"Embrapii: What Can We Learn About Precision Agriculture and Environmental Sustainability After Investments of US$100 Million+ in Agricultural Industrial Innovation in Brazil?"

José Henrique Videira Menezes[1], Fabio Stallivieri[2], Luciano Cunha de Sousa[3], Maria Lídia Rebello Pinho Dias Scoton[4], Diego Humberto de Oliveira[5], Isabela Mendes Gaya Lopes dos Santos[6], Eduardo Mario Dias[7]

A paper from the Proceedings of the
17th International Conference on Precision Agriculture and 11th Brazilian Congress on Precision and Digital Agriculture
13-15 July 2026
Porto Alegre, Brazil

1 Polytechnic School, University of São Paulo / Brazilian Ministry of Development, Industry, Commerce and Trade / Brazilian Agency for Industrial Research and Innovation. Av. Prof. Luciano Gualberto, 158 – Universidade de São Paulo, São Paulo - SP - Brazil, 05508-900 / josemenezes@usp.br

2 Fluminense Federal University, Brazilian Ministry of Education / Brazilian Agency for Research and Industrial Innovation / Edifício Armando Monteiro Neto, SBN Quadra 01 Bl. I. 13th, 14th and 15th Floors, Brasília - DF - Brazil, 70040-913 / fabio_s@id.uff.br

3 Brazilian Ministry of Development, Industry, Commerce and Trade. Esplanada dos Ministérios, Brasília - DF - Brazil, 70050-000 / luciano.sousa@mdic.gov.br

4 Polytechnic School, University of São Paulo. Av. Prof. Luciano Gualberto, 158 - São Paulo, Brazil, 05508-900 E-mail: lidiadias@pea.usp.br

5 Polytechnic School, University of São Paulo. Av. Prof. Luciano Gualberto, 158 - São Paulo - SP - Brazil, 05508-900. E-mail: diegohagro@gmail.com

6 Polytechnic School, University of São Paulo. Av. Prof. Luciano Gualberto, 158 - São Paulo - SP - Brazil, 05508-900. E-mail: isabelagaya@gmail.com

7 Polytechnic School, University of São Paulo. Av. Prof. Luciano Gualberto, 158 - São Paulo - SP - Brazil, 05508-900. E-mail: emdias@pea.usp.br

Abstract

Innovation policies have increasingly targeted digital and sustainable transformation, yet systematic assessments of large-scale public-private investments in precision agriculture innovation remain scarce, particularly in tropical contexts. This article analyzes the experience of Embrapii (Brazilian Agency for Research and Industrial Innovation) after fostering more than US$100 million in investments in over 400 research, development, and innovation (RD&I) projects applied to agriculture and food.

A database was developed covering total financial volume co-invested between research centers, private companies and public resources, companies profile, enabling technologies, technology readiness levels (TRLs) and intellectual property outputs. Projects were selected according to ISPA`s precision agriculture definition and additional criteria related to economic and sustainability benefits. Five case studies were investigated to illustrate relations: internet of things and sensing applied to irrigation; blockchain applied to food traceability; artificial intelligence applied to soil spatial variability; biophotonics applied to carbon stock certification; and drones applied to the dispersion of biological agents.

Findings indicate some patterns. Micro and small companies and cooperative projects (involving more than one company) have a relevant representation. A larger proportion of projects operate at intermediate TRLs (3–6). Enabling technologies such as biotechnology, systems integration and artificial intelligence play a significant role. Chemistry, prototyping, robotics and new materials also contribute to precision agriculture innovation. In the case studies analyzed, main economic benefits included improved management efficiency and higher productivity; main environmental gains involved reductions in CO_2, energy use, and chemical inputs.

The article contributes to literature in three different ways. Empirically, it offers a comprehensive mapping of public-private supported precision agriculture development projects in a large tropical economy. Methodologically, it proposes a replicable method for classifying precision agriculture RD&I projects. From a policy perspective, it identifies design implications for innovation funding instruments, including the need for clearer environmental indicators and stronger links between digital technologies and measurable ecological outcomes. By examining this Brazilian scenario, it provides insights for policymakers, entrepreneurs and scholars seeking to align agricultural transformation with environmental sustainability in tropical countries.

Keywords: Embrapii, Collaborative Innovation, Precision Agriculture, Environmental Sustainability

1. Introduction

Inspired by the Brazilian Agricultural Research Corporation (Embrapa) and organizations like Fraunhofer Society, the Brazilian Agency for Research and Industrial Innovation (Embrapii) was created in 2013, with operations focused on supporting technological research and innovation in Brazilian industry. Operating usually at a pre-competitive technological maturity level (Technology Readiness Levels three to six) (Mankins 1995), applied research centers aggregate competencies and absorb the technical and financial risk that neither universities (generally focused on lower TRLs) nor companies (usually focused on higher TRLs) are willing to assume alone, ensuring that the generated knowledge is not lost (Llanos-Paredes 2023). Embrapii is a non-profit institution with partnerships and funding from Brazilian ministries such as Science, Technology and Innovation (MCTI), Development, Industry, Commerce and Services (MDIC), as well as institutions such as the National Bank for Economic and Social Development (BNDES). It supports Science and Technology Institutions (STIs) in research, development and innovation (RD&I) projects in cooperation with companies, acting through a network of more than 90 accredited STIs. Its model prioritizes business technological challenges and risk sharing via co-investment (Embrapii 2024; Embrapii 2025a).

