LUCAS DE PAULO ARCANJO

DECISION-MAKING SYSTEMS FOR MANAGEMENT OF THE INVASIVE PEST *Neoleucinodes elegantalis* (GUENÉE) (LEPIDOPTERA: CRAMBIDAE) IN COMMERCIAL TOMATO CROPS ACCORDING TO INSECTICIDE SPRAY METHOD AND PLANT STAGE

Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Entomologia, para obtenção do título de *Magister Scientiae*.

Orientador: Marcelo Coutinho Picanço

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Lucas de Paulo Arcanjo

Autor

Marcelo Coutinho Picanço

Orientador

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Aos meus pais,

Pelo amor incondicional e suporte,

Eu dedico.

RESUMO

ARCANJO, Lucas de Paulo, M.Sc., Universidade Federal de Viçosa, julho de 2020. **Decision-making systems for management of the invasive pest *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Crambidae) in commercial tomato crops according to insecticide spray method and plant stage.** Orientador: Marcelo Coutinho Picanço.

Neoleucinodes elegantalis (Guenée) (Lepidoptera: Crambidae) é uma praga de difícil manejo na cultura do tomate e pode causar até 90% de perdas. Os sistemas de tomada de decisão são uma ferramenta essencial para o controle de *N. elegantalis* em programas de manejo integrado de pragas (MIP), que incluem nível de dano econômico (EIL) e planos de amostragem. Neste estudo, foi determinado um sistema de tomada de decisão, baseado em planos de amostragem sequencial para ovos de *N. elegantalis*, de acordo com métodos de pulverização de inseticida (manual, tratorizada e aeronave) e estágio fenológico das plantas [estágio de frutificação um (FSI) que tem ≤ 3 cachos e estágio de frutificação dois (FSII) que tem > 3 cachos]. Os sistemas de tomada de decisão foram determinados em condições reais usando dados coletados de 260 lavouras comerciais. Este estudo é o primeiro a explorar diferentes sistemas de tomada de decisão de insetos pragas em função de métodos de pulverização de pesticidas. Os EILs variaram de 0,105 a 0,239 frutos com ovos por amostra, dependendo do método de aplicação do inseticida e do estágio da planta. Os EILs foram menores no FSI para pulverização tratorizada e por aeronaves e maiores para plantas no FSII manejadas com pulverizadores manuais. Os planos de amostragem sequencial tomaram decisões corretas com economia de tempo no processo de amostragem variando de 37,76% a 65,40%. Em conclusão, esse sistema de tomada de decisão pode ser incorporado aos programas de MIP de *N. elegantalis* em lavouras de tomate porque toma decisões corretas, rápidas e econômicas.

Palavras-chave: Plano de amostagem sequencial. Broca pequeno do tomateiro. Nível de dano econômico. *Solanum lycopersicum*.

ABSTRACT

ARCANJO, Lucas de Paulo, M.Sc., Universidade Federal de Viçosa, July, 2020. **Decision-making systems for management of the invasive pest *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Crambidae) in commercial tomato crops according to insecticide spray method and plant stage.** Adviser: Marcelo Coutinho Picanço.

Neoleucinodes elegantalis (Guenée) (Lepidoptera: Crambidae) is a challenging pest to manage in tomato crops and can lead up to 90% of losses. Decision-making systems are an essential tool to manage *N. elegantalis* in integrated pest management (IPM) programs, which include economic injury levels (EIL) and sampling plans. In this study, we determined a decision-making system, based on sequential sampling plans for *N. elegantalis* eggs, according to insecticide spraying methods (hand sprayer, tractor, and aircraft) and plant stages [fruiting stage one (FSI) which has ≤3 clusters and fruiting stage two (FSII) which has >3 clusters]. Decision-making systems were determined under real conditions using data collected from 260 commercial fields. This study is the first to explore different decision-making systems for insect pests as a function of pesticide spray methods. EILs ranged from 0.105 to 0.239 fruits with eggs per sample depending on the insecticide spray method and plant stage. EILs were lower at the FSI for tractor, and aircraft sprays and higher for plants at FSII managed with hand sprayers. The sequential sampling plans led to correct decisions with time saving on the sampling process ranging from 37.76% to 65.40%. In conclusion, this decision-making system could be incorporated into *N. elegantalis* IPM programs on tomato crops because it makes correct, fast, and cost-effective decisions.

