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Economic injury levels for control decision-making of thrips in soybean crops (*Glycine max* (L.) Merrill)

Níveis de dano econômico para tomada de decisão de controle de tripes na cultura da soja (*Glycine max* (L.) Merrill)

Niveles de daño económico para la toma de decisiones para el control de trips en soja (*Glycine max* (L.) Merrill)

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Abstract
Soybean, *Glycine max* (L.) Merrill, is the most cultivated crop worldwide. Recently, thrips (Thysanoptera: Thripidae) has caused of up to 17% production losses to this crop. To improve its management, economic injury levels (EIL) are key tools in supporting decision-making systems in integrated pest management (IPM) programs. The EIL depend on the technology used for insecticide application. In this regard, pesticide treatment on soybean crops can be successfully performed by aircraft or tractors, especially among major producers (e.g., Brazil, the United States, Argentina, and China). There are currently no economic injury levels (EIL) for thrips in soybean crops. Therefore, the objective of this work was to determine economic injury levels for thrips in soybean, with insecticide applications by aircraft and by tractors. The study was carried out in four commercial soybean crops for two years. *Frankliniella schultzei* and *Caliothrips phaseoli* were observed attacking soybean plants. The EIL were 4.53 and 3.43 thrips sample^{-1} for insecticide application with aircraft and tractor, respectively. The economic injury levels, established in this study, can be used in integrated pest management program for soybean crops.
Keywords: *Frankliniella schultzei*; *Caliothrips phaseoli*; Economic damage; *Glycine max*.

Resumo
A soja, *Glycine max* (L.) Merrill, é a cultura mais cultivada no mundo. Recentemente, o tripes (Thysanoptera: Thripidae) tem causado perdas de até 17% na produção desta cultura. Para melhorar seu manejo, os níveis de dano econômico (NDE) são ferramentas fundamentais para apoiar os sistemas de tomada de decisão em programas de manejo integrado de pragas (MIP). O NDE depende da tecnologia utilizada para aplicação de inseticidas. Nesse sentido, o tratamento com agrotóxicos nas lavouras de soja pode ser realizado, com sucesso, por aeronaves ou tratores,

principalmente entre os grandes produtores (por exemplo, Brasil, Estados Unidos, Argentina e China). Atualmente, não há níveis de dano econômico (NDE) para tripes nas lavouras de soja. Portanto, o objetivo deste trabalho foi determinar os níveis de dano econômico para tripes em soja, com aplicações de inseticidas por aeronaves e tratores. O estudo foi realizado em quatro lavouras comerciais de soja durante dois anos. *Frankliniella schultzei* e *Caliothrips phaseoli* foram observados atacando plantas de soja. Os NDE foram de 4,53 e 3,43 tripes amostra^{-1} para aplicação de inseticidas com aeronave e com trator, respectivamente. Os níveis de dano econômico, estabelecidos neste estudo, podem ser utilizados em programa de manejo integrado de pragas da cultura da soja.
Palavras-chave: *Frankliniella schultzei*; *Caliothrips phaseoli*; Danos econômicos; *Glycine max*.

Resumen

La soja, *Glycine max* (L.) Merrill, es el cultivo más cultivado en todo el mundo. Recientemente, los trips (Thysanoptera: Thripidae) han causado pérdidas de producción de hasta un 17% en este cultivo. Para mejorar su manejo, los niveles de daño económico (EIL) son herramientas clave para apoyar los sistemas de toma de decisiones en los programas de manejo integrado de plagas (IPM). Los EIL dependen de la tecnología utilizada para la aplicación de insecticidas. En este sentido, el tratamiento con plaguicidas en los cultivos de soja se puede realizar con éxito mediante aviones o tractores, especialmente entre los principales productores (por ejemplo, Brasil, Estados Unidos, Argentina y China). Actualmente no hay niveles de daño económico (EIL) para los trips en los cultivos de soja. Por lo tanto, el objetivo de este trabajo fue determinar los niveles de daño económico por trips en soja, con aplicaciones de insecticidas por avión y por tractor. El estudio se llevó a cabo en cuatro cultivos comerciales de soja durante dos años. Se observaron *Frankliniella schultzei* y *Caliothrips phaseoli* atacando plantas de soja. Los EIL fueron 4,53 y 3,43 trips muestra^{-1} para la aplicación de insecticida con avión y tractor, respectivamente. Los niveles de daño económico, establecidos en este estudio, pueden ser utilizados en un programa de manejo integrado de plagas para cultivos de soja.
Palabras clave: *Frankliniella schultzei*; *Caliothrips phaseoli*; Daño económico; *Glycine max*.

