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Cost-Benefit Analysis of Integrated Pest Management in Soybean Crops in the Midwest Region of Brazil

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Title Page

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Keywords: Biological control, Environmental cost; Sustainable management; Crop Production; Insects; Agribusiness.

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Declarations

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Not applicable.

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Availability of data and materials

Data will be made available if requested.

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Abstract: Soybean is the most traded agricultural commodity in the world and the main agricultural product exported by Brazil. The study was conducted in Midwest region of Brazil, during the 2018/2019 harvest. The conventional pest management carried out by the rural producer and the integrated pest management with biological control carried out by the MS Foundation were compared. After data collection, operational costs were calculated for both managements and subsequently an environmental cost and a cost-benefit analysis of the application of chemical pesticides were performed. An adapted model of environmental cost and cost-benefit analysis was used. The results show the economic viability of adopting biological control in one of the tested areas. This was due to the greater amount of pesticide applications by the farmer in conventional management, showing the importance of analyzing the environmental cost of the pesticides and avoiding products that have a high impact on non-target individuals.
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1. Introduction

Exotic species are a threat to natural and managed ecosystems (Pejchar; Mooney, 2009; Simberloff et al., 2013) in such a way that they may cause significant ecological and economic impacts (Valente et al., 2018). Costs for controlling insect invasions worldwide are estimated at US$ 70 billion per year at least (Bradshaw et al., 2016). An alternative for the control of these pests in agricultural production is integrated pest management (IPM). This type of management integrates actions that aim to reduce pests in a given crop. Thus, the actions taken reduce the development of pests and consequently decrease the use of chemical inputs and the economic, environmental, and human health risks (FAO, 2017).

Among the actions carried out in this management is the classic biological control. It is a useful strategy for the management of non-native species, identified as pests in an area. Thus, the use of this control occurs via identification of species considered an issue and the introduction of a natural enemy to it seeking the permanent control of the pest (Kenis et al., 2017). The use of classic biological control in agricultural production is associated with a need to reduce the dependence that this traditional production has on the use of pesticides and synthetic fertilizers during the production process. It also ensures a sustainable agricultural management in relation to natural resources, increasing productivity and income for rural producers (Launio et al., 2020).

There have been several initiatives related to classical biological control in the world. However, analyses that identify economic costs and benefits of this practice are difficult to find (Greathead, 2003; Kenis; Branco, 2010; Naranjo et al., 2015; Valente et al., 2018). Such scarcity of information can be justified by the lack of funding for monitoring the entire process of implementing biological control, difficulty in evaluating this process, or attribution of values to externalities (McFayden, 2008; Cock et al., 2015; Valente et al., 2018). However, there are some of these studies, such as on potato tubers in Tunisia (Walker; Crissman, 1996), weed control in Australia (McFayden, 2008), coconut production in Benin (Oleke et al., 2013), papaya in India (Myrick et al., 2014), and eucalyptus in Portugal (Valente et al., 2018).

The purpose of this study is to analyze the economic cost and benefit of using integrated pest management in soybean production. Among the most severe pests to soybean are bedbugs. They cause damage to crops because they suck the grains and pods, thus decreasing the quality of grains (Fritz et al., 2008; Thancharoen et al., 2018). Soybean is the most traded agricultural commodity in the world and the main agricultural product exported by Brazil (COMTRADE, 2018; Escobar et al., 2020). In addition, Brazil is the largest producer and exporter of this grain in the world, together with the United States (OECD/FAO, 2017; Cattelan; Dall'Agnol, 2018). Altogether, farmers in Brazil planted over 75 million hectares of land in 2019, of which 47% were occupied by soybeans (IBGE, 2020).

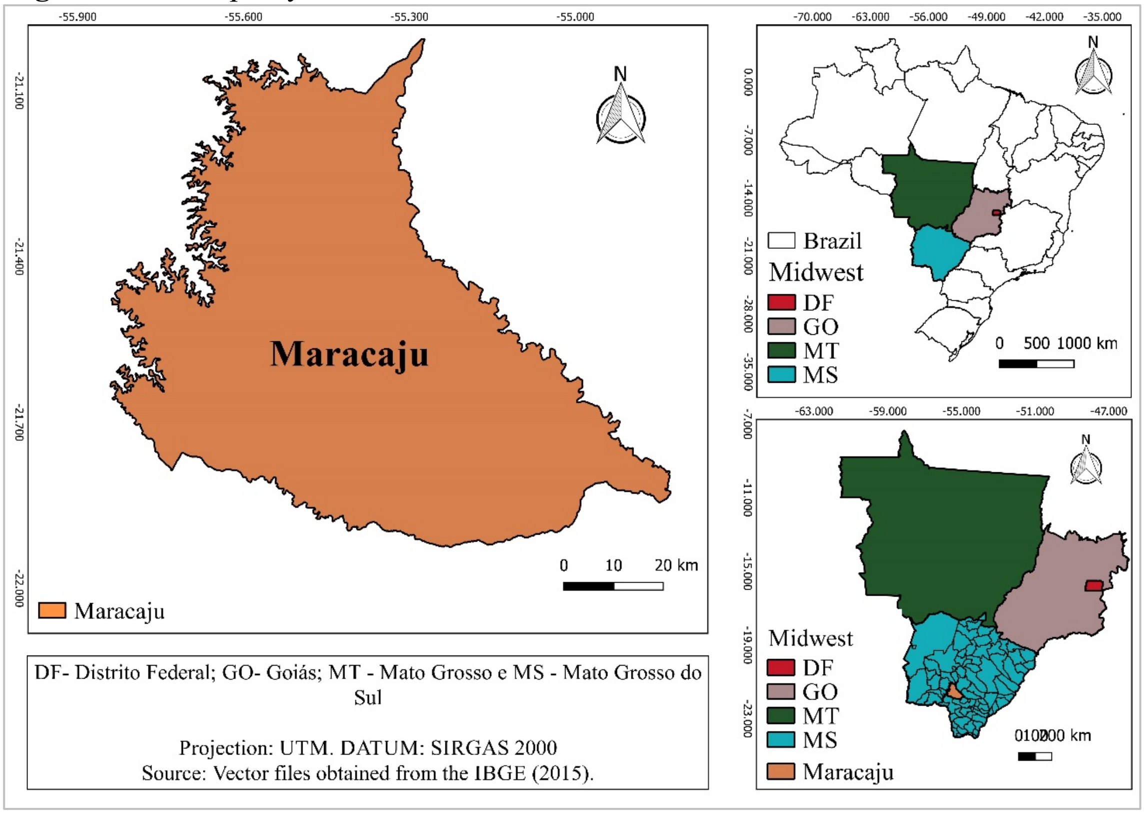
Brazil's initiative for biological control in soybean crops began in 1979 with the introduction of the parasitoids *Trissolcus basalis* and *Telenomus podisi*. These parasitoids parasitize bedbug eggs, feed, and develop inside the eggs until they hatch and feed with nectar as adults. Field research carried out by Embrapa Soja showed the viability of these parasitoids for an effective pest control comparing with similar chemical controls, and that this method has been used and improved over the years (Corrêa-Ferreira et al., 2002). In this study, this parasitoid was used in an integrated pest management. In addition, this study was conducted in the Midwest region of Brazil. This region is a productive highlight in the production of monocultures such as soybeans (IBGE, 2020).