1.2 Climate Change and Market Access

The new context of climate change, its effects on agriculture itself, the needs for mitigation and adaptation (Malhi et al. 2021), combined with climate neutrality commitments of the Paris Agreement and COP 30 (UNFCC 2022; COP30 2025), in addition to the pressure from consumer markets with regulations such as the European Union Deforestation Regulation (EUDR 2023), demand significant innovation from food-exporting countries in terms of resource efficiency and sustainability. From the consumers' perspective, not only food quality and safety are being demanded. Voluntary certifications play a role in reinforcing consumer confidence in product sustainability. Environmentally friendly practices also represent an opportunity for product and process innovation, allowing for an additional and significant competitive differential (Banterle 2013). Product traceability generates economic benefits, reduces reputational risks, and increases market access (both international and premium) (Kim, Laskowiski 2017; Hinkes, Peter 2020). Embrapii, which itself represents an institutional innovation of decentralized resources for RD&I (Gordon, Stallivieri 2019) has contributed to dynamizing Brazilian agricultural industrial companies, as will be demonstrated in this article.

1.3 Objective

The objective of this article is to collaborate with precision agriculture and innovation policies by presenting Embrapii's results from 2014-2024, as well as exposing the development and application of new technologies in Brazilian agriculture in terms of technological focus, maturity, economic and environmental gains. Contributions are presented based on project portfolio data and case studies of precision agriculture projects supported by Embrapii.

2. The Embrapii Innovation Support Model and its Results

In late 2013 Embrapii began its operation in Brazil. The institution's primary objective is to support innovation in Brazilian industrial companies through partnerships with STIs accredited as Embrapii Units (EUs). Its operational model adopts specific characteristics, reducing the technological risk inherent in innovation and sharing project costs (Gordon, Stallivieri 2019; Embrapii 2025a). RD&I project financing in Embrapii`s model is tripartite, with the institution supporting on average up to one third of the project value with non-reimbursable resources, and the remaining value being divided case by case between the EU that will develop the project and the company(ies) demanding the technological solution.

In this sense, on the one hand, Embrapii provides a significant reduction in technological risk, as projects are developed by EUs with technical capacity and state-of-the-art infrastructure. On the other hand, it allows a reduction in project development costs, as part of the contribution is made by Embrapii with non-reimbursable resources. By the end of 2024, the institution had a network of 93 EUs distributed across all regions of Brazil. Examples of Embrapii Units include the National Center for Research in Energy and Materials (CNPEM), which is responsible for Sirius, one of the most advanced synchrotron light sources in the world, and is accredited to act in biotechnology, biomass processing and nanomaterials. Lavras Federal University EU (ZETTA/UFLA) is focused on geotechnology smart systems. SENAI Cimatec, located in Bahia, focuses on solutions such as automation, product/process optimization and robotics. The EU at the University of São Paulo`s Luiz de Queiroz Superior School of Agriculture (ESALQ/USP) specializes in bioinputs applied to agriculture. Embrapii also has an EU at Embrapa`s ITECH-AGRO Unit, accredited on agribusiness enabling technologies integration. There are dozens of other EUs with diverse technological focuses (Embrapii 2025b).

2.1 Embrapii Projects in Agricultural Industrial Innovation

Out of a total of 3,063 Embrapii projects in 2014-2024, 468 had agribusiness as their main area of application, making this segment the most representative in terms of the organization’s support measured by number of projects (15.3%) (Embrapii 2026). These projects were carried out in partnership with 420 companies, of which 58 were large firms, 42 medium-sized firms and 209 micro and small firms. They mobilized US$104 million in RD&I investments, with Embrapii contributing approximately US$39 million, companies US$40 million and Embrapii Units US$25 million. Out of the 468 projects, 195 had biotechnology as their main enabling technology, followed by Systems Integration (73), Prototyping (43), Artificial Intelligence (37), Manufacturing (37), Materials (30), Chemistry (26), Automation and Robotics (13), Hardware Development (9) and Communication Systems (5 projects) (Embrapii 2026). Table 1 provides additional information.