1. Introduction

In the decision-making process, the pest density must be compared with the economic injury level (EIL). The EIL corresponds to the lowest pest density that causes economic damage in the crop (Higley & Pedigo, 1996). To calculate the EIL is used the value of crop production without pest's attack, the cost of control, and the efficiency of the control method (Pedigo & Higley, 1992). The control cost is related to the method of pesticide application, which can be by handheld sprayers or by sprayers mounted like aircraft or tractors (Bueno et al., 2020; Pedigo & Higley, 1992; Pedigo & Rice, 2014).

Soybean, *Glycine max* (L.) Merrill, is the most cultivated crop in the world, with an annual production of 361 million tons of grain harvested from 125 million hectares (USDA, 2020). In recent years, soybean production has been expanding mainly driven by China's demand (Giraudo, 2020). Consequently, there is a growing need to effectively control insect pests in cultivated crops while maintaining high productivity levels (Bueno et al., 2020).

Among the insects that attack soybean, thrips (Thysanoptera: Thripidae) are considered emerging pests (Agrocampo, 2019; Engel & Pasini, 2020), with reported productivity losses of up to 17% (Gamundi & Perotti, 2009). Thrips cause direct damage, by sucking up cell content and injecting toxins into plants, and indirect damage, as they are a vector of tospoviruses such as *Soybean vein necrosis virus* and *Tobacco streak virus* (Han et al., 2019; Irizarry et al., 2016). In the main producing regions, particularly in the Americas and Asia, the management of thrips in soybean crops is mainly based on the application of insecticides by aircraft or tractors (Cunha et al., 2017). And these two application methods have different costs, speed, limitations, and potential use (Costa, 2017).

There are currently no economic injury levels (EIL) for thrips in soybean crops. Therefore, the objective of this study was to determine economic injury levels for thrips in soybean, with insecticide applications by aircraft and by tractors.

2. Methodology

Experimental conditions

This work was carried out from 2017 to 2019 in four commercial soybean crops, located counties of Formoso do

Araguaia (11° 49' 2.80" S, 49° 39' 15.40" W, 240 m altitude) and Gurupi (11° 45' 20.90" S, 48° 51' 24.20" W, 287 m altitude) in the state of Tocantins, Brazil, where in the climate is tropical, with dry winters and rainy summers. The soybean crops had approximately 20 ha each, and were planted with the cultivar M8808 IPRO (maturation group 8.8, determined growth and late-cycle) with 0.45 m spacing between rows and 10 plants per meter. The cultural practices recommended for cultivation were realized in the fields (Sediyama et al., 2015).

The thrips specimens observed attacking soybean plants in each crop were collected and stored in bottles containing 10 mL of 90% ethyl alcohol solution for later identification. The specimens were identified by Professor Dr. Adriano Cavalleri from the Universidade Federal do Rio Grande, São Lourenço do Sul, Rio Grande do Sul, Brazil.

Determination of economic injury levels

Concerning the economic injury level, we initially determined the pest control costs. Then, we calculated the crop production value without thrips attack. Finally, the economic injury levels were established.

Pest control costs

A survey was carried out, in collaboration with farmers and technicians, of the insecticides, adjuvants, average number of applications and equipment employed to control thrips in soybean crops using aircraft and tractors.

To calculate the control cost, the insecticides most commonly used by producers were selected, and that also met the principles of pesticide rotation (Lopes et al., 2019; Mouden et al., 2017; Paes et al., 2019). Also, input prices were surveyed in the main soybean-producing regions in Brazil. Finally, the control cost was calculated considering insecticides, adjuvants, equipment, labor costs (wage and non-wage costs) and application method (by aircraft and tractors) (Pedigo & Rice, 2014; Pereira et al., 2017).