2. Materials and Method

2.1 Location and characterization of the area

The areas of the experiments are in the Municipality of Maracaju, state of Mato Grosso do Sul, in the Midwest region of Brazil (Figure 1).

Figure 1: Municipality Location



The experiments were conducted by the MS Foundation in three areas of rural producers with 20 hectares each. The study was carried out from October 2018 to March 2019, covering the 2018/2019 harvest. Each area was divided into two equal parts, so that it was possible to compare the traditional management using chemical insecticides for the control of caterpillars and bedbugs and the productive management using classic biological control. To perform this biological control, the parasitoids *Telenomus podisi* and *Trichogramma pretiosum* were used.

Five thousand eggs of the parasitoid *Telenomus podisi* were released for the control of the bedbug complex and 100 thousand eggs of the parasitoid *Trichogramma pretiosum* were released for the control of the caterpillar complex in the crop. The eggs were released with the aid of a *dispenser* coupled to a drone, which flew over the area at a height of 20 m, with flight lines spaced 30 m apart. In addition, in the area of release of biological control agents, when the pests reached the level of control determined for each pest in Brazil (Hoffmann-Campo et al., 2000), chemical insecticides were applied. The use of these applications was necessary because isolated control strategies do not guarantee success.

Weekly samplings were carried out in all experimental areas at ten random points per area. At each point, sampling was performed using the tapping cloth technique. The number of pests per meter of line was recorded. In addition, the number of insecticide applications used to control the caterpillar and the bedbug complex was recorded. This sampling was carried out in both areas in order to quantify the pests in each treatment. In the area of conventional pest management, monitoring was carried out as described above. The control was carried out in accordance with previously established control levels. This area was called conventional management because the pest control used exclusively chemical insecticides.

All applications were carried out with the help of a trailed sprayer with a capacity of 2,000 liters of syrup. In the area of biological control, whenever necessary, applications were made three days before each release or five days after the release of natural enemies to avoid any interference from the released agents and possible interactions with the sprayed broth. The data obtained were used to plot population fluctuation graphs of soybean pests in the three areas of the assay. The data were subjected to analysis of variance, and the treatment means were compared by Tukey test ($p<0.05$).

The cost information for the investments made in each area was estimated through budgets at local resellers. For the analysis of biological control costs, budgets were calculated for the purchase of parasitic eggs at the applied quantities and for the purchase of a drone, as well as training costs in releasing these parasitic eggs. The application of the parasitoids by a third party company was also budgeted, without the need to purchase the drone.

2.2 Analysis of operating and environmental costs

To carry out the cost-benefit analysis, it was decided to use the equation proposed by Belarmino (1992), considering that it was better suited to the characteristics of the study, where:

$$CB = \frac{(\mathrm{PI}) x\ (EC)}{(\mathrm{PP}) x\ (ECP) x\ (AL)} \tag{1}$$

CB is the cost-benefit, PI is the price of the insecticide (price of the product at the dosage used), EC is the environmental cost, PP is the product's performance, ECP is the effective control period, and AL is the avoided loss.

PI was estimated after the collection of local information. To estimate the environmental cost of applying an agrochemical substance, Belarmino (1992) proposes to use the following parameters: operator safety, toxicity to bees, birds, aquatic animals, and natural enemies. These components can be estimated by:

Operator safety (OS): This calculation was included due to the toxicological effects on human health, which lead to acute and chronic implications.

$$OS = \frac{DL_{50}\ ORAL + DL_{50}\ DERMAL}{DOSE\ (M.C./ha)}\ x\ 10 \qquad (2)$$

Where: DL_{50} Oral = Ingested dose capable of killing 50% of a population. DL_{50} Dermal = Contact dose capable of killing 50% of a population. The value is divided by the dosage used per hectare. Multiplying by ten is necessary to avoid values lower than the unit and to enable the transformation into the following equivalences: Score 1 = OS > 1,000; Score 2 = OS between 200 and 1,000; Score 3 = OS between 50 and 200; Score 4 = OS between 10 and 50; Score 5 = OS < 10

Toxicity to bees (TB): This calculation was included due to the importance of bee pollination for the reproduction and maintenance of various plant species in the entire ecosystem. The formula is as follows:

$$TB = \frac{DL_{50}\ CONTACT}{DOSE\ (M.C./ha)}\ x\ 1000 \qquad (3)$$

The equivalences of this analysis are similar as those used for operator safety analysis: Score 1 = TB > 1,000; Score 2 = TB between 200 and 1,000; Score 3 = TB between 50 and 200; Score 4 = TB between 10 and 50; Score 5 = TB < 10

Toxicity to birds (TBi): Information included due to the importance of birds in the ecosystem. As they feed on insects and grains in crops, they become contaminated with the agrochemicals used in traditional management, causing population disorders.