Table 1 Number of projects, number of cooperative projects, number of companies involved, average ticket size, and investments by each co-investor (US$ million[a])

Date	Projects Number	Cooperative Projects Number	Companies Number	Average Ticket	Embrapii Investment	EUs Investment	Companies Investment	Total Invest.	Embrapii Share	EUs Share	Companies Share
2014	1	0	1	$0,63	$0,21	$0,18	$0,24	$0,63	32,89%	28,97%	38,14%
2015	2	1	3	$0,13	$0,09	$0,03	$0,14	$0,26	33,33%	11,89%	54,78%
2016	3	0	3	$0,46	$0,45	$0,28	$0,63	$1,37	32,98%	20,75%	46,27%
2017	11	1	12	$0,16	$0,60	$0,53	$0,65	$1,78	33,80%	29,67%	36,53%
2018	31	4	35	$0,37	$4,00	$2,74	$4,86	$11,60	34,45%	23,65%	41,90%
2019	34	3	34	$0,46	$5,05	$3,47	$7,14	$15,66	32,26%	22,13%	45,61%
2020	37	4	38	$0,23	$2,91	$2,42	$3,23	$8,56	34,00%	28,24%	37,77%
2021	57	13	67	$0,16	$3,35	$2,36	$3,32	$9,03	37,05%	26,16%	36,79%
2022	87	10	90	$0,18	$5,90	$3,83	$6,04	$15,77	37,42%	24,27%	38,31%
2023	84	5	86	$0,19	$7,17	$3,48	$5,72	$16,36	43,80%	21,25%	34,95%
2024	121	15	131	$0,19	$9,57	$5,30	$7,98	$22,86	41,88%	23,19%	34,93%
Total	**468**	**56**	**420**	**$0,22**	**$39,30**	**$24,62**	**$39,97**	**$103,89**	**37,82%**	**23,70%**	**38,48%**

Source: prepared by the authors based on Embrapii 2026 / [a] values converted from BRL to US$ (14Jan26 rate).

Within the Embrapii model, cooperative projects also play a strategic role, as they promote greater interaction among firms and stimulate collaborative arrangements for innovation. As Table 1 indicates, they represent a relevant portfolio share (11,9%) and are characterized by involving more than one firm in the joint execution of the same technological demand. This expands the scope and complexity of the solutions developed, knowledge spillover and diffusion, which is aligned with international best practices in network-oriented RD&I policies (Fundeanu, Badele 2014).

This agricultural industrial innovation portfolio presented a larger proportion of projects with intermediate TRLs (3–6), indicating a pre-competitive technology development focus. It also generated 240 intellectual property deposits. This set of data underscores the relevance of this economic segment within the context of Embrapii.

3. Embrapii Precision Agriculture Projects was a Lever for Economic and Environmental Gains

To expand the understanding of Embrapii's 2014-2024 contributions to Brazilian agribusiness, field research on precision agriculture projects supported by the institution were conducted. The focus was to identify the potential of the technologies developed, from the perspective of three different agents, to generate economic and environmental gains.

3.1 Research Method and Sample Selection for the Case Studies

The research was designed in 2024 and carried out in 2025, developing case studies (Yin 2018). Questionnaires, interviews, and process tracing (Bennett, Checkel 2014) were used as research tools, adopting a qualitative approach. The data used to identify and characterize the projects were provided by Embrapii`s Information Registration System (SRInfo) (Embrapii, 2025c) and by Embrapii Units involved in each project. Additional data were collected through semi-structured interviews, document analysis (technical reports, patents, public data, etc.), as well as direct observation to verify the application of the technologies in the field.

For the implementation of the case studies and the respective field research, three types of actors were consulted: (i) Embrapii Units responsible for developing the solutions; (ii) companies which contracted the Embrapii projects (and became providers of the new solutions in the market); and (iii) companies demanding (users of) the new technological applications (farmers, agribusiness firms and an international certification body). All questionnaires and interviews were semi-structured and conducted individually. For EUs, questionnaires were sent and answered electronically. For companies, questionnaires were administered through in-person interviews. To elicit and systematize the knowledge obtained from the in-person interviews, Mind Maps and Concept Maps were employed (Buzan 2024; Novak, Cañas 2008). Questionnaires to the Embrapii Units were sent and answered between March 12, 2025 and April 4, 2025. Interviews with companies which hired the Embrapii projects and with user companies of the new technologies took place between March 24, 2025, and September 17, 2025, in different cities across Brazilian states of Ceará, Rio Grande do Norte, Goiás, and São Paulo.

The projects selection criteria were as follows: (i) Application - among all projects supported by Embrapii, an "Agribusiness" filter was applied, as well as the International Society of Precision Agriculture definition of precision agriculture (ISPA 2024); (ii) Enabling Technologies - for this filter, it was used the classification proposed by Schwab (2017); (iii) Connection with Environmental Sustainability - analyses were conducted in partnership with the Sustainability and Traceability Laboratory in Tropical Environments (STLab/University of São Paulo), applying the following 12 criteria (the project had to meet at least one): resilience gain; crop economic relevance; optimization of water resources; energy optimization; optimization of agrochemicals; optimization of fertilizers; productivity gains; expansion of traceability; data generation; data and systems integration; preservation or regeneration of vegetation; and reduction of CO_2 emissions;

(iv) Project status – whether the project had already been completed and whether the product or service was already on the market; and (v) Data access – whether the technology provider and user companies were willing to participate in the study.

