse) are significantly associated with productivity.

In this sense, it was observed that rural producers who have their own dryers and warehouses are mostly concentrated in the productivity range between 165.31 sc/ha and 206.60 sc/ha, one of the highest. Indeed, this allows producers to have greater control over the moisture rate and risks related mainly to the Aflatoxin index, reflecting increased productivity.

Figure 3 – Type of storage used by rural producers versus productivity (sc/ha)



Source: Prepared by the authors from the research data (2022). *Significant at 5%, indicating that the variables are associated.

Figure 4 shows the production management structure employed by the surveyed producers. It is observed that technologies in production management have been used by producers in the West Paulista region

in some ways to assist in planting planning and execution to improve efficiency, increase productivity, and ensure profitability.

According to Figures 4.e and 4.a, all surveyed producers have business management carried out by a professional (they hire managers and professional technicians) and have agronomic assistance provided by cooperatives/resellers (they rely on technical competence in assistance, guidance, and care in agricultural production procedures). Additionally, about 25% of them also have agronomists on their teams.

On the other hand, it is observed that technologies associated with business management software (Figure 4.c), trained operators (Figure 4.d), and certification (Figure 4.f) have lower adoption percentages. Business management software aims to provide technological management with more accurate control and information, enabling more assertive decision-making (Hermans *et al.*, 2019). In this sense, the rural producer needs to have a team of operators qualified to use this software and agribusiness-oriented applications so that these technologies can improve production results (Rodrigues *et al.*, 2020). Product quality certification (Pró-Amendoim-ABICAB or others), in turn, allows the producer to gain competitiveness through differentiation and strategic positioning (ABICAB, 2022; Nico *et al.*, 2016).

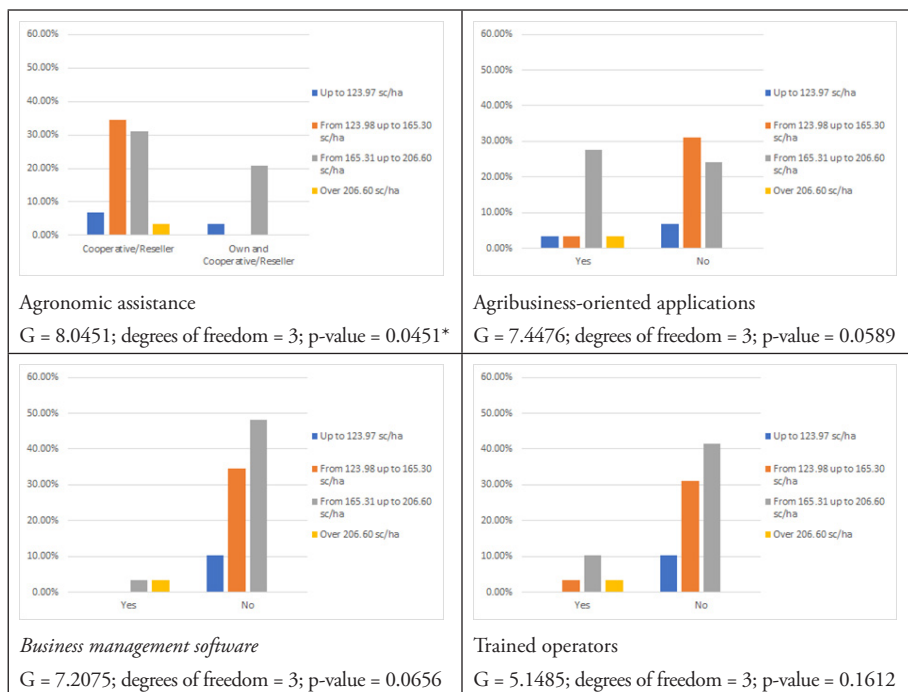
Agribusiness-oriented applications are used by more than 30% of the surveyed rural producers (Figure 4.b). These technological resources are employed to achieve better results, minimizing losses, damage, and/or impacts (Silva *et al.*, 2020).