$$TBi = \frac{DL_{50}\ ORAL}{DOSE\ (M.C./ha)}\ x\ 100 \qquad (4)$$

The equivalences of this analysis refer to effects on birds: Score 1 = TBi > 1,000; Score 2 = TBi between 200 and 1,000; Score 3 = TBi between 50 and 200; Score 4 = TBi between 10 and 50; Score 5 = TBi < 10

Toxicity to aquatic animals (TA): The information was included to highlight disturbances caused to rivers, such as mortality of fish that feed on aquatic fauna, also generating population disorders for aquatic animals.

$$\mathrm{TA} = \frac{\mathrm{CL_{50}\ ORAL}}{\mathrm{DOSE\ (M.C./ha)}} \text{ x } 100 \qquad (5)$$

The equivalences of this analysis refer to effects on aquatic animals:

Score 1 = TA > 1,000; Score 2 = TA between 200 and 1,000; Score 3 = TA between 50 and 200; Score 4 = TA between 10 and 50; Score 5 = TA < 10

Toxicity to natural enemies (TN): The impact on natural enemies, one of the most important indicators of environmental cost, reveals how much a certain pesticide reduces parasitism or predation of beneficial insects in crops (Belarmino, 1992). To obtain the results of insecticide selectivity over natural enemies, the research by Netto et al. (2014) was considered.

The equivalences of this analysis refer to the reduction of parasitism or predation: Score 1 = Reduction of 0 to 20%; Score 2 = Reduction of 20 to 40%; Score 3 = reduction of 40 to 60%; Score 4 = Reduction of 60 to 80%; Score 5 = Reduction of 80 to 100%

Environmental persistence factor (EPF): This factor measures the time the component residues stay in the soil. The values were obtained from the package inserts of the products and from the works of Marchetti and Luchini (2004), Júnior and Franco (2013), and Nogueira (2015).

The equivalences of this analysis are: Score 1 = EPF between zero and one week; Score 2 = EPF between one and two weeks; Score 3 = EPF between two and three weeks; Score 4 = EPF between three and five weeks; Score 5 = EPF > five weeks.

After collecting this information, the environmental cost is estimated using the general index (GI), as follows:

$$\mathrm{GI} = \mathrm{OS} + \mathrm{TN} + \mathrm{EPF} + \mathrm{BI} \qquad (5)$$

Where: GI = is the general index. Sum of scores of operator safety (OS), toxicity to natural enemies (TN), environmental persistence (EPF), and toxicity to biological indicators, birds, bees, and aquatic animals (BI).

After obtaining the GI, the environmental cost (EC) is determined based on the application of equality proposed by Belarmino (1992):

$$EC = (GI - 4) \text{ x } 0.625 \quad (6)$$

After obtaining the environmental cost value, other information is necessary to estimate the cost-benefit, namely:

Product performance factor (PPF): This factor determines the product's technical efficiency in pest control. To obtain the information used in this calculation, the studies by Grigolli (2016, 2017, 2018) were used.

$$PPF = \frac{\text{MEAN EFFICIENCY ABOVE 80\%}}{{}^{4}/_{\text{number of efficient dataes}}} \quad (7)$$

Effective control period factor (ECP): The assay observation period; this is the period in days of data collection of the control test. To obtain this information, the results of Grigolli's research (2016, 2017, 2018) were used.

$$ECP = \frac{\text{EFFECTIVE CONTROL PERIOD (ECP)}}{\text{ASSAY OBSERVATION PERIOD (AOP)}} \quad (8)$$

Avoided loss factor (AL): this factor considers production losses caused by pests avoided by the use of pesticides. Data were obtained from the studies of Grigolli, (2016, 2017, 2018) (unpublished data). The equivalences are: Score 1 = 0 to 100 Kg/ha**;** Score 2 = 100 to 200 Kg/ha**;** Score 3 = 200 to 300 Kg/ha**;** Score 4 = 300 to 400 Kg/ha**;** Score 5 = > 400 Kg/ha.

3. Results and Discussion

3.1. Soybean production and revenue

Area 1: The results obtained in this evaluated area showed no marked effects of the release of biological control agents in the bedbug population because the population peaks in the area with release and in the area without release are similar, indicating that there was no delay in infestation as expected (Figures 2 and 3). The applications of chemical control and biological control were demarcated according to connotations below:

Biological control: *Trichogramma pretiosum* *Telenomus podisi*

Chemical control: Bedbugs Caterpillars

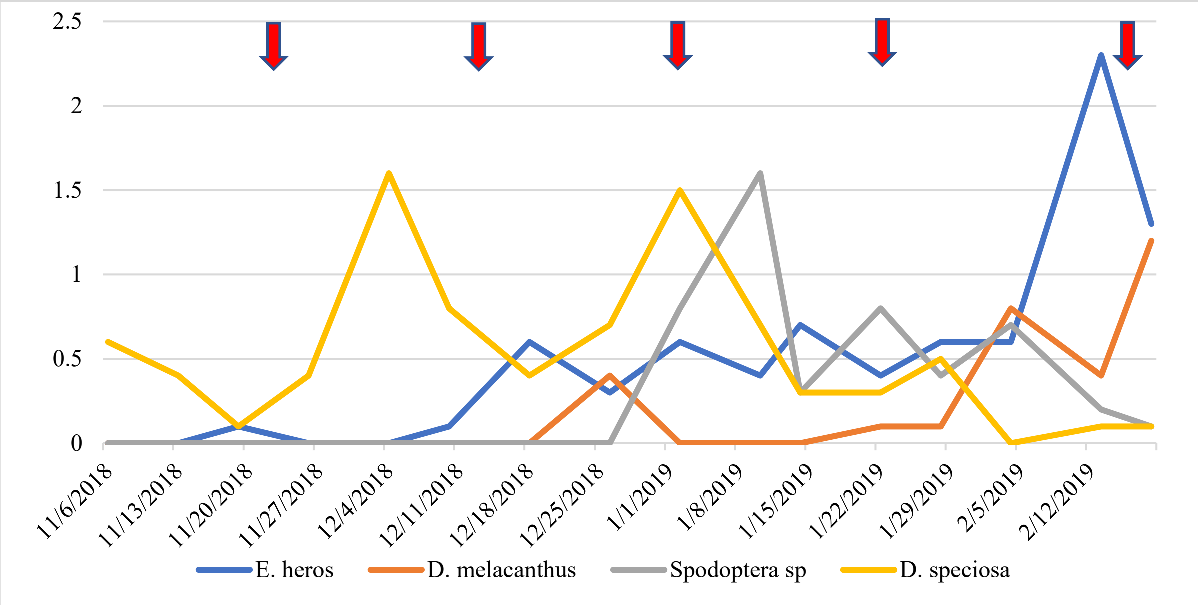


Figure 2. Area 1 - Results of chemical applications carried out according to the producer's management in Area 1 soybeans to control *E. heros* in MS in the 2018/2019 harvest.
Source: Prepared by the author based on the results of this study.

