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ARTICLE

Economic viability and opportunity cost of on-farm microorganism multiplication units for soybean pest management in Brazil

Viabilidade econômica e custo de oportunidade de unidades de multiplicação de microrganismos On-Farm para o manejo de pragas da soja no Brasil

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Abstract: This case study in Brazil aimed to evaluate the opportunity cost of implementing an on-farm unit for the multiplication of entomopathogenic fungi and bacteria for pest and disease management (On-Farm) in soybean cultivation during the 2022/2023 season. The economic simulation analyzes four multiplication unit models, catering to producers of 50, 200, 500, and 1,000 hectares. To analyze the investment costs for implementing the unit, the costs were estimated for raw materials, labor for the multiplication of biological control agents, and the costs of insecticides and fungicides for conventional management, covering the complete soybean cycle for the 2022/2023 season. Subsequently, the costs of pest and disease control in soybean cultivation were compared for Conventional, Integrated Pest, and On-Farm management to identify the opportunity cost in the exchange relationship between management strategies. The results demonstrate that the savings generated by choosing On-Farm biological control compared to conventional management were approximately 73% for 1,000 ha, 63% for 500 ha, 70% for 200 ha, and 27% for 50 ha, considering only soybean cultivation in the season of implementing the multiplication unit.

Keywords: on-farm production, entomopathogenic microorganisms, biological pest control, opportunity cost analysis, soybean integrated pest management.

Resumo: Este estudo de caso realizado no Brasil teve como objetivo avaliar o custo de oportunidade da implementação de uma unidade on-farm para multiplicação de fungos e bactérias entomopatogênicas para manejo de pragas e doenças (On-Farm) na cultura da soja durante a safra 2022/2023. A simulação econômica analisa quatro modelos de unidade de multiplicação, atendendo produtores de 50, 200, 500 e 1.000 hectares. Para analisar os custos de investimento para implementação da unidade, foram estimados os custos de matéria-prima, mão de obra para multiplicação de agentes de controle biológico e os custos de inseticidas e fungicidas para o manejo convencional, abrangendo o ciclo completo da soja para a safra 2022/2023. Posteriormente, foram comparados os custos de controle de pragas e doenças na cultura da soja para o manejo Convencional, Integrado de Pragas e On-Farm para identificar o custo de oportunidade na relação de troca entre as estratégias de manejo. Os resultados demonstram que a economia gerada pela escolha do controle biológico On-Farm em comparação ao manejo convencional foi de aproximadamente 73% para 1.000 ha, 63% para 500 ha, 70% para 200 ha e 27% para 50 ha, considerando apenas o cultivo de soja na época de implantação da unidade de multiplicação.

Palavras-chave: produção *on-farm*, microrganismos entomopatogênicos, controle biológico de pragas, análise de custo de oportunidade, manejo integrado de pragas da soja.

1 Introduction

With a protein content of approximately 40%, soybeans are an essential food source for both human and animal consumption. They have also generated significant interest as alternatives to meat in diets. Although combating hunger is crucial, it is equally important to promote health by choosing sustainable production alternatives (Penha et al., 2014).

Soybeans (*Glycine max* (*L.*) *Merrill*) originated in northeastern China, with records dating back to 1100 B.C. In the United States, the first record was from 1765. In 1882, Gustavo D'Utra first cultivated soybean in Brazil (Gazzoni, 2018).

Brazil is the largest producer of soybeans in the world, with a production of 140.53 million tons, followed by the United States with 120.48 million tons, Argentina with 51.50 million tons, China with 18.50 million tons, and India with 11.03 million tons in the 2020/2021 season, according to the Food and Agriculture Organization (2021).

According to the National Supply Company (CONAB), in the 2022/2023 season, Brazilian soybean production has reached a planted area of over 43 million hectares, with a total production of 151 million tons and an average yield of 57.98 sacks per hectare (Brasil, 2023a). Specifically, in Mato Grosso do Sul, the planted area has exceeded 4 million hectares, with an average yield of 58.86 sacks per hectare.

Despite the significant growth in soybean cultivation in Brazil, the average productivity per hectare still presents challenges and opportunities for improvement. One of the factors that hinders not only the maximization of soybean production but also that of many other crops is the occurrence of pests and diseases (Martin, 2020; Silva, 2021; Basseto et al., 2022). In a study conducted in China, Zhang (2019) demonstrated that pest insect attacks can lead to losses of up to 20% in soybean production, highlighting the importance of monitoring and controlling pests and diseases.

Stink bugs are the main pests causing damage to soybean crops, feeding directly on the pods and affecting the grain yield and quality. This problem has been increasing each season due to various factors such as high insect populations, low adoption of pest monitoring practices, evolution of insecticide-resistant populations, and indiscriminate pesticide applications, leading to imbalances and rapid resurgence of these insects (Muller et al., 2017).