Estimated production value of soybean fields without thrips attack

The production value of the soybean fields without pest attack was calculated using the equation (*1*):

$$V_0 = Y_0 \times Pr$$

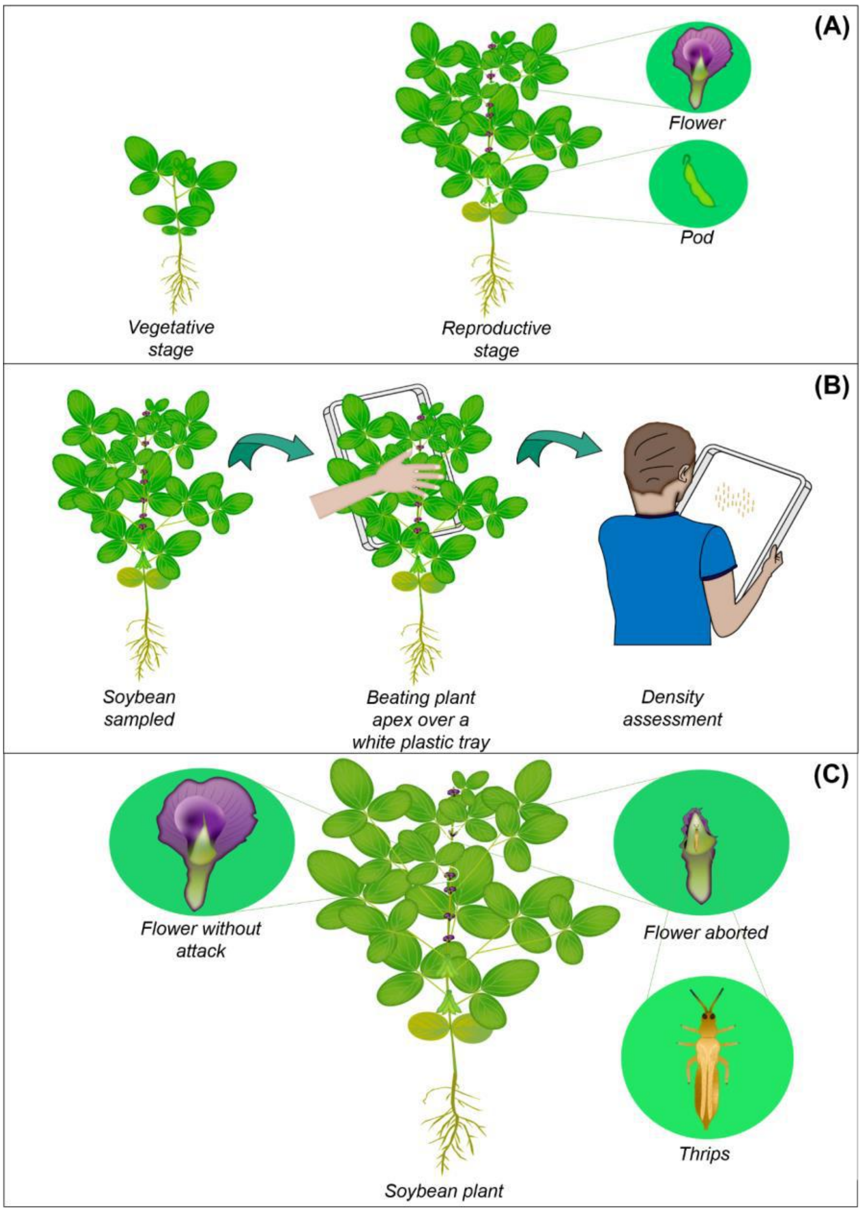
where V_0 is the production value without pest attack (US\$ ha^{-1}), Y_0 is the harvest yield without pest attack (kg ha^{-1}), and *Pr* is the average soybean price (US\$ kg^{-1}). The average soybean price was determined from a price survey in Brazil in recent years (CONAB, 2017). The average productivity of soybean crops in Brazil was used in the Y_0 calculation (FAOSTAT, 2018).

Yield loss curve as a function of pest density

The determination of the yield loss curve was carried out in four commercial soybean fields from 2017 to 2019. Each field's area was divided into 20 parts (replicates), resulting in 80 replicates of 1 hectare, with agronomic characteristics and cultivation practices. In each replicate, we randomly selected 10 plants and recorded the percentage of flowers aborted and the density of thrips. Thrips densities were evaluated when soybean plants were at the vegetative and reproductive stages.