Keywords: Sequential sampling plan. Small tomato borer. Economic injury level. *Solanum lycopersicum*.

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Decision-making systems for management of the invasive pest *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Crambidae) in commercial tomato crops according to insecticide spray method and plant stage

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Keywords: Sequential sampling plan; Small tomato borer; Economic injury level; *Solanum lycopersicum*

HIGHLIGHTS

- *Neoleucinodes elegantalis* can cause up to 90% of losses in tomato crops.
- Economy injury levels (EILs) were 0.105 to 0.239 tomato fruits with eggs per sample.
- EILs were higher in crops managed with hand sprayers than those operated with tractors or aircraft.
- The sequential sampling plans yielded correct decisions and time-saving between 37.76% to 65.40%.
- This decision-making system helps control the pest before it penetrates the fruit.
- This decision-making tool may be useful as a basis to develop similar sampling methods if this pest establishes out of the Neotropical region.
- Monitoring tables are available for tomato operations as supplementary material.

SUMÁRIO

1. Introduction

Neoleucinodes elegantalis (Guenée) (Lepidoptera: Crambidae), also known as small tomato borer, causes significant damage on tomato fruits (up to 90%) making them unmarketable (Oepp and Bulletin, 2015; Silva et al; 2018; Silva et al., 2019). This pest occurs in the Neotropical region, but recent modeling studies have shown wide ecoclimatic adequacy for important tomato production regions worldwide, such as sub-Saharan Africa, China, Malaysia, Australian coast and northern New Zealand (Silva et al., 2017). This pest has not yet been found in Europe, however, due to its destructive potential to tomato crops, *N. elegantalis* has been recommended for regulation as a quarantine pest A1 by the European Public Prosecutor's Office (EPPO) (Oepp and Bulletin, 2015).

Management of *N. elegantalis* in tomato crops has been a challenge over the years, in part because of this insect biology. The moth lays eggs on the surface of tomato, and as soon as the eggs hatch, neonates penetrate fruits where they stay feeding on the columella of the fruit until pupation (Montilla et al., 2013; Silva et al., 2017b). Once inside the fruits, its management is impracticable, leading to inevitable tomato production losses (Picanço et al, 2017; Silva et al., 2019).

For *N. elegantalis* management, sampling of adults has involved using sex-pheromones baited traps has been adopted (Salas et al., 1992; Badji et al., 2003; Jaffe et al., 2007). However, this sampling method has been reported as an inefficient (Montilla et al., 2017), as the correlation between moths and egg density on fruits is not always strong (Benvenga et al., 2010). In addition, cost of pheromone lures is high, and its efficiency varies among *N. elegantalis* populations (Montilla et al., 2017; Promip, 2020). Therefore, sampling plans should focus on eggs, which is a more accurate and cheaper method for decision-making systems (Silva et al., 2019).

Decision-making systems are essential tools to manage *N. elegantalis* in Integrated Pest Management (IPM) programs. These systems are in general composed of sampling plans and economy injury levels (EILs) (Pereira et al., 2017; Moura et al., 2018; Lima et al., 2019). Sampling plans are used to determine pest density in a crop, and can be conventional or sequential. In conventional sampling plans, the pest density is evaluated using a fixed number of samples (Rosado et al., 2014; Lima et al., 2017). However, in sequential sampling plans, the number of samples used to make decisions changes according to pest density. Sequential sampling plans should make the same decisions as conventional sampling plan and promote time-savings (Severtson et al., 2016; Gutierrez-Coarite et al., 2019). The EIL is the lowest pest density that causes economic damage to the crop, and therefore, the control decision should be made before the pest density achieves the EIL (Pedigo et al.,1986).

EILs and sequential sampling plans could be influenced by factors such as control costs and plant phenological stage (Higley and Pedigo, 1993; Ramsden et al., 2017; Moura et al., 2018). Pesticides remain the most used method to regulate pest populations in crops (Carvalho, 2017). The control cost has two primary components: the pesticide cost (insecticides and adjuvants) and the application cost (labor and equipment). Depending on the farming operations, different insecticide spray methods (hand, tractor, and aircraft) may be used to manage pests. These spraying methods have different costs that influence the EIL as well as pest sequential sampling plans. The susceptibility of the plants to yield losses may also differ according to plant life stage impacting on EILs (Pedigo et al., 1986). Therefore, observing the EIL sensibility improves the decision-making systems power (Higley and Pedigo, 1993; Hunt et al., 1995; Moura et al., 2018).