To reduce the use of agrochemicals, strategies have been developed as part of integrated pest and disease management. Integrated Pest Management (IPM) seeks to promote the balance and health of agroecosystems by applying a combination of preventive, cultural, biological, and chemical measures in an integrated manner (Tinoco et al., 2023).

Among the IPM strategies that have been adopted for pest control is biological control, which presents advantages over conventional methods, such as reducing environmental impact, decreasing risks to human health, and improving the quality of the produced food. Furthermore, the use of biological control can contribute to the preservation of local biodiversity and reduce production costs (Gurr et al., 2016; Muller et al., 2017).

Latin America has vast biodiversity, which has facilitated the development of regional biological control programs, including the export of biological control agents between countries in the region and other continents (Colmenarez et al., 2016).

Entomopathogenic microorganisms have emerged as one of the main biological control strategies used for soybean cultivation. Studies have demonstrated the effectiveness of these strategies in controlling pests, such as soybean caterpillars and brown stink bugs (Farias, 2019; Magalhães, 2020; Souza, 2020). Compared to the conventional agrochemical industry, the biocontrol industry is growing 5.3 times faster (Costa et al., 2020).

While the environmental and health benefits of sustainable agricultural practices are undeniable, their economic viability is crucial for widespread adoption. Farmers, facing constant trade-offs, must consider that choosing one production system means foregoing the benefits of another. This highlights the importance of evaluating agricultural transitions through the lens of opportunity cost, which assesses the true economic implications beyond just direct expenditures by accounting for the value of the foregone alternative. Thus, understanding both direct costs and opportunity costs is essential for guiding decisions toward more sustainable and profitable agricultural futures.

Given the need to adopt management practices that cause less environmental impact as well as economically viable alternatives, the following research question arises: What is the opportunity cost of transitioning from conventional pest management to On-Farm biological management?

To achieve the aim of this study, we analyzed the opportunity costs of implementing an On-Farm multiplication unit for entomopathogenic fungi and bacteria for soybean cultivation in the State of Mato Grosso do Sul, Brazil. We examined the costs of implementing and operating the multiplication unit, simulating farms of different sizes (50, 200, 500, and 1000 ha), as well as the costs of agrochemicals, according to the dosages recommended by agronomic technical assistance operating in the region of Maracaju-MS. By comparing the costs of the two management systems and the financial benefits of the substitution in the short, medium, and long terms, we determined the opportunity cost.

2 Theoretical Foundation

In Brazil, the National Bioinputs Program was conceived to expand and strengthen the sector. One of the Program's actions was the launch of a specific credit line for bioinputs. For the first time, funds were allocated to finance farmers, cooperatives, and companies for the installation and acquisition of equipment for multiplication units to produce bioinputs (Vidal et al., 2021).

According to Ministério da Agricultura Agropecuária e Abastecimento - MAPA (Brasil, 2020), a bioinput is characterized as "...the product, process, or technology of plant, animal, or microbial origin, intended for use in the production, storage, and processing of agricultural products, in aquatic production systems or planted forests, that positively influence the growth, development, and response mechanisms of animals, plants, microorganisms, and derived substances, and interact with the physical-chemical and biological products and processes."

Biological products contain microorganisms or microbial derivatives as active agents, with beneficial potential and natural occurrence. In agriculture, the use of these products as biostimulants and biopesticides has grown, mainly because of research demonstrating their benefits and credibility in integrated crop management systems (Adesemoye, 2017; Vidal et al., 2020).

In addition to commercial biological products, there is the alternative of On-Farm production. On-Farm production allows farmers to multiply fermented broths containing microorganisms on their farms and apply them to their crops. This production method is preferred by farmers as it reduces costs and promotes sustainability in agriculture (Fontes; Valadares-Inglis; Santos et al., 2020).

According to Decree No. 10,833/2021, it is established that "phytosanitary products with approved use for organic agriculture produced exclusively for personal use in organic or conventional production systems are exempt from registration" (Brasil, 2021, § 8).

In the On-Farm bioinput production system, tanks are used where the farmer adds culture medium, water, antifoam agent, granulated sugar, and microbial inoculum. Microbial inoculum is acquired from a registered commercial product. For multiplication, air is injected into the solution through a piping system to ensure aeration, and after 48 h of system operation, the multiplied product is ready for use (Santos et al., 2020).