In total, out of the 468 agricultural industrial innovation projects (and 117 derived precision agriculture), five potential case studies fully met all previously established criteria and requirements and were thus selected.

3.2 Results Obtained from the Application of the Method

This section presents information on the five case studies analyzed: internet of things and sensing applied to irrigation; blockchain applied to food traceability; artificial intelligence applied to soil spatial variability; biophotonics applied to carbon stock certification; and, finally, drones applied to the dispersion of biological agents. The names of the interviewees were substituted by codes for privacy reasons.

3.2.1 Case A – Internet of Things and Sensing Applied to Irrigation

3V3 Tecnologia is a small technology-based company from Ceará state, specializing in the development of technological solutions ranging from greenhouse automation systems to integrated platforms for crop management, irrigation automation, and sensing. The development of the initial solution was carried out in partnership with the Embrapii Unit at the Federal Institute of Education, Science and Technology of Ceará (IFCE). At the time, it was observed that measurements in agricultural soils based on radiofrequency or microwaves were already widely used in the sector, particularly in assessing the dielectric properties of seeds, fruits, and soils. However, the sensors available in the domestic market showed low repeatability, insufficient performance for commercial use, and high operational and configuration complexity. In contrast, the international market offered technologically more advanced sensors, with better usability and quality, but without adaptation to tropical conditions. Considering this, the project focused on developing a solution that would meet the demands of the agricultural sector while taking into account local operating conditions in Northeast Brazil (such as high salt levels and extreme heat) (Embrapii 2025c).

Currently, the company offers a customized irrigation and fertigation management and control system that enables farmers to monitor and automate the agricultural irrigation process via radio and edge computing. The company has clients in ten Brazilian states (Field research – data obtained from interviewee MF in Fortaleza on March 24, 2025). One of the technology users, Agrícola Famosa, operates 28,500 hectares (ha) across 14 farms, generating an annual production of 350,000 tons of fruit - mainly melon and watermelon - from 12,000 ha cultivated. This client reported that with the use of 3V3's solution, it achieved 10% energy savings, up to a 25% reduction in fertilizer use, productivity gains of approximately 30% and water savings of 200 m^3/ha (Agrícola Famosa, 2025; Field research – data obtained from interviewee CR in Mossoró on March 25, 2025). Figure 1 illustrates 3V3`s remote monitoring center in one state and its equipment in use in a melon field in another state in the Caatinga biome in Northeastern Brazil.

Figure 1 3V3 monitoring center (a) and equipment in use in a melon field (b).

(a) (b)

Source: field research – photographic record by the authors – Fortaleza, March 24, 2025, and Mossoró, March 25, 2025.

3.2.2 Case B – Blockchain Applied to Food Traceability

Safe Trace is a small technology-based company headquartered in Minas Gerais state, specialized in traceability solutions for food supply chains, integrating information from all stages, from production to final consumption. Through products identified with the Safe Trace seal, consumers gain access to the origin of food products and verification that producers comply with socio-environmental and sanitary standards, ensured by a continuous process of monitoring and verification. The company's solutions are compliant with European certifications and the organization has collaborations with initiatives such as Partnership for Forests, WWF, The Nature Conservancy, among others (Safe Trace, 2025).

The development of the initial blockchain solution applied to food traceability was carried out in partnership with the Embrapii Unit CPqD, in Campinas (Embrapii 2025c). The case study involved two projects: one focused on beef cattle traceability and the other on soybean traceability. The first developed a decentralized digital identity wallet for animals, facilitating herd management and reporting to government agencies and slaughterhouses, ensuring that the meat supplied is not associated with deforestation. The second structured traceability within the soybean production chain through verifiable credentials related to stock and carbon reduction, secure data sharing, and integration with carbon credit issuance platforms, also using decentralized digital identity (Embrapii 2025c).

Figure 2 Safe Trace solution – simplified illustration

Source: Safe Trace, 2025.

The company using the technology which was visited and interviewed was QIMA, a large organization with offices in Botucatu and global headquarters in Hong Kong. It operates in more than 100 countries through 70 offices and laboratories, serving over 30,000 clients. The company offers food safety certification services, organic and sustainability validation, as well as product inspections and quality assessments throughout the supply chain, expanding its clients' access to global markets, suppliers, and retail networks. It has expertise in fruit and vegetable production, primary animal production, the food industry and animal feed (QIMA, 2025). QIMA estimated that this type of automating data collection and validation processes leads to certification cost reductions of between 20% and 30% (Field research – data obtained from interviewees VP and AH in Botucatu on April 2, 2025).

It is noteworthy that the integration of geomonitoring data with blockchain records - such as that carried out by Safe Trace in verifying deforestation in the Amazon - enables companies to access strategic information and indicators to meet export requirements, such as those of the European Union Deforestation Regulation (EUDR, 2023), facilitating access to relevant international markets. Its data systems are also used to support farm-level management decisions. (Field research – data obtained from interviewees VP and AH in Botucatu on April 2, 2025).