To evaluate the density of thrips, we used the beating tray technique on the apical part of the plant. In this respect, a plastic beating tray (40 × 25 × 3 cm) was placed beneath the plant's apex while the branch bearing the apical foliage was struck sharply. Subsequently, the number of thrips that fell into the tray was immediately recorded (Figure 1). This technique was used because it has been reported as the most suitable for thrips sampling (Silva et al., 2019).

Figure 1. (A) Phenological stages of soybean plants, (B) sampling the density of thrips using a plastic tray, (C) assessing losses due to flower abortion.



Source: Authors.

To perform the flowers abortion assessment, all flowers of the plant were marked. Then, we recorded the number of flowers that became pods and those that were aborted (Figure 1). This evaluation was carried out because we observed high levels of aborted soybean flowers associated with the incidence of thrips in the fields. The rate of flowers aborted was calculated using the equation (2):

$$Far = 100 \times Naf \div Tnf$$

where *Far* is the flower abortion rate (%), *Naf* is the number of flowers aborted in each replicate, and *Tnf* is the total number of flowers in each replicate.

The relationship between flower abortion rates at each phenological stage and thrips densities in the 80 replicates were evaluated using Pearson's correlation analysis (α = 0.05) (Freedman et al., 2007). For the phenological stage that showed a significant correlation, a simple linear regression analysis of flower abortion as a function of thrips density was performed (α =

0.05). This model was used because it has previously been used for describing yield loss as a function of pest density (Higley & Pedigo, 1996; Pereira et al., 2017).

Calculation of economic injury levels

Initially, we calculated the percentage of losses caused by thrips that correspond to the economic injury levels for insecticide application using tractors or aircraft (Higley & Pedigo, 1996; Lima et al., 2019; Lopes et al., 2019). These losses were calculated using equation (*3*):

$$PLi = (Ci \times 100) \div (V_o \times k)$$

where *PLi* is the percentage loss of income corresponding to the economic injury level for the pesticide application method *i* (*i* = 1, tractor; *i* = 2, aircraft), *Ci* is the cost of thrips control for *i* (US$ per ha), V_o is the production value without pest attack (US$ per ha), and *k* is the pest control efficacy coefficient. We used *k* = 0.80 because this is the minimum efficacy required for insecticide registration in Brazil (Lopes et al., 2019; Pereira et al., 2017; Silva et al., 2019).

The thrips' economic injury levels were determined using the *PLi* values in the equation of losses in the production components as a function of thrips density. In this equation, the *PLi* value refers to the dependent variable (Y) and the economic damage levels to the independent variable (X) (Lopes et al., 2019; Moura et al., 2018).

3. Results

Cost for the control of thrips on soybean crops

The cost of pesticide application on soybean fields was US$ 13.09 ha^{-1} for aircraft spraying and US$ 9.03 ha^{-1} for tractors. Of these costs, 38% and 56% were spent on insecticides, 59% and 40% on equipment and services and, 3% and 4% on adjuvants for pest control using aircraft and tractor, respectively (Table 1).

Table 1. Cost of insecticides, adjuvant, equipment, and services used to control spraying thrips using tractor or aircraft.

Inputs	Chemical group	Unit	U.C (US$)	Quantity	S.C (ha^{-1})
Insecticides:					
Acephate 750 SP	Organophosphate	kg	10.31	0.500	5.16
Cypermethrin 250 EC	Pyrethroid	L	6.90	0.200	1.38
Clorfenapir 240 SC	Analog pyrazole	L	31.32	0.250	7.83
Espinetoram 120 SC	Spinosyn	L	128.30	0.075	9.62
Methomyl 215 SL	Oxime methylcarbamate	L	6.07	0.400	2.43
Acetamiprid 200 SP	Neonicotinoid	kg	17.02	0.250	4.25
Imidacloprid 700 WG	Neonicotinoid	kg	23.96	0.100	2.40
Thiamethoxan 250 WG	Neonicotinoid	kg	28.30	0.250	7.08
(1.1) Insecticide average cost per application (US$)					5.02
Adjuvant:					
(1.2) Spreader sticker 200 SL		L	4.15	0.09	0.37
(1) Insecticide + Adjuvant (1.1 + 1.2)					5.39
Cost of insecticide application by tractor (equipment and services)					
PPE*			19.12	0.008[a]	0.15
Tractor spray**			3.49	1.00[b]	3.49
(4) Subtotal					3.64
(4.1) Cost of one spray (1) + (4)					9.03
Cost of insecticide application by aircraft (equipment and services)					
PPE*			19.12	0.008[a]	0.15
Aircraft Spray***			7.55	1.00[b]	7.55
(5) Subtotal					7.70
(5.1) Cost of one spray (1) + (5)					13.09