Multiplication units play a fundamental role as prominent biotechnological tools, offering numerous advantages to farmers. Compared with the acquisition of ready-made commercial products, there is a significant reduction in manufacturing, storage, and transportation costs (Vidal et al., 2021). However, suppose On-Farm production is conducted under inadequate operational conditions. In that case, it can generate contaminating substances, the spread of harmful microorganisms, environmental accidents, and even the production of products that do not meet the desired purpose (Xavier, 2022).

In Brazil, the GAAS – Associated Group of Sustainable Agriculture has been promoting and disseminating good practices to produce soybeans, corn, and cotton, among others. The production practices of these conventional farmers include the use of functional microorganisms, composting and efficient microorganisms, cover crops, syntropy, development of adapted varieties, soil remineralizers, and on-farm multiplication of biological products to promote sustainable agriculture (Costa et al., 2020; Vidal et al., 2021).

When deciding to switch from conventional management to biological management, the farmer must consider the opportunity cost. According to Brannstrom et al. (2019), opportunity costs are relevant in the decision-making process of farmers, particularly when choosing between conventional and organic agricultural practices. Considering the costs and benefits of each option, it is possible to identify the best alternative for farmers in terms of profitability, sustainability, and food security.

In a study on grape production in Brazil, Daminello (2017) evaluated the opportunity cost of adopting integrated pest management practices compared with the use of chemical pesticides. They concluded that integrated pest management resulted in lower production costs and reduced environmental impact while maintaining the quality of production and health of workers.

When comparing the production costs of conventional soybean farming with those associated with Integrated Pest Management (IPM) from the 2013/2014 to 2017/2018 harvests, IPM costs were consistently lower than those in the conventional system. Moreover, production under IPM remained higher throughout the analyzed period, offering lower costs and higher yields. In terms of insecticide use, the conventional system averaged 83% more applications than IPM, which resulted in production costs 110% higher in the conventional system (Staback et al., 2020).

Muller et al. (2017) compared the performance of some chemical and biological products in controlling brown stink bugs in soybeans. Their results demonstrated that, among the tested products, the biological product achieved similar results to the chemical products, which made it more attractive to farmers because of its lower cost.

3 Methodology

3.1 Research area

The study was conducted in Maracaju, Mato Grosso do Sul within the Cerrado biome. The Cerrado is the second largest biome in South America and is located on the Central Plateau, covering approximately 24% of the Brazilian territory. It is recognized as the richest savanna in the world in terms of its biodiversity (Brasil, 2022).

This study was conducted based on the prices practiced in Maracaju, MS, the largest soybean producer in the state of Mato Grosso do Sul. In the 2022/2023 crop season, Maracaju produced a total of 15 million tons of soybeans on 4 million hectares, with an average yield of 70.44 sacks per hectare (Federação da Agricultura e Pecuária Mato Grosso do Sul, 2023). Mato Grosso do Sul ranked as the fifth-largest soybean producer in Brazil during the mentioned crop season (Brasil, 2023b). Brazil is the world's largest soybean producer, reaching 163 million tons in the 2022/2023 season, followed by the United States (117 million tons), and Argentina (48 million tons) (United States Department of Agriculture, 2023).

3.2 Investment data

For the implementation of the multiplication unit, we estimated the costs, including labor costs for masonry construction with PVC ceiling, tiled floor, walls for enhanced hygiene, stainless steel sink, air conditioning, one door, and one window. The labor and raw material costs were calculated to cover a soybean crop season, producing enough to supply farms of 50, 200, 500, and 1000 ha, allowing us to assess the economic feasibility across different farm sizes.

We considered market prices for the equipment required to set up the multiplication unit, along with expenses for labor and raw materials to cover the soybean cycle during the 2022/2023 season (October 2022 to March 2023), based on recommendations from specialized technical assistance in sustainable management in the Maracaju-MS region.

We tabulated the collected data using Microsoft Excel®, categorizing them into the following categories: investment in the multiplication unit, labor costs, and raw materials. This allowed us to identify the total investment required to meet the demand for the soybean crop season.

Conventional, IPM and On-Farm Biological Management Costs.

We estimated the costs of conventional pest and disease management using fungicides and insecticides at dosages recommended by input supplier technicians in the Maracaju-MS region. The cost of agrochemicals was determined based on information from CONAB and input suppliers in the same region.

Finally, to estimate the costs of applying biological agents, we extracted the values from the sum of total investment and raw materials, and divided the total amount by hectares, thus identifying the cost of each product in On-Farm biological management, according to the following formula:

$$Cp = \frac{In + Ma}{Ha} \quad (1)$$

where Cp represents the cost of the product, In is the investment in the multiplication unit, Ma denotes the costs of raw materials combined with labor, and Ha signifies the hectares that this production will serve.