The company already has clients in all regions of Brazil, including groups such as Walmart, Carrefour, Assaí, and Bayer. Its solutions have also been exported to Chile, Mexico, the United States, Canada, China and other markets. It has opened offices in USA and Switzerland (Field research – data obtained from interviewee VP in Botucatu on April 2, 2025). From the two projects carried out by Safe Trace in partnership with Embrapii, 14 intellectual property filings have been registered with the National Institute of Industrial Property (Embrapii 2025c).

3.2.3 Case C – Artificial Intelligence Applied to Soil Spatial Variability

Cropman, based in São Paulo state, is a small technology-based company focused on precision agriculture solutions for site-specific and intelligent crop management (Cropman 2025). The development of the initial AI-based solution - and other enabling technologies - applied to soil spatial variability was carried out in partnership with the Embrapii Unit at ESALQ/USP. At the time, the project's objective was defined as evaluating the application of apparent soil electrical conductivity in identifying the spatial variability of soil compaction in agricultural areas, aiming to characterize soil physical conditions and delineate compaction zones. The goal was to enable rapid and accurate assessment, supporting farmers' decision-making regarding the need for soil decompaction interventions (Embrapii 2025c). Figure 3 illustrates Cropman`s Soil Xplorer solution in use on a rural property in Brazil.

Figure 3 Cropman solution – Soil Xplorer in use on a rural property

Source: Cropman 2025.

The company using the technology which was visited and interviewed was Companhia Agropecuária Monte Alegre, a medium-sized organization based in Barretos. It is the first Brazilian feedlot certified by Rainforest Alliance. Its core business is animal nutrition and beef cattle production, with a static capacity of 20,000 animals (CMA, 2025). Cropman's solution employs an intelligent sampling method that analyzes more than 10,000 points/ha, enabling highly precise identification of effectively compacted areas. As a result, there is an approximate 50% reduction in the need for subsoiling, concentrating intervention only in areas where it is technically justified (Field research – data obtained from interviewee HJ in Barretos on June 27, 2025). Reducing soil disturbance prevents CO_2 emissions, with an estimated mitigation potential of approximately 1 tCO_2eq/ha (metric ton of carbon dioxide equivalent per hectare) in sandy soils and 2.8 tCO_2eq/ha in clay soils. Based on the metrics and criteria of Six et al. (2002), Besen et al. (2018) and IPCC (2019), the company estimates that in an area of 25,000 ha - already serviced by Cropman - the technology has enabled the mitigation of approximately 53,000 tCO_2eq (Field research – data obtained from interviewee HJ in Barretos on June 27, 2025).

The reduction in the use of agricultural machinery can reach up to 70%, lowering fossil fuel consumption and freeing up equipment for other operations, thereby reducing energy costs (NRCS 2022). In the same 25,000 ha area, estimated savings from reduced subsoiling range between US$2.6 million and US$3.9 million. Moreover, the technology enables comprehensive and detailed soil characterization, including physical-chemical and microbiological aspects (Field research – data obtained from interviewee HJ in Barretos on June 27, 2025).

The company has clients in several Brazilian states and in countries such as Argentina, Paraguay, Colombia, and Guatemala. More than 300 clients are already using Cropman's solution developed with support from Embrapii (Cropman 2025).

3.2.4 Case D – Biophotonics Applied to Carbon Stock Certification

Agrorobótica, a small technology-based company headquartered in São Paulo state, defines itself as a green fintech organization providing solutions to support farmers in addressing global challenges such as climate change mitigation and strengthening food security, while generating value through carbon monetization mechanisms and value addition to agricultural commodities (Agrorobótica 2025). The development of the initial biophotonics solution applied to carbon stock certification was carried out by the Embrapii Unit at the Institute of Physics of São Carlos (IFSC/USP) in partnership with Embrapa (Agrorobótica 2025; Embrapii 2025c). At the time, an opportunity was identified to develop an ablation chamber for agro-environmental photonic analysis using the LIBS technique (Laser-Induced Breakdown Spectroscopy), enabling the identification and quantification of chemical elements in agricultural and environmental samples through the interaction of high-energy laser pulses with matter (Embrapii 2025c).

Figure 4 shows the equipment developed and an example report provided by Agrorobótica`s solution, with a thematic soil map indicating a gridcode of cation exchange capacity classes in a specific terrain analysis.

Figure 4 Agrorobótica equipment (a) and example of thematic soil map (b)

(a) (b)

Source: field research – photographic record by the authors – São Carlos, July 7, 2025 and (Agrorobótica 2025).

The technological solution developed enables large-scale, rapid, and precise soil chemical analysis (conducting spectral records with an acquisition rate of 1,200 samples per day), providing a robust database for effective precision (and tropical) agriculture, including carbon stock mapping (Field research – data obtained from interviewee FA in São Carlos on July 7, 2025). Agrorobótica's model allows for a potential generation of carbon credits in the agricultural market equivalent to 1.5 tCO_2eq/ha, with an estimated price of US$30.00 (for this type of credit and market), resulting in US$45.00/ha/year in carbon credit monetization. It is also noteworthy that the solution undergoes auditing under the Verified Carbon Standard – Verra (Field research – data obtained from interviewee FA in São Carlos on July 7, 2025).