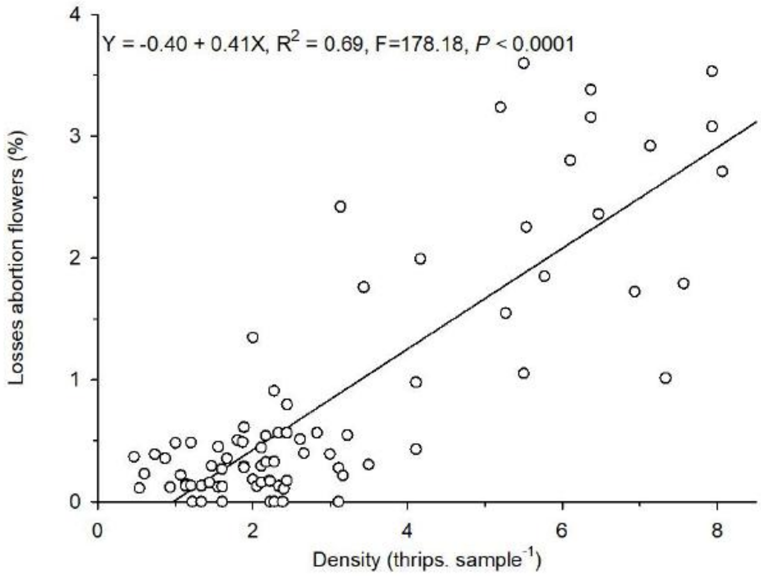
U.C = unit cost in US dollar. S.C = Spray cost (US$ ha^{-1}). * The personal protective equipment (PPE) consisted of a respirator, protective eyewear, long pants, rubber boots, chemical-resistant suit, gloves, and apron. ** Operating cost of tractor + bar sprayer + wage + non-wage labor costs. *** Operating cost of aircraft + bar sprayer + wage + non-wage labor costs. [a] Value obtained according to the durability of the PPE and hand sprayer. The same values were used for aircraft and tractor spray.
[b] Value obtained according to spray efficiency. Source: Authors.

Losses in plant production components as a function of thrips density

In the soybean fields, nymphs and adults of thrips were observed attacking new leaves and flowers of soybean plants. Attacked leaves had clear puncture lesions resulting from puncturing and sucking of cellular content. Conversely, attacked flowers had thrips feeding on pollen grains, and many of them were aborted and fell to the ground.

In plants in the reproductive stage, thrips densities significantly correlated (P = 0.0086) with flower abortion rates in soybean fields. Conversely, in plants in the vegetative stage, the density of thrips showed no correlation (P = 0.83) with flower abortion rates. The simple linear model showed that productivity losses increased with thrips densities, in the reproductive stage (Figure 2).

Figure 2. Linear regression of yield losses (%) as a function of thrips density on soybean plants in the reproductive stage. Each circle represents the data for one of 80 replicates.



Source: Authors.

Determination of economic injury levels

The average yield of commercial soybean crops in Brazil used in our analysis was 3,390 kg ha^{-1} (FAOSTAT, 2018). The average price received by soybean farmers was US$ 0.33 kg^{-1} (CONAB, 2017). Using these data, the average production value for commercial soybean crops was US$ 1,121.79 ha^{-1}.

For insecticide application using aircraft, the economic injury level was reached when thrips caused 1.46% of soybean yield loss. Alternatively, for insecticide application using tractor, the economic injury level was reached when thrips caused 1.01% of soybean productivity loss (Table 2). Applying these values to the yield loss curve as a function of thrips densities (Figure 2), the economic injury levels were 4.53 and 3.43 thrips sample^{-1} for aircraft and tractor application, respectively (Table 2).