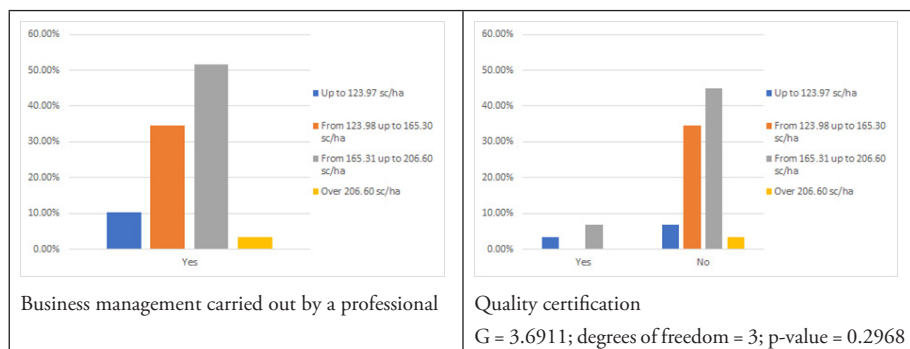
Using business management software and applications in peanut agriculture, when applied in an integrated and well-planned manner, can offer several benefits. These tools help farmers optimize the planting process, monitor plant growth, manage fertilizer and pesticide applications more efficiently, and assist in pest and disease control. Software and applications also allow for recording and analyzing data on weather conditions, soil management, and other relevant factors for peanut cultivation. Based on this information, farmers can make more informed and precise decisions,

which can lead to higher productivity and profitability with the help of these management tools (Lima *et al.*, 2020).

Additionally, using these technologies in peanut agriculture contributes to sustainability and environmental preservation by allowing more rational use of natural resources and reducing waste of inputs. Overall, they can boost the agricultural sector, making it more efficient, competitive, and sustainable (Almeida; Buainain, 2016).

Figure 4 – Management tools employed by rural producers versus productivity (sc/ha)





Source: Prepared by the authors from the research data (2022). *Significant at 5%, indicating that the variables are associated.

As for the p-values of the G tests applied to verify the independence between each management tool used (or not) by rural producers and productivity, only agronomic assistance is significantly associated with productivity. In this sense, it was observed that almost 70% of the surveyed producers who use only agronomic assistance from the cooperative/reseller had productivity above 123.98 sc/ha, showing that this type of assistance has been effective in peanut production management in the studied region.

Sampaio (2016) points out that one of the challenges of peanut production lies in the relationship this crop has with sugarcane production, highlighting the importance of studies that show the performance and feasibility of production technologies in the Alta Mogiana and Alta Paulista regions, and whether these technologies are truly adapted to the different conditions required by sugarcane renewal areas. The author also emphasizes the need for improving machines, implements, and equipment for planting and harvesting in peanut production systems, corroborating the results obtained in this research.

FINAL CONSIDERATIONS

The research results highlight the technological infrastructure based on Agriculture 4.0 for peanut production by rural producers in the West Paulista region and its relationship with crop productivity.

As for technologies in machines and equipment, it was observed that the surveyed producers have directed their investments towards implementing harvesters, self-propelled sprayers, GPS, and section cutting on the sprayer. However, adherence to other technologies is much less effective. In this sense, statistical tests did not show a significant association between the use of these technologies and productivity increases.

Regarding inputs, it was observed that most rural producers conduct annual soil analysis and apply microbiologicals. Integrated pest and disease management, however, is rarely practiced, even though statistically, there is a significant relationship between these technologies and productivity.

For storage technologies, statistical tests showed that rural producers who have their own dryers and warehouses tend to have a significant productivity gain, as they have greater control over procedures and, consequently, face lower risks of contamination and product deterioration.

As for management technologies, there is greater adherence by rural producers to professionalized management, agronomic assistance, and agribusiness-oriented applications. In this sense, statistical tests showed a significant association between agronomic assistance and productivity, indicating that producers who use this type of assistance tend to achieve higher productivity.

The evidence presented in this work indicates the incipience of Agriculture 4.0 technologies in peanut farms in the state of São Paulo. In addition to effective business management, storage, and agricultural input tools, this paradigm foresees the extensive use of digital technologies, including geographic information systems, GPS, yield monitors, precision soil sampling, proximal and remote spectroscopic sensing, unmanned aerial vehicles, self-guided and directed equipment, and variable rate technologies (Kovács; Husti, 2018).

The main limitation of this work is the research sample, restricted to rural producers in the West Paulista region. However, considering the exploratory nature of the research, it is expected that this work can contribute to the literature by presenting a preliminary scenario regarding

the implementation of Agriculture 4.0 technologies in peanut cultivation and their impacts on agricultural productivity.

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