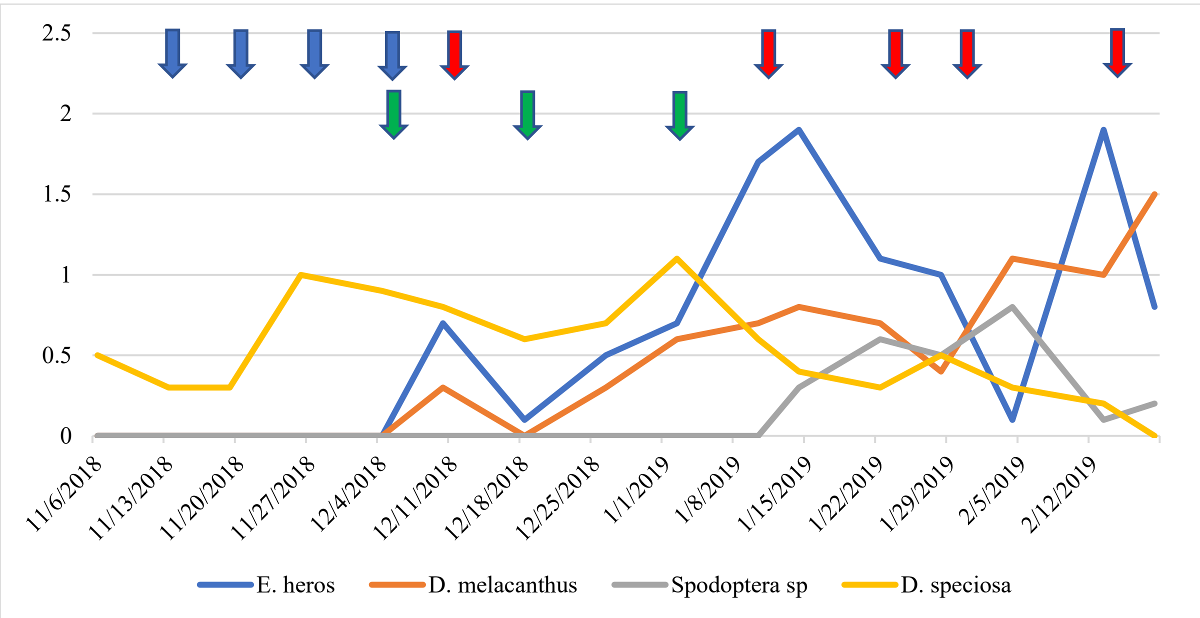


Figure 3. Area 1 - Results of the applications of *T. podisi* and *T. pretiosum* for the biological control and chemical applications carried out in soybean Area 1 according to the strategies of using IPM in MS in the 2018/2019 harvest.
Source: Prepared by the author based on the results of this study.

There were no differences in the number of chemical insecticide applications between areas. It is worth mentioning that, in this case, the management of the producer followed the control levels and that the applications were carried out when they reached the control level. Probably due to this characteristic, there was no change in applications. As for grain yield, there were no significant differences between treatments (Table 1).

Table 1. Number of chemical insecticide applications, grain yield (bag ha^{-1}) in the area of IPM, and producer management. Maracaju, MS, Brazil, 2019.

Area 1	**Number of Applications of Chemical Insecticides**		**Grain Yield (bag ha^{-1})**
	Caterpillars	**Bedbugs**	
IPM area	0	5	54.3 a
Producer Management	0	5	49.4 a
T test	---	---	2.01^{ns}
CV (%)	---	---	7.23

Note: Means followed by the same lowercase letter on the row do not differ statistically from each other by t test at 5% probability. ^{ns} not significant; * and ** significant at 5% and 1% probability, respectively.

Area 2: In this area, the releases of *T. podisi* contributed to a smaller population of the pest in November. The release of *T. pretiosum* was extremely effective, completely eliminating the need for chemical insecticide applications for the control of caterpillars (Figures 4 and 5).

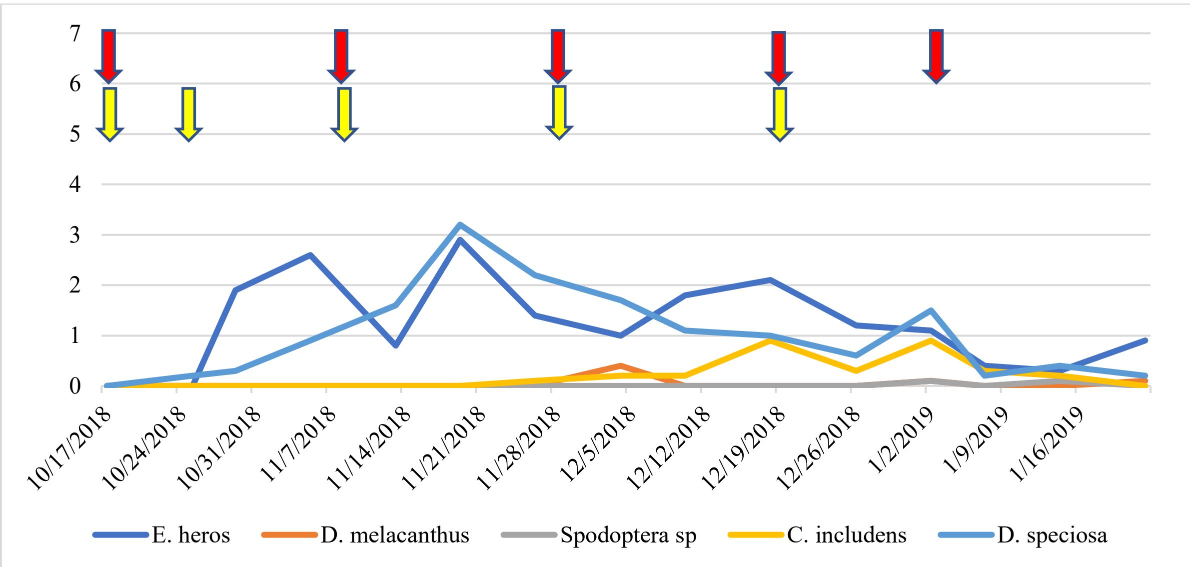


Figure 4. Area 2 - Results of chemical applications carried out according to the producer management in Area 1 to control *E. heros* in MS in the 2018/2019 harvest.
Source: Prepared by the author based on the results of this study.