We developed an Integrated Pest Management protocol, in which the applications of biological agents were simulated, and chemical fungicides and insecticides were included at the critical stages of pest and disease attack in soybeans. The costs of Integrated Management were derived from the costs obtained in the Conventional Management and On-Farm Biological Management in this study.

3.3 Opportunity cost

After gathering the investment data for the multiplication unit and the costs of pest and disease management, we tabulated the information using Microsoft Excel. The opportunity cost of a production factor in each situation equals the net income that the factor generates in its best alternative use (Beuren, 1993). Assuming that productivity in both management approaches is similar, we consider only the costs for this analysis, as outlined in the model below:

$$CO = Mb - Mq \quad (2)$$

where: CO represents the Opportunity Cost, Mb is the cost of production in Biological Management, and Mq denotes the cost of agrochemicals in Conventional Management. Thus, it is possible to identify the pest and disease management approaches that are more economically attractive to farmers.

4 Results and Discussion

In this section, we present the research results in three subsections. The first subsection outlines the costs of implementing the multiplication unit, as well as the costs of raw materials and labor for producing bioinputs that cover the soybean cycle. The second subsection compares the costs of IPM, On-Farm biological and conventional management. Finally, we present the results of the opportunity cost in the decision to switch from conventional management to IPM and On-Farm management.

4.1 Multiplication unit implementation and production costs

Table 1 shows the cost breakdown of the investment in the multiplication unit capable of supplying bioinputs for pest and disease management, catering to farms of 1000 ha, 500 ha, 200 ha, and 50 ha.

Table 1. Costs of implementing the multiplication unit.

Item	1.000 ha	500 ha	200 ha	50 ha
Bioreactor Stainless Steel				
Component	Total US$	Total US$	Total US$	Total US$
Tank 1000 L, 500 L, 200 L, 50 L	3362.12	2647.34	1341.08	672.79
Bioreactor Polypropylene				
Component	Total US$	Total US$	Total US$	Total US$
Tank 1000 L, 500 L, 200 L, 50 L	2681.22	2077.11	374.93	177.75
Kit Aerador				
Component	Total US$	Total US$	Total US$	Total US$
Compressor Radial CRC - 2 410 25 SS	696.56	696.56	-	-
Compressor Radial CRC - 2 210 16 SS	-	-	416.4	416.4
Air filter kit; PVC Tube; Clamp; TEE derivation; Short Weldable Adapter	204.03	204.03	203.15	203.15
Total	900.59	900.59	619.57	619.57
Water Kit				
Component	Total US$	Total US$	Total US$	Total US$
Modular Filter 100 1.1/2” Disco 130 M + Ozone water treatment kit	301.34	301.34	301.34	301.34
Extraction Kit				
Component	Total US$	Total US$	Total US$	Total US$
Self-breathing Stainless Steel Centrifugal Motor Pump 1/2hp	258.32	258.32	223.97	81.6
Reduction1”; Hose 1”; Quick hose coupling 1”; Quick adapter for hose 1”; Weldable register 1”; PVC Connector 1”				
Storage				
Component	Total US$	Total US$	Total US$	Total US$
Fermentation tanks 1000L, 500L, 200L, 50L, output1”	3.790.31	1.915.76	616.4	373.28
Other materials				
Component	Total US$	Total US$	Total US$	Total US$
Thread seal tape 18 meters; Pipe glue tube; Sandpaper sheet 180 FPP	42.62	42.62	42.62	42.62

Source: Own preparation, based on quotes from resellers in the Maracaju-MS region and virtual stores.

Table 1. Continued...

Item	1.000 ha	500 ha	200 ha	50 ha
Labor cost				
Component	Total US$	Total US$	Total US$	Total US$
Brickwork 48m²	11157.25	11157.25	-	-
Brickwork 9,00m²	-	-	3.091,60	3.091.60
Air conditioner 12.000 BTUS	614.03	614.,03	307.01	307.01
Total	11.771.28	11.771.28	3.398.62	3.398.62
Total Stainless Steel investment	20.426.57	17.837.25	6.543.59	5.489.82
Total investment Polypropylene	19.745.68	17.267.02	5.577.45	4.994.78
Investment per hectare Stainless Steel	20.43	35.67	32.72	109.8
Investment per hectare Polypropylene	19.75	34.53	27.89	99.9

Source: Own preparation, based on quotes from resellers in the Maracaju-MS region and virtual stores.

As shown in Table 1, the components for implementing the Multiplication Unit are divided into the following categories: bioreactors, which are tanks used to receive the raw material for multiplication; electrical and hydraulic materials, which are essential components for the operation of bioreactor aeration; fermentation tanks, which store the finished product until it is used; costs for masonry construction, which could be replaced by acquiring a container that includes the equipment internally; and air conditioning, which is essential for controlling the ideal temperature for microbial multiplication.