The agribusiness company using the technology which was visited and interviewed was Grupo Mitre - Elisa Agro Sustentável, a large organization operating in the municipality of Britânia, Goiás. It manages an area exceeding 8,000 ha, with emphasis on crop-livestock integration systems and the cultivation and processing of cotton, beans, corn, soybeans, and brachiaria in areas irrigated by central pivots. The company has verified multiple economic and environmental gains by using the solution (Field research – data obtained from interviewee EV in Britânia on April 4, 2025).

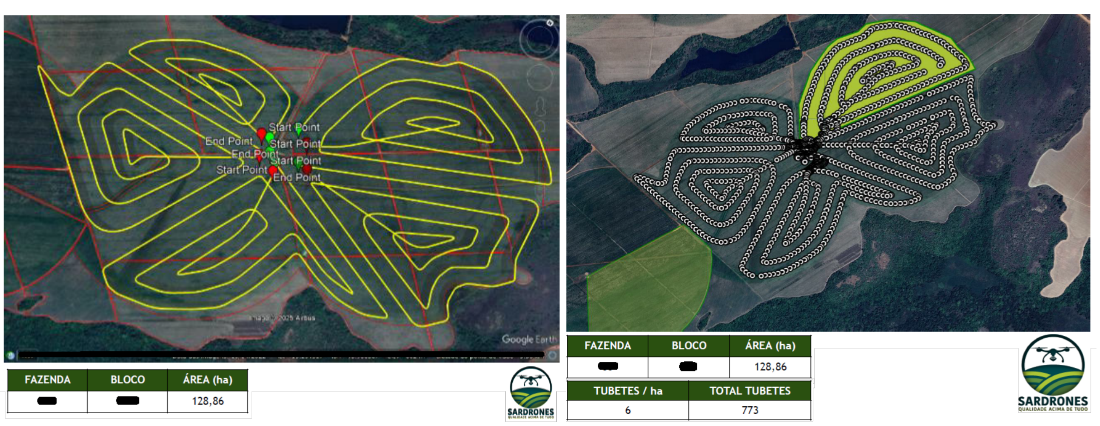
3.2.5. CASE E – Drones Applied to the Dispersion of Biological Agents

Sardrones is a small company also based in São Paulo state. It positions itself as a drone-based service provider focused on biological pest control in agriculture and on the dispersal of native seeds in forests (Sardrones 2025). The development of the initial solution for dispersing biological agents was carried out in partnership with the Embrapii Unit at ESALQ/USP. The EU and the company identified an opportunity for an RD&I project to create and validate airborne dispersal systems capable of releasing different types of biological agents in agricultural and forest areas, with software remote management (Embrapii 2025c).

Cotesia flavipes, a parasitoid wasp, has long been used (although previously applied manually) as a biological control agent against the sugarcane borer, parasitizing it and preventing its development. This practice represents a more sustainable alternative to chemical control, which relies on insecticides to eliminate pests through toxicity and may generate environmental impacts and resistance (Nava et al. 2009; Gomes, Oliveira 2020). The release of this micro-wasp can prevent significant economic losses in sugarcane fields. One hectare of sugarcane with only 1% of stalks attacked by the borer may result in production losses of approximately 30 liters of ethanol and 35 kilograms of sugar. Losses to Brazilian ethanol and sugar mills due to such damage and the need for pest control are estimated at no less than US$745 million per year. The cost of biological control per hectare tends to be up to 40% lower than chemical control (CTC 2016). In addition to being efficient, Cotesia flavipes represents an economically attractive alternative for producers, especially when dispersed via drones (Field research – data obtained from interviewees GS and AR in Ribeirão Preto and Jaboticabal, São Paulo, on August 28, 2025 and September 17, 2025, respectively).

According to the companies providing and using the technology, the solution significantly contributed to productivity and quality gains. Previously, the method used in the fields was manual, with workers entering the sugarcane fields to manually distribute containers (plastic cups) containing Cotesia. Open-field conditions frequently involve intense heat and direct health risks to workers, such as snake bites. With the drone-embedded system, these issues were fully addressed, generating substantial productivity gains and quality improvements. Application precision is incomparably higher, as the dispenser releases the biological agent in a georeferenced manner (enabling traceability) with high accuracy and coverage of up to 300 ha/day (Figure 5). Another advantage is enhanced management intelligence enabled by the flight reports data (Field research – data obtained from interviewees GS and AR in Ribeirão Preto and Jaboticabal, São Paulo, on August 28, 2025 and September 17, 2025, respectively).

Figure 5 Example of flight plan (a) and flight performed by the solution (b)



(a) (b)

Source: actual report provided by Sardrones (client data omitted for privacy reasons).