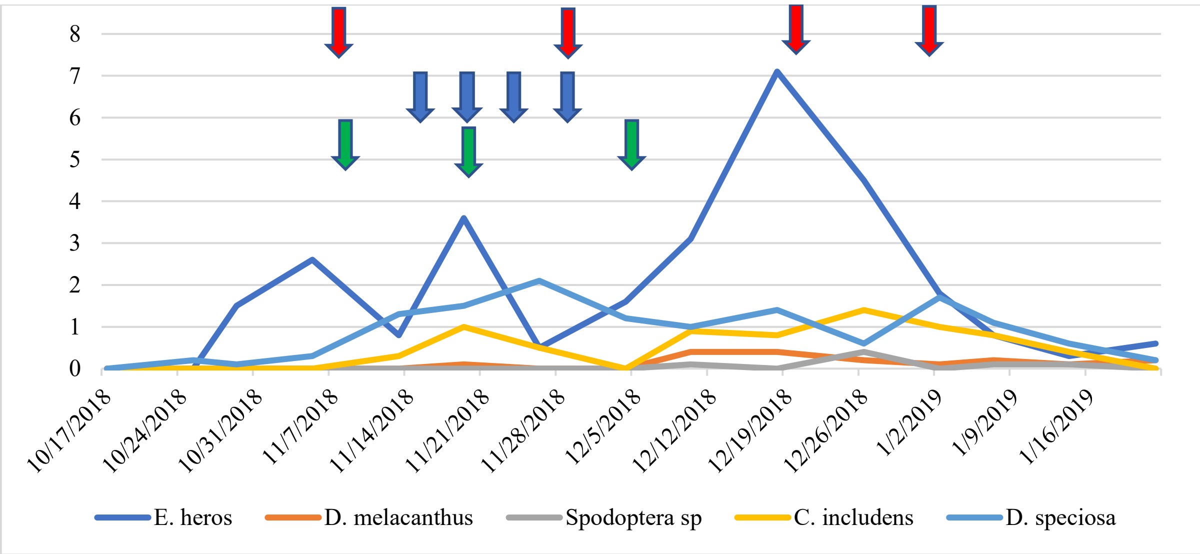


Figure 5. Area 2 - Results of the applications of *T. podisi* and *T. pretiosum* for the biological control and chemical applications carried out in soybean Area 2 according to the strategies of using IPM in MS in the 2018/2019 harvest.
Source: Prepared by the author based on the results of this study.

As for the number of chemical insecticide applications for the control of caterpillars, there was a positive result. In the area with the release of *T. pretiosum* (biological management), no chemical insecticide application was necessary, while in the other area (producer management), five applications were necessary. For bedbugs in the IPM area, four applications were necessary, while in producer management there were five applications (Table 2). This result indicates that the IPM area with the release of biological control agents reduced by six the applications of chemical insecticides in relation to that of producer management.

Table 2. Number of chemical insecticide applications, grain yield (bag ha-1) in the area of IPM and that of producer management. Maracaju, MS, Brazil, 2019.

Area 2	**Number of Applications of Chemical Insecticides**		**Grain Yield (bag ha^{-1})**
	Caterpillars	**Bedbugs**	
IPM area	0	4	64.7 a
Producer Management	5	5	62.0 a
T test	---	---	1.74^{ns}
CV (%)	---	---	9.45

Note: Means followed by the same lowercase letter on the row do not differ statistically from each other by t test at 5% probability. ^{ns} not significant; * and ** significant at 5% and 1% probability, respectively.
Source: Prepared by the author.

Compared to Area 1, there was a reduction of one application of chemical pesticides for bedbugs and a reduction of five applications for caterpillars. In Area 2, IPM practices are essential to reducing the use of chemical pesticides.

Area 3: There was a significant effect of the release of *T. podisi* in the area for the control of bedbugs, since there was a delay in the second peak in the IPM area in relation to that of producer management, including a delay in the first application of chemical insecticide, when comparing the two areas (Figures 6 and 7).