We compared the costs of bioreactors made from two different materials, Polypropylene and Stainless Steel. Polypropylene is resistant to various chemicals and high temperatures, virtually insoluble in all organic solvents at room temperature, and highly resistant to breakage under environmental stress (Ebewele, 2000). Stainless Steel has high corrosion resistance and lower susceptibility to microbial growth (Telles, 2003).

To obtain the bioinput, as recommended by specialized technical assistance, we estimated the costs of raw materials and labor to meet the demand for a complete soybean cycle, in addition to the costs of water used from an artesian well with a lifespan of 30 years and a capacity of 5,000 liters of water per hour. The labor cost estimated in this study was the hiring of a technician responsible for the multiplication and maintenance of the multiplication unit (R$ 3,000.00 per month for six months) (Table 2). However, there is an alternative to hiring technical assistance to perform this work and providing recommendations or even training for the farmer or one of their collaborators.

Table 2. Raw materials and materials used for On Farm multiplication of biological agents for the 2022/2023 soybean harvest.

Component	Total 1000 ha	Total 500 ha	Total 200 ha	Total 50 ha
CRX Culture Medium; Antifoam; Chlorine Neutralizer; Chlorine Identifier; odine; Sodium Hypochlorite; Ammoniacal Detergent; Inocula; Cleaning products; Electric energy; Water (Production + cleaning)*; Labor (technician months)	32.142.25	18.529.88	6.195.69	2.111.98

*Considering the costs for implementing an artesian well, in the Maracaju-MS Region. With costs diluted by the water collection capacity and useful life of 30 years.
Source: Own preparation, based on quotes from resellers in the Maracaju-MS region.

Among the components used for multiplication, as described in Table 2, the Growth Medium provides nutrients for microorganisms to develop, inoculants are the microorganisms that will be multiplied, the Chlorine Identifier is necessary to assess the chlorine level in the water used for multiplication, and the Chlorine Neutralizer specifically neutralizes any chlorine present in the water, thereby preventing it from interfering with the microorganism's development.

For the 200- and 50-hectare areas, we did not include labor costs because, due to the smaller production volume, it is feasible for the farmers themselves to conduct the multiplication without needing to hire additional labor.

4.2 Management costs: conventional, biological on farm and IPM

To calculate the cost of conventional management, we requested technical recommendations for pest and disease management from an agricultural advisory service operating in the Maracaju-MS region. Based on these recommendations, we estimated the cost of agrochemicals (fungicides and insecticides) per application/ha, as shown in Table 3.

Table 3. Costs per dosage for pest and disease control in Conventional Management.

Application date	Active ingredient	Total US$
45 days	Tiametoxam; Acetamiprido; Acefato; Imidacloprido; Fluxapiroxade	65.39
65 days	Tiametoxam; Acetamiprido; Acefato; Imidacloprido; Pirazol Carboxamida	72.43
85 days	Tiametoxam; Acetamiprido; Acefato; Imidacloprido; Estrobilurina, Picoxystrobina; Clorotalonil	56.54
	Total/ha	**194.35**

Source: Own preparation, based on information from the CEPEA website, ABC Foundation and budgets from input resellers in the Maracaju-MS region (Fundação ABC, 2023).

The recommendation of agrochemicals mentioned in Table 3 exemplifies a standard agronomic prescription using insecticides and fungicides commonly used in the study region. However, farmers may apply additional treatments outside the recommended schedule if they perceive the need to further control pests or diseases.

For the conventional management schedule recommended by agronomic advisors in the Maracaju-MS region, three application timings were estimated at 45, 65, and 85 d after planting. However, farmers may conduct corrective applications if pest or disease incidences occur, thereby potentially increasing the conventional management costs.

For biological management, the recommended dosage per hectare was provided by a technical assistance company operating in the Maracaju-MS region, which oversees the implementation and management of the multiplication unit. We estimated the costs per hectare for application after summing the costs of unit implementation and the expenses for obtaining the product after On Farm multiplication (Table 4). Table 5 contains the management costs from the second crop cycle after unit implementation, focusing solely on raw materials and labor costs.

The microorganisms listed in Table 4 are commonly used by technical assistance services in the study region. These microorganisms have undergone performance testing in various studies, proving their efficiency before they are marketed for On Farm multiplication.

As shown in Table 4, it was observed that the 1,000-hectare area has the lowest product cost, as the implementation and labor costs are spread over a larger production area compared to 500 hectares. Similarly, this occurs in production for 200 hectares compared to 50 hectares, where implementation costs are similar but diluted by higher production in the 200-hectare scenario, resulting in lower production costs in the first year.