Table 2. Economic injury levels for thrips in soybean crops according to the method of application of insecticides.

Application method	Economic injury level	
of insecticides	Losses (%)*	Thrips sample^{-1}**
Aircraft	1.46	4.53
Tractor	1.01	3.43

* Values were obtained by the equation EIL (%) = (100 × cost of control) / (0.8 × production value without pest's attack).
** Values were obtained by the yield loss curve (%) in the equation contained in Figure 2. Source: Authors.

4. Discussion

Economic thresholds for thrips species have been developed for other crops such as onion (Rueda et al., 2007; Shelton et al., 1987), watermelon (Pereira et al., 2017), bell pepper (Paes et al., 2019) and melon (Diamantino et al., 2021). However, this issue has long been neglected in soybean crops, despite the emerging importance of thrips in soybean crops (Zeiss & Klubertanz, 2020).

The cost of insecticide applications using a tractor (US$ 9.03 ha^{-1}) is lower compared with aircraft (US$ 13.09 ha^{-1}), indicating that thrips control in soybean fields should be made using a tractor. However, in large areas, and when a tractor cannot enter the area due to waterlogged soil or plant size, it is appropriate to use an aircraft (Costa, 2017; Sediyama et al., 2015). Moreover, when there is urgency in pesticide application, it is sometimes recommended to use aircraft applications because of the fast speed (0.167 min ha^{-1}) (Matthews et al., 2014).

The negative impact of thrips on soybean production components only occurred when this pest attacked plants at the reproductive stage, indicating this is the soybean's phenological growth stage where damage occurs. For every 2.44 thrips per sample (evaluated by the beating tray technique), 1% of soybean flowers were aborted (Fig. 2B). Thus, *F. schultzei* and *C. phaseoli* at the observed densities (i.e., up to eight thrips $sample^{-1}$) caused damage to soybean plants by aborting flowers. Furthermore, it was observed that in flowers attacked by thrips, the pollen grains formed clusters, and the flowers aborted.

Here, the economic injury levels for thrips in soybean crops were determined for the first time. The economic injury levels were developed for insecticide applications using tractors and aircraft, which are the most widely used methods in the main producing regions such as Brazil, the United States, Argentina, and China (Cunha et al., 2017). In addition, these economic injury levels were determined in commercial fields, reflecting the reality of soybean crops. However, in regions where viruses transmission by thrips are a concern (Estévez de Jensen et al., 2019; Sharman et al., 2015; Zambrana-Echevarria et al., 2021).

In integrated pest management programs, the decision to control thrips should only be made when its density is equal to or greater than the economic injury level to prevent economic damage (Moura et al., 2018). This avoids unnecessary insecticide applications, which increases the production cost and exposure of non-target organisms such as natural enemies and pollinators to insecticides (Paes et al., 2019; Picanço et al., 2007). Moreover, this approach helps mitigate the collateral effects of pesticides on human health and environmental impacts (Carvalho, 2017) which are mainly caused by spray drift (Al Heidary et al., 2014; Bueno et al., 2017; Hladik et al., 2014), which in turn depends on, among others, the equipment used to spray (Al Heidary et al., 2014).

The economic injury level for insecticide spraying using a tractor (3.43 thrips $sample^{-1}$) was lower than that of aircraft (4.53 thrips $sample^{-1}$), owing to the lower operating cost. This should be taken into account in IPM programs in soybean crops. In this context, in soybean fields where outbreaks of thrips occur early in the season, insecticides should be applied using a tractor. This should be done because of the lower cost for this application and thereby lower economic injury level (Costa, 2017; Matthews, 1998). In large and flat areas, in which the canopy of soybean plants cover the whole area, aircraft is the recommended application method because of the need for rapid pest control and easiness to move along the area (Costa, 2017; Matthews et al., 2014).

5. Conclusions

The EIL determined in this study for the *F. schultzei* and *C. phaseoli* thrips will help in decision making and can be incorporated into integrated pest management programs in soybean crops. The EILs are 4.53 and 3.43 thrips $sample^{-1}$ for insecticide application using an aircraft or tractor, respectively. The results obtained in this work will contribute to future research involving the monitoring of these pests in the field.

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