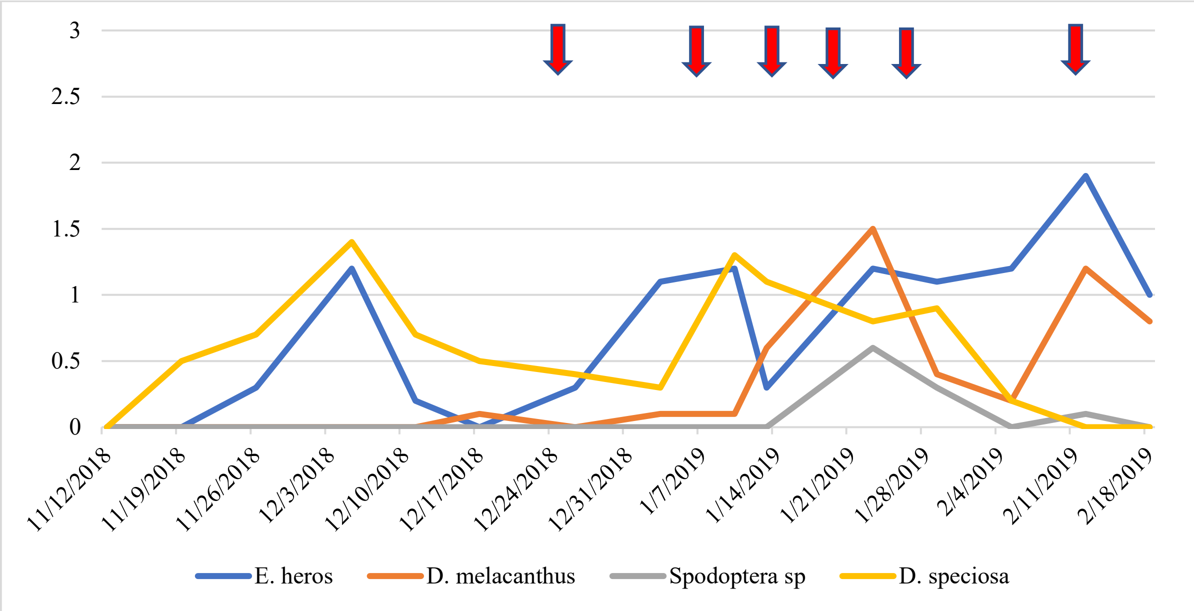


Figure 6. Area 3 - Results of chemical applications carried out according to the producer management in Area 3 to control *E. heros* in MS in the 2018/2019 harvest.
Source: Prepared by the author based on the results of this study.

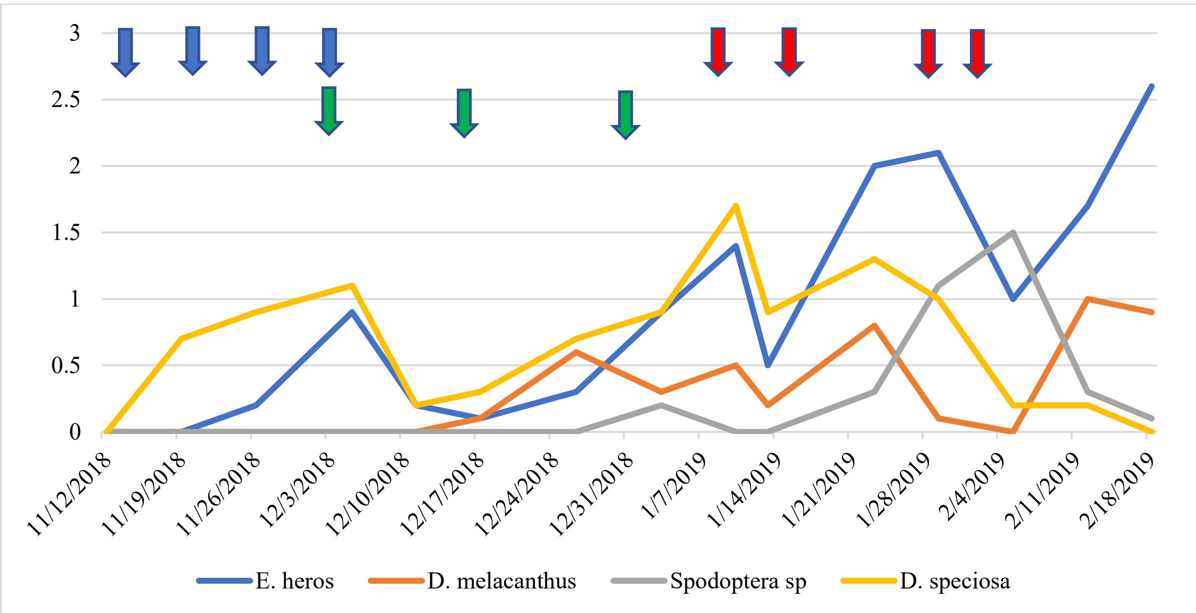


Figure 7. Area 3 - Results of the applications of *T. podisi* and *T. pretiosum* for the biological control and chemical applications carried out in soybean Area 3 according to the strategies of using IPM in MS in the 2018/2019 harvest.
Source: Prepared by the author based on the results of this study.

As for the number of chemical insecticide applications, there were no applications for caterpillars in any of the areas. As for bedbugs, there were four applications in the area of IPM and six applications in the producer management area. There was a positive effect of IPM and a reduced use of insecticides. As for grain yield, there were no significant differences between treatments (Table 3).

Table 3. Number of chemical insecticide applications, grain yield (bag ha-1) in the area of IPM and that of producer management. Maracaju, MS, Brazil, 2019.

Area 3	**Number of Applications of Chemical Insecticides**		**Grain Yield (bag ha^{-1})**
	Caterpillars	**Bedbugs**	
IPM area	0	4	45.9 a
Producer Management	0	6	51.4 a
T test	---	---	2.51^{ns}
CV (%)	---	---	9.71

Note: Means followed by the same lowercase letter on the row do not differ statistically from each other by t test at 5% probability. ^{ns} not significant; * and ** significant at 5% and 1% probability, respectively.

There are singularities in each evaluated area. In Area 1, producer management and IPM were similar, with no need for chemical insecticide applications in any of the areas and five chemical applications to control bedbugs. However, in Area 2, the producer management area required ten chemical applications, five for the control of caterpillars and five for the control of bedbugs, while in the IPM area, using biological control, no chemical application was necessary to control caterpillars and only four were necessary to control bedbugs.

In Area 3, no chemical application was necessary to control caterpillars. However, for the control of bedbugs, six applications were required in the producer management area and four in the IPM. Thus, the adoption of IPM is effective in reducing the use of chemical pesticides. With the use of biological control, it was possible to control the caterpillar population without the need for any application of chemical pesticides, thus reducing the environmental impact in controlling soybean pests.

The differences identified may be related to the characteristics of areas and producers. Area 1 is a research area, in which there was a simulation of situations that occur in rural properties. Area 2 is a private property, in which the producer follows a schedule for the use of agrochemicals; however, before their use, the producer does not consider the population levels of pests, thus performing unnecessary applications. Finally, in area 3, the cultural influences of the producer allow being more cautious with the use of agrochemicals. Thus, the association with biological control reduces the use of pesticides.