Table 4. Cost per hectare for pest and disease control in Farm Biological management, referring to the 1st year with investment costs.

Biological Management		1000 ha	500 ha	200 ha	50 ha
Date	**Product**	**Cost w/invest**	**Cost w/invest**	**Cost w/invest**	**Cost w/invest**
In-groove application	*Bradyrhizobium japonicum; Azospirillum brasilense; Bacillus aryabhattai; Bacillus amyloliquefaciens; Bacillus megaterium; Mechanization*	7.90	10.79	8.92	21.17
V3-V4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
V8-V9	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
R3	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
R5.1	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
R5.4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
R7	*Bacillus pumilus; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	6.37	8.69	7.19	16.99
	Total US$/ha	**53.77**	**73.44**	**60.72**	**144.03**

Source: Own preparation, based on the results in Tables 1 and 2.

Table 5. Costs per hectare for pest and disease control in On Farm Biological Management for the 2nd year.

Biological Management		1000 ha	500 ha	200 ha	50 ha
Date	**Product**	**Cost/ha 2nd year**	**Cost/ha 2nd year**	**Cost/ha 2nd year**	**Cost/ha 2nd year**
In-groove application	*Bradyrhizobium japonicum; Azospirillum brasilense; Bacillus aryabhattai; Bacillus amyloliquefaciens; Bacillus megaterium; Mechanization*	4.99	5.72	4.82	6.48
V3-V4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
V8-V9	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
R3	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
R5.1	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
R5.4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
R7	*Bacillus pumilus; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.05	4.63	3.91	5.24
	Total US$/ha	**34.01**	**38.93**	**32.85**	**44.11**

Source: Own preparation, based on the results in Tables 1 and 2.

In biological management, seven applications of bioinputs were recommended, as this type of management is preventive and should occur before pests and diseases reach control levels, unlike in conventional management. The costs of biological management reflect the costs of the year of unit implementation, in which investment costs are embedded in product costs. From the second year of operation onwards, only the costs of producing bioinputs were considered, thereby reducing production costs.

Based on the results from Tables 4 and 5, we compiled a summary (Table 6), presenting the costs per liter of product produced in unit multiplication models using stainless steel and polypropylene bioreactors. This allows the verification of cost differences in implementation across different equipment types.

Table 6. Costs per liter produced, for pest and disease control in On Farm Biological Management, referring to the bioreactor material in the investment.

Item	1000 ha	500 ha	200 ha	50 ha
Stainless steel bioreactor 1st harvest	1.55	2.14	1.87	4.47
Polypropylene bioreactor 1st harvest	1.53	2.10	1.73	4.18
Value L/ha 2nd harvest (without investment)	0.94	1.09	0.91	1.24

Source: Own elaboration, based on the results in Tables 4 and 5.

It should be noted that the difference in costs per liter produced was similar, regardless of the bioreactor material used (Table 6). However, the more liters produced, the greater the dilution of implementation costs, thereby reducing costs in the simulation for 1,000 ha and 200 ha.

Polypropylene bioreactors provide suitable conditions for running the multiplication unit and have lower acquisition costs than stainless steel bioreactors (Table 6). In the second crop season, production costs remained the same because investment costs were amortized in the first season, and only raw material and labor costs were considered. Table 7 shows the savings generated by choosing to invest in the multiplication unit using the cheaper option.

Table 7. Costs per hectare for pest and disease control in Integrated Pest Management (IPM), referring to the 1st year with investment costs.

IPM		1000 ha	500 ha	200 ha	50 ha
Date	Product	Cost/ha 1nd year	Cost/ha 1nd year	Cost/ha 1nd year	Cost/ha 1nd year
In-groove application	*Bradyrhizobium japonicum; Azospirillum brasilense; Bacillus aryabhattai; Bacillus amyloliquefaciens; Bacillus megaterium; Mechanization*	7.90	10.79	8.92	21.17
V3-V4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
V8-V9	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Orkestra; Sperto Mechanization*	33.23	36.12	34.25	46.5
R3	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
R5.1	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Vessarya; Engeo Pleno; Mechanization*	48.83	51.72	49.85	62.1

Source: Own preparation.

Table 7. Continued...

IPM		1000 ha	500 ha	200 ha	50 ha
Date	**Product**	**Cost/ha 1nd year**	**Cost/ha 1nd year**	**Cost/ha 1nd year**	**Cost/ha 1nd year**
R5.4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	7.90	10.79	8.92	21.17
R7	*Bacillus pumilus; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	6.37	8.69	7.19	16.99
	Total US$/ha	**120.03**	**139.69**	**32.85**	**44.11**

Source: Own preparation.