Another strategic advantage derived from the solution is the expansion of access to premium international markets. Bonsucro certification is the leading global reference for sustainable sugarcane production and is valued or required by buyers in Europe, the United States of America, and Asia. It establishes environmental and management criteria such as reduced pesticide use, adoption of Integrated Pest Management (IPM), biodiversity protection, and mitigation of environmental risks, among others (e.g. criteria 4.3 and 4.4 of the Bonsucro Production Standard Version 5.2, 2023) (Santana Rangel et al. 2024; Bonsucro 2025). Producers who replace chemical inputs with biological agents are therefore better positioned to meet these requirements and to demonstrate compliance during certification audits. The solution is already being used by several sugarcane producers in the Brazilian states of Goiás, São Paulo, and Minas Gerais. In 2024 alone, the company released biological agents (Cotesia flavipes) over an area of 85,000 ha, using 680,000 packages in its dispensers (Field research – data obtained from an interview conducted in Ribeirão Preto, São Paulo, on August 28, 2025).

3.3. Comparative Analysis of the Observed Effects Across the Three Groups

A comparative analysis of the contributions of the technologies as observed by three distinct groups of stakeholders was conducted. For each item (e.g., productivity gains or CO_2 reduction), the number of affirmative responses attributed by each respondent group was considered. The average intensity observed was calculated based on the three groups: Embrapii Units, solution-providing companies and solution-demanding companies (technology users). Results show that the economic and informational benefits of the developed technologies occupy a central position. Productivity gains present a high average intensity (4.33 on a 0 to 5 scale), being widely recognized by all groups. Similarly, benefits such as enhanced management intelligence based on generated data (3.67), integration of data and systems (3.33) and adoption of good agricultural practices (3.33) also showed high intensity levels, indicating consensus among the groups regarding the relevance of these effects. With regards to environmental sustainability, a high average intensity was observed for the overall recognition of the technologies' contribution to this (4.67), while specific environmental effects displayed greater heterogeneity. CO_2 emissions reduction stands out as the most strongly recognized environmental effect, followed by reductions in agrochemical use and energy consumption.

4. Conclusion

According to the parameters and methods used, the information presented allows the interpretation that Embrapii was able to promote agricultural industrial innovation over the period analyzed (2014–2024). There has been an increase in the number of supported projects, volume of funds allocated, engagement with companies of different sizes - particularly micro and small and cooperative projects - and increased intellectual property fillings, fostering the conversion of intellectual capital into industrial property assets and precision agriculture solutions. Enabling technologies such as biotechnology, systems integration and artificial intelligence play a significant role. Chemistry, prototyping, robotics and new materials also contribute to precision agriculture innovation. Within the analyzed case studies, the main economic benefits observed in the application of these technologies in Brazilian agriculture include improved management optimization and increased productivity. The principal environmental gains identified include reductions in CO_2 emissions, energy consumption and use of agrochemicals. Technologies such as blockchain, smart sensors, biotechnology, and artificial intelligence are already being applied in scale in Brazil to enhance product traceability, optimize input use, and reduce environmental impact. These experiences may contribute to new models adapted to the realities of tropical agriculture, increasing access and competitiveness of Brazilian agricultural products in global markets. Precision agriculture innovation thus represents a promising approach to improving resource-use efficiency and strengthening the resilience of agricultural systems in face of climate change.

Funding

This work did not receive any grants from any institution. Field research costs were self-funded by the authors.

Conflicts of Interest

The authors declare no known conflicts of interest.

Acknowledgments

The authors would like to thank the Polytechnic School of the University of São Paulo Management in Automation and IT Research Group (GAESI) and the Brazilian Agency for Research and Industrial Innovation (Embrapii).

References

Agrícola Famosa (2025). Informações institucionais. https://agricolafamosa.com.br/about. Accessed December 29, 2025.

Agrorobótica (2025). A Agrorobótica. https://agrorobotica.com.br. Accessed December 27, 2025.

Banterle A, Cereda E, Fritz M. (2013) Labelling and sustainability in food supply networks: A comparison between the German and Italian markets. *British Food Journal*, doi:10.1108/00070701311331544

Bennett, A., Checkel, J.T., eds. (2014) *Process Tracing: From Metaphor to Analytic Tool*. 1st ed. Cambridge University Press, Cambridge, United Kingdom, doi:10.1017/CBO9781139858472

Besen M, Ribeiro R, Rigo A, Iwasaki G, Piva J. (2018). Soil conservation practices and greenhouse gases emissions in Brazil. *Scientia Agropecuaria*, doi:10.17268/sci.agropecu.2018.03.15

Bonsucro (2025). Production Standard v 5.2. https://bonsucro.com/production-standard/. Accessed September 20, 2025.

Buzan, T (2024). *Mind Map Mastery: The Complete Guide to Learning and Using the Most Powerful Thinking Tool in the Universe*. Jaico Publishing House.

CMA. Informações institucionais. https://www.cma.agr.br/historiacma. Accessed December 29, 2025.