The results regarding the sustainability of agricultural production systems that use IPM depend on the optimization of their management in order to reduce the negative externalities related to chemical inputs and still maintain the economic yield of production (Lechenet et al., 2014; Lamichhane et al., 2016). In addition, the use of IPM has been recommended for different global locations, such as the European Union since 2014 (Hokkanen, 2015) and the United States (Lefebvre et al., 2015). However, the adoption of its use is still limited (Lefebvre et al., 2014). Furthermore, characteristics such as the reduction or non-use of chemical inputs during the production process is one of the main factors for increasing the use of IPM, according to Norwegian farmers (Steiro et al., 2020).

3.2. Investments, costs, and revenues obtained in the assessed soybean areas

In Area 1, insecticide applications were similar both in producer management and in IPM, totaling US$ 67.30/ha in the conventional area and values ranging between US$ 157 and US$ 179 in the IPM area (Table 4). It is important to highlight that the monitoring of pests is adopted for the application of chemical insecticides and thus the release of biological control agents exerts a negative impact on production costs, since the applications are targeted and restricted according to the farmer needs.

The costs for using biological control were US$ 63.78 for the four applications of *T. pretiosum* (caterpillar control) and US$ 47.76 for three applications of *T. podisi* (bedbug control) (Table 4). For the contracting of an outsourced company, in the three areas the costs were the same because the amounts are also the same, being US$ 42.33 per hectare for the four applications of *T. pretiosum* (caterpillar control) and US$ 47.62 per hectare for the three applications of *T. podisi* (bedbug control).

In Area 2, in conventional management, the producer made ten applications for pest control, totaling US$ 111.30/ha. With the adoption of IPM, there was a reduction of six insecticide applications (Table 2). In the IPM, four applications of chemical products were made, totaling US$ 69.27/ha. The costs for using biological control were US$ 63.78 for the four applications of *T. pretiosum* (caterpillar control) and US$ 47.83 for three applications of *T. podisi* (bedbug control). This large difference between the number of applications indicates that an indiscriminate and scheduled use of insecticides may result in an increase in the number of applications, as well as in significant impacts on production costs.

In Area 3 there was a reduction of two applications of insecticides. The producer made six applications for pest control, totaling US$ 74.23/ha (Table 4). In the IPM, four applications of chemical products were made, totaling US$ 47.70/ha. The costs for using biological control were US$ 63.78 for the four applications of *T. pretiosum* (caterpillar control) and US$ 47.83 for three applications of *T. podisi* (bedbug control).

Table 4. Costs of pest control in Areas 1, 2, and 3 under conventional management compared to IPM with biological control applied by the farmer and biological control applied by a third party.

Area	Conventional US$	IPM with BC* US$	Difference US$
1	67.30	178.84 *	111.54
1	67.30	157.25 **	89.95
2	111.30	187.76 *	76.47
2	111.30	166.10 **	54.80
3	74.23	164.49 *	90.26
3	74.23	142.90 **	68.66

*IPM practices using biological control and pesticides whenever necessary. **Parasitoids applied by the producer. ***Parasitoids purchased and applied by a third party company.

There were significant differences in the prices of chemical applications among the three areas and differences in the quantities of applications. In addition, the reason for such differences in insecticide values is in the option the producers made regarding the brands of the products. Some are more cautious about the cost of production and use cheaper products, while others use more expensive products. In relation to the Area 2, the farmer used applications without reaching the level of pest control. This means unnecessary applications, making pests more resistant, increasing production costs, and contaminating the ecosystem.

When used as a component of IPM, the effectiveness of biopesticides can be the same as that of conventional areas using chemical pesticides (Kumar, 2012). According to the productivity results of this study, the adoption of IPM is effective when the number of applications of chemical insecticides is reduced and productivity is kept stable. This was also observed in other studies, such as Buragohain et al. (2021) for the cultivation of tomatoes, Abid et al. (2021) for the production of dates, and Malacrinò et al. (2020) for the bean production process. In addition, there is an advantage in using the IPM and in this reduction in the use of chemical inputs: the possible benefits to health and the environment. Negative externalities are related to the use of pesticides are associated with human health, contamination of natural resources, residues of these inputs in food, and pest resistance to pesticides (Carvalho, 2006; Chagnon et al., 2015).

The IPM reduces the use of pesticides and consequently reduces costs in pest management, but the adoption of biological control replacing chemicals is still more expensive. One of the probable reasons for this scenario is the lack of public policies seeking a sustainable agriculture in Brazil. In Brazil, there is no fiscal incentive for the creation, commercialization, and use of biological agents, hindering the market competition for this type of management.

3.3. Environmental cost analysis

For environmental cost analysis, the cost and benefit components were analyzed separately to clearly demonstrate the results obtained in the model used. As Table 5 shows, the pesticides are arranged by active ingredient; some names are repeated because the doses used in different areas were not the same, thus being necessary to present each product according to the dose used.

The items presented are price per dose in US dollars, general index (the sum of scores of operator safety, toxicity to natural enemies, environmental persistence, and toxicity to biological indicators - birds, bees, and aquatic organisms - the arithmetic mean was calculated and rounded to the nearest whole number), and environmental and total cost. Table 5 shows all results of calculations.

Table 5 . Environmental cost factors for pesticides used in the three areas. Price paid per dose of each product, result of the calculation of the general index multiplied by the environmental cost, and result of the total value per dose.

Area	Pesticide (active ingredient)	Price/ha US$	General index OS + TN + EPF + BI	Environmental Cost	Total US$
1	Zeta-Cypermethrin	4.4	12	5	22
1	Bifenthrin + Carbosulfan	7.7	13	5.6	43.31
1,2,3	Imidacloprid + Bifenthrin	9.8	12	5	49
1,3	Pyraclostrobin + Methyl thiophanate + Fipronil	9.45	9	3.1	29.53
2	Methomyl	1.99	10	3.8	7.46
2	Chlorantraniliprole	13.97	9	3.1	43.66
2	Fipronil	1.8	13	5.6	10.13
2	Zeta-Cypermethrin + Bifenthrin	5.93	11	4.4	25.94
2	Zeta-Cypermethrin + Bifenthrin	5.15	10	3.8	19.31
2	Teflubenzuron	3.56	8	2.5	8.9
2	Teflubenzuron	5.33	9	3.1	16.66

2	Teflubenzuron	4.27	9	3.1	13.34
2	Chlorantraniliprole	6.05	6	1.3	7.56
3	Acephate	8.86	9	3.1	27.69
3	Acephate	14	13	5.6	78.75

Source: Prepared by the author based on the results of this study.