The suggested Integrated Management protocol consists of On-Farm Biological Management, with the inclusion of chemical fungicides and insecticides at stages V8-V9 and R5.1, as recommended by technical assistance.

Tables 7 and 8 present the costs of an Integrated Management protocol, developed with technical assistance, which combines On-Farm Biological Management with Chemical Management. Chemical insecticides and fungicides were included at the critical stages of the soybean cycle, where pests commonly begin to cause economic damage.

Table 8. Costs per hectare for pest and disease control in Integrated Pest Management (IPM), referring to the 2nd year.

IPM		1000 ha	500 ha	200 ha	50 ha
Date	**Product**	**Cost/ha 2nd year**	**Cost/ha 2nd year**	**Cost/ha 2nd year**	**Cost/ha 2nd year**
In-groove application	*Bradyrhizobium japonicum; Azospirillum brasilense; Bacillus aryabhattai; Bacillus amyloliquefaciens; Bacillus megaterium; Mechanization*	4.99	5.72	4.82	6.48
V3-V4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
V8-V9	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Orkestra; Sperto Mechanization*	30.31	31.04	30.14	31.8
R3	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
R5.1	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Vessarya; Engeo Pleno; Mechanization*	45.92	46.65	45.75	47.41
R5.4	*Bacillus pumilus; Bacillus subtilis; Bacillus thuringiensis subsp. Kurstaki; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.99	5.72	4.82	6.48
R7	*Bacillus pumilus; Bacillus thuringiensis subsp. aizawai; Cromobacterium subtsugae; Compost Tea; Mechanization*	4.05	4.63	3.91	5.24
	Total US$/ha	**100.27**	**105.18**	**99.1**	**110.36**

Source: Own preparation.

Table 9 presents the savings generated from the choice to invest in the Multiplication Unit by selecting the most cost-effective option. The costs for Biological Management and Integrated Pest Management are shown, in addition to Conventional Management, where only the costs of the products are included.

4.3 Opportunity costs

To assess the opportunity costs, the costs of each management were compared, considering the investment in the multiplication unit in the first year and, from the second year onwards, only the costs of obtaining the raw material and multiplying by the biological agents to obtain the product (Table 9).

Table 9. Annual cost of managements, with investment of the multiplication unit in the 1st harvest and 2nd harvest without investment, compared to conventional management.

2nd harvest	1.000 há	500 ha	200 ha	50 ha
Conventional Management	194.354.39	97.177.19	38.870.88	9.717.72
IPM	100.266.29	52.591.90	19.820.50	5.518.18
On Farm Bio Management	32.142.25	18.529.88	6.195.69	2.111.98
Savings per hectare IPM vs. Chemical	94.09	89.17	95.25	83.99
Savings per hectare Biological vs. Chemical	162.21	157.29	163.38	152.11
Total Savings IPM vs. Chemical	**94.088.10**	**44.585.29**	**19.050.38**	**4.199.54**
Total Savings Biological vs. Chemical	**162.212.14**	**78.647.32**	**32.675.19**	**7.605.74**

Source: Own elaboration, based on the results in Tables 3, 6, 7 and 8.

Table 9 shows the viability of On Farm multiplication. Even If pests reach the control level and the use of agrochemicals is necessary, as per IPM, cost reduction will be advantageous, except for production on 50 ha in the year of implementing the Multiplication Unit. From the second harvest onwards, IPM is beneficial for small farmers.

Table 10 shows, in percentage terms, the savings generated by choosing On Farm biological control and IPM over conventional management. In the first harvest, the investment costs of setting up the multiplication unit, raw materials, and labor. In the following harvest, we considered only raw materials and labor.

Table 10. Annual savings of On Farm biological control and IPM compared to conventional management.

Manegement	1.000 ha	500 ha	200 ha	50 ha
IPM 1st Harvest	38%	28%	35%	-8%
Biological 1st Harvest	73%	62%	69%	26%
IPM 2nd Harvest	48%	46%	49%	43%
Biological 2st Harvest	83%	81%	84%	78%

Source: Own elaboration, based on the results in Table 9.

It is important to consider that the multiplication unit can produce bio-inputs for other crops, such as corn, which is a very important crop in the analyzed region, especially in the crop rotation system. Thus, the adoption of On-Farm biological control can bring benefits not only to soybean cultivation but also contribute to more sustainable and economical agriculture.

Considering the results in Table 10, we projected the savings generated over ten years from switching from conventional management to alternative management (Table 11).

We also present the quantity of liters of agrochemicals that will no longer be applied in soybean production for pest and disease control, according to technical assistance recommendations in the Maracaju-MS region, over a decade.