COP30 (2025). Call of Belem for the Climate. Accessed December 26, 2025. https://cop30.br/en/news-about-cop30/documents/call-of-belem-for-the-climate-eng-2.pdf

CROPMAN (2025). Soluções. https://cropman.com.br. Accessed December 30, 2025.

CTC (2016). Causando prejuízo bilionário, broca da cana é um dos maiores problemas das usinas. https://ctc.com.br/causando-prejuizo-bilionario-broca-da-cana-e-um-dos-maiores-problemas-das-usinas/. Accessed January 3, 2025.

De Santana Rangel H., Conceição E.V., Lopes Santos D.F. (2024). The economic value of sustainability certification for sugarcane farms. *Journal of Cleaner Production*, doi:10.1016/j.jclepro.2024.143005

EMBRAPII (2025a). Empresa Brasileira de Pesquisa e Inovação Industrial - Sobre a Embrapii. https://embrapii.org.br/sobre-a-Embrapii. Accessed December 18, 2025.

EMBRAPII (2025b). Unidades Embrapii. https://embrapii.org.br/nossas-unidades. Accessed December 26, 2025.

EMBRAPII (2025c). Sistema Embrapii SRInfo. https://srinfo.embrapii.org.br/. Accessed December 14, 2025.

EMBRAPII (2026). Innovation indicators - Power BI. https://embrapii.org.br/power-bi. Accessed January

10, 2026.

EUDR (2023). European Union Deforestation Regulation. https://eur-lex.europa.eu/eli/reg/2023/1115/oj. Accessed December 3, 2025.

Fundeanu, D.D., Badele, C.S. (2014). The Impact of Regional Innovative Clusters on Competitiveness. *Procedia - Social and Behavioral Sciences*, doi:10.1016/j.sbspro.2014.02.502

Gomes, J.D.A, Oliveira, A.L. (2020). Eficácia para o combate da broca da cana-de-açúcar. *Interface Tecnológica*, doi:10.31510/infa.v17i1.818

Gordon, J.L., Stallivieri, F. (2019). Embrapii - um novo modelo de apoio técnico e financeiro à inovação no Brasil. *Revista Brasileira de Inovação*, doi:10.20396/rbi.v18i2.8653648

Hinkes C, Peter G. (2020). Traceability matters: A conceptual framework for deforestation-free supply chains applied to soy certification. *Sustainability Accounting Management and Policy Journal*, doi:10.1108/SAMPJ-04-2019-0145

IPCC (2019). INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE. Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html. Accessed January 8, 2026.

ISPA (2024). International Society of Precision Agriculture - Precision agriculture definition. Published online. https://www.ispag.org/resources/definition. Accessed: December 20, 2024.

Kim H, Laskowski M. (2017). Agriculture on the Blockchain: Sustainable Solutions for Food, Farmers, and Financing. *SSRN Journal*, doi:10.2139/ssrn.3028164

Llanos-Paredes P. (2023). The effect of applied research institutes on invention: Evidence from the Fraunhofer centres in Europe. *Research Evaluation*, doi:10.1093/reseval/rvad028

Malhi G, Kaur M, Kaushik P. (2021). Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability*, doi:10.3390/su13031318

Mankins J. (1995). Technology Readiness Levels. A White Paper. http://www.artemisinnovation.com/images/TRL_White_Paper_2004-Edited.pdf. Accessed: December 19, 2024.

Nava De, Pinto, A. de S., SILVA, S.D. dos A (2009). Controle biológico da broca da cana-de-açúcar. https://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/746793. Accessed December 17, 2025.

Novak, J.D., Cañas, A.J. (2008) *The Theory Underlying Concept Maps and How to Construct and Use Them.* Florida Institute for Human and Machine Cognition. Pensacola, USA.

NRCS (2022). Reduction in Annual Fuel Use from Conservation Tillage. 2022. https://www.nrcs.usda.gov/sites/default/files/2022-11/CEAP-Croplands-2022-ConservationInsight-FuelSavingswithConservationTillage.pdf. Accessed December 11, 2025.

QIMA (2025). Informações institucionais - nossa história. https://www.qima.com.br. Accessed December 29, 2025.

SAFE TRACE (2025). Conheça a Plataforma Blockchain Safe Trace. https://www.agrotransparencia.com.br. Accessed December 30, 2025.

Sardrones (2025). Biblioteca institucional. https://sardrones.com.br/biblioteca.php. Accessed December 27, 2025.

Schwab K. (2017). *The Fourth Industrial Revolution*. Portfolio Penguin. London, UK.

Six, J., Conant, R.T., Paul, E.A., Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturation of soils. *Plant and Soil*, doi:10.1023/A:1016125726789

UNFCC (2022). Brazil Paris Agreement Nationally Determined Contribution (NDC). ttps://unfccc.int/sites/default/files/NDC/2022-06/Updated%20-%20First%20NDC%20-%20%20FINAL%20-%20PDF.pdf. Accessed January 2, 2026.

Yin, R.K (2018). *Case Study Research and Applications: Design and Methods*. SAGE. Sixth edition. Thousand Oaks, USA

***