As Table 5 shows, the price is the amount the producer pays for the product per dose used in the evaluated areas. The general index is the sum of the impacts of these products on non-target organisms. The environmental cost is the result of the general index subtracted by four and multiplied by the constant 0.625, aiming an integer up to ten. The total is the multiplication of the environmental cost by the price paid when purchasing the product. The greater the impact this product causes on the environment, the greater its total cost. This is the value that should be considered by the producer when choosing the products (Belarmino, personal account, 2019).

The environmental cost plays a role in pricing the residual action of the pesticide on non-target organisms. Thus, this method of analysis assists the farmer in making decisions about the use of pesticides that cause less damage to the ecosystem. In addition to the environmental cost, it is necessary to analyze the benefits of using a certain pesticide and then determine the cost-benefit index for each product at the dose used.

3.4. Cost-benefit analysis

In Area 1, the difference in values for conventional and IPM management is considerably great, indicating a low cost-benefit ratio for the use of biological control (Table 6). It is noteworthy that this farmer adopts IPM, with sampling and decision-making of application based on control indexes, so that this is probably the reason for the great difference observed. In Area 2, the difference between conventional management and IPM with biological control decreased in relation to Area 1 and amounted to US$ 29.20/ha (applied by the producer) or US$ 7.54/ha (applied by the third party company). In Area 3, the difference in the results between the conventional area and the area with IPM and biological control varied between US$ 8.70/ha (applied by the producer) and US$ 12.89/ha (applied by a third party company).

Table 6. Costs of pest control with the inclusion of environmental cost over the pesticides used in Areas 1, 2, and 3.

AREA	CONVENTIONAL US$	IPM with BC* US$	DIFFERENCE US$
1	297.40	408.94 **	111.54
1	297.40	387.35 ***	89.95
2	383.46	412.67 **	29.20
2	383.46	391.00 ***	7.54
3	288.79	297.49 **	8.70
3	288.79	275.90 ***	12.89

*IPM practices using biological control and chemical pesticides whenever necessary. **Parasitoids applied by the producer. ***Parasitoids purchased and applied by a third party company.
Source: Prepared by the author based on the results of this study.

Due to the use of more aggressive products, which consequently obtained the highest environmental cost, Area 3 had an increase in costs, showing that environmental cost analysis is essential for the decision making by the producer, who opts for products that are less harmful to the environment, besides this being one of the principles of IPM. Another aspect observed in this work is the economic impact of using IPM. Area 1 showed the biggest difference between producer management and IPM with biological control. This happens because the producer performs the applications only when necessary, underestimating the effects of the release of biological control agents.

Estimating the economic costs of environmental risks is essential to weigh differences between risks and to integrate environmental and economic data. Taking environmental risks into account is an important analysis to improve decision-making when using IPM (Higley, Wintersteen, 1992).

The indirect costs of using pesticides for the environment and public health need to be balanced against the benefits of using them. In the United States, indirect expenses resulting from the use of pesticides were estimated in 2014, totaling around 9.6 million dollars. Among such indirect expenses are: Public health impacts 114, loss of natural enemies 520, cost of pesticide resistance 1,500, loss of bees and pollination 334, and fishing and poultry losses US$ 2,260 million. Such a complete and long-term cost-benefit analysis of the pesticide could reduce its use and the profitability of producers (Pimentel, Brugress, 2014). The challenge is to develop a regulatory system capable of balancing the widely defined costs and benefits of biopesticides compared to synthetic pesticides (Kumar; Singh, 2014).

Companies that develop biopesticides and farmers that adhere to this practice will only do so if there is profit. In 2009, the European Union approved legislative measures based on the principles of IPM. Programs funded by the Common Agricultural Policy were created to provide financial incentives to farmers who implement IPM in their crops (Chandler et al. 2011).

As mentioned in the present study, there are several barriers to the use of IPM by farmers. Among the main ones, there are the ease of use and efficiency in the use of chemical pesticides, the lack of dissemination of IPM by technicians and agronomists, the low price of pesticides, the industry also performing the role of technical assistance and occasionally offering chemical pesticides that favor its sales, absence of public policies in Brazil aiming the use of biological agents, and the low funding for research on alternative methods of pest and disease control (Gazzoni, 2012; Parsa et al., 2014).

In the USA, the Environmental Protection Agency (EPA) facilitates since 1994 registration to encourage the development and use of biopesticides. The EPA requires less data to register a biopesticide than to register a chemical pesticide. It often takes more than a year to register a new biopesticide compared to the more than three years to register a chemical pesticide in the USA (Kumar, 2012). The National Farmer Policy recommends the promotion of biopesticides, prioritizing farmers' health and the environment. It also recommends research and development of biological products and presentation of pest control methods (Gupta; Dikshit, 2010).

Conclusions

With the results obtained, IPM associated with the release of biological control agents reduces the number of applications of chemical insecticide in different areas without compromising productivity. However, the lack of information regarding the practices adopted by IPM, both of technicians and rural producers, still limits the adoption of this type of management, thus limiting the use of chemical pesticides.

Productivity in the evaluated areas, both under conventional and IPM management, is similar, proving the efficiency in productivity in adopting IPM and breaking the paradigm that only agrochemicals generate high productivity. These results show that the producer can be highly productive and still reduce environmental impacts.

As for the feasibility of adopting biological pest control in soybean crops to replace conventional management, the use of agrochemicals is still more economically viable than the biological control. This result shows that the lack of public policies, associated with the encouragement of commercialization, use of biological control, and adoption of IPM practices, discourages the adoption of sustainable practices.

The environmental cost analysis model proposed in this study is able to assist the producer in choosing the products for the farm, prioritizing the reduction of environmental impacts. It is hoped that this study serves as a basis for future research seeking to promote the adoption of IPM practices associated with biological control.

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