Table 11. 10-year projection, from the change from conventional management to On Farm biological management.

Management	1000 ha	500 ha	200 ha	50 ha
Financial savings IPM	921.135.30	428.585.91	184.926.36	37.000.62
Financial savings Bio On Farm	1.600.505.52	768.271.02	320.800.41	70.969.14
Liters of agrochemicals avoided IPM	66.500	33.250	13.300	3.325
Liters of agrochemicals avoided Bio On Farm	84.500	42.250	16.900	4.225

Source: Own elaboration, based on the results in Tables 3, 6, 7 and 8.

Despite all the financial savings generated by choosing On Farm production, one of the challenges in adopting this method lies in the production process, which, despite improvements, still faces the issue of contaminants, whether due to lack of adequate equipment, poor-quality raw materials, or a shortage of specialized professionals (Mazaro et al., 2022).

Cruvinell et al. (2022) conducted a field experiment between 2012 and 2022 in Goiás to compare the costs and profitability of conventional and biological management. Biological management with On Farm-produced inputs reduced production costs by 58.6%. The authors observed a 13% increase in productivity and 175% increase in soybean crop profitability, demonstrating the economic benefits of substituting agrochemicals with On Farm biological control.

Salviano (2021) conducted a study on sustainable practices in soybean farming in Rio Verde-GO by interviewing managers from various segments of the soybean farming chain. According to the manager of Cooperativa Comigo, biological inputs not only promote soil sustainability and improve fertility through the reproduction of natural microorganisms but also have a final cost up to 40% lower than that of chemicals. Considering the continuous application of biological inputs over 5 to 10 years, there is natural stabilization in pest control, reducing the number of applications and potentially lowering costs by up to 80% while maintaining or increasing productivity.

Although cost reduction represents a significant opportunity, On Farm multiplication of microorganisms requires rigor in all processes and technical oversight to ensure product quality. Costs should not only be considered a competitive factor but also a means of control to enhance all processes (Lima, 2023).

According to Associação dos Produtores de soja do Mato Grosso do Sul (2022), soybean production costs for the 2022/2023 harvest increased by 26.6% compared to the previous season. The search for alternatives to reduce production costs is crucial for soybean producers to shield themselves from price volatility, thereby ensuring the sustainability and continuous profitability of their operations.

With the savings generated by replacing conventional management with the implementation of a multiplication unit for pest and disease control, farmers can allocate their resources to other investments, such as acquiring photovoltaic solar energy, precision agriculture investments, and other actions that promote more sustainable production practices.

5 Conclusions

Our findings unequivocally demonstrate the financial viability and long-term advantages of adopting on-farm multiplication units for bio-inputs in soybean cultivation in Mato Grosso do Sul, Brazil. Beyond promoting sustainability, this transition offers a strong economic incentive, with substantial savings reaching up to 73% in the initial harvest for large-scale producers.

This study, while providing a robust economic analysis, has certain limitations that warrant attention. First, the analysis did not delve into the technical risks of contamination in on-farm production. The viability of bio-inputs depends on strict quality control, and contamination by pathogens or loss of efficacy can impact productivity and incur unforeseen costs. Another important limitation is the non-inclusion of regulatory barriers to the on-farm production and use of bio-inputs. Brazilian legislation on this topic is still evolving, and the lack of a clear regulatory framework can lead to legal uncertainty and bureaucracy, directly affecting producers' investment decisions. Finally, although the economic feasibility analysis considered different production scales, the study did not detail the adoption profile of small-scale producers, who may face significant barriers such as initial investment and the need for technical training.

Based on the results, the study shows that adopting on-farm bio-input production units is an economically viable and sustainable solution for agribusiness. The main practical implication is the economic feasibility of these units, which not only generates significant savings and a quick return on investment, but also reduces the dependency on chemical inputs, minimizing environmental and health impacts. Furthermore, local bio-input production increases producer autonomy, allowing for more flexible management and the optimization of financial resources for other investments.

For these benefits to be widely adopted, support from specific public policies is crucial. The study suggests that the government should implement fiscal incentives for producers who invest in these technologies, create facilitated credit lines with reduced interest rates for the implementation of the units, and strengthen training and rural extension programs. These measures are essential to remove entry barriers and accelerate the transition to a more resilient and advantageous agricultural model.

Authors' contributions

DW: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project management, Software, Validation, Visualization, Writing (original draft), Writing (review & editing). MMS: Formal analysis, Funding acquisition, Investigation, Methodology, Project management, Supervision, Validation, Visualization, Writing (review & editing). TC: Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing (review & editing).

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Conflicts of interest:

Nothing to declare

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Not applicable

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Research data is available upon request

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