The use of decision-making systems can promote efficient management of *N. elegantalis*, avoiding neonates' entrances inside the fruits and preventing inappropriate pesticide application. In addition, the decision-making tool may be useful to develop similar sampling methods for this pest if it establishes in other countries. Nowadays, there is only one conventional sampling plan to *N. elegantalis* eggs in tomato crops (Silva et al., 2019). However, no economic injury level and sequential sampling plans have been determined for *N. elegantalis* eggs. Therefore, this study aimed to determine decision-making systems, based on sequential sampling plans for *N. elegantalis* eggs, according to insecticide spraying methods and tomato crop stages.

2. Material and methods

This work was conducted in 260 commercial tomato fields (Débora Max variety) in Coimbra (20º51'24" S, 42º48'10" W, 720 m altitude and tropical climate with dry winter), state of Minas Gerais, Brazil. Each commercial tomato field had about 3 ha, and the plants were spaced 1.0 × 0.5 m. The commercial production of these fields aimed at fresh market consumption (Silva and Vale, 2007). The production system included staking tomatoes and drip irrigation. The fertilizer recommendation was based on the requirements for the dystrophic Red-Yellow Latosol (Ribeiro et al., 1999). *Neoleucinodes elegantalis* evaluations were performed according to the sampling plan previously determined for this pest by Silva et al. (2019). In these evaluations, the crops were separated into two groups according to the plant stage: fruiting stage one (FSI) (when the plants had up to three clusters) and fruiting stage two (FSII) (when the plants had more than three clusters) (Fig. 1). The crop separation in these two groups was due to samples for evaluating *N. elegantalis* density variation in these two tomato plant stages (Silva et al., 2019). In this context, when the tomato plants are at the FSI, the evaluation should be the number of fruits with *N. elegantalis* eggs in the last cluster of tomato plants. When the plants are at the FSII, the evaluation should be the number of fruits with *N. elegantalis* eggs in the 2nd and 3rd clusters from the top of tomato plants (Fig. 1).

The work was divided into three steps. In the first, the economic injury levels of *N. elegantalis* were determined. In the second, the sequential sampling plans for the pest were established. Finally, sequential sampling plans were validated.

2.1. Economic injury levels determination

This part of the work was developed in two parts. In the first one, *N. elegantalis* control costs were calculated. Then, the economic injury levels were determined.

2.1.1. *N. elegantalis* control costs determination

Chemical pest control cost has two main components: product costs (e.g., insecticides and adjuvants) and the application cost (e.g., labor and equipment). To determine the chemical product costs, a survey was performed among farmers, agronomists, and dealerships in the study-site region to get information about insecticides, adjuvants, and a number of insecticide sprays used to control *N. elegantalis* in tomato fields. The product selection to calculate *N. elegantalis* control costs was based on the following criteria: (i) the most used insecticides and adjuvants, and (ii) differences in mode of action of insecticides, as rotation for the resistance management is often used in fields (Costa et al., 2019; Lima et al., 2019; Lopes et al., 2019). In this study, we have selected the insecticides more used by Brazilians growers to control *N. elegantalis* (Silva et al., 2018b). Subsequently, a survey on the price of the selected products in the main tomato growing regions of Brazil was performed. Using this survey and product application rates, the average product cost per application (US$/ha) was calculated (Costa et al., 2019; Lima et al., 2019).

The insecticide application costs were determined for three application methods: hand sprayer, tractor, and aircraft. A survey about these services was performed with companies and growers considering the equipment used in the operations, and the unit cost for each one. From this data, the average cost of one insecticide application for hand sprayer, tractor, and aircraft method was calculated. Subsequently, the pest control cost was calculated for each of the three insecticide application methods using the formula (1).

(1) $C_i = (CP + AC_i) \times n$: where:

C = cost (US$·crop^{-1}) of managing *N. elegantalis* using the application method i (1 = hand sprayer, 2 = tractor and 3 = aircraft) in tomato cultivation; CP = average cost (US$·Application^{-1}) of the products used in an application; ACi = cost (US$·application^{-1}) of an insecticide application using the application method i e; n = mean number of insecticide applications for *N. elegantalis* control in tomato fields (12 applications).

2.1.2. Economic injury level determination for *N. elegantalis*

Initially, the production value of tomato crops without the pest attack was calculated using formula (2):

(2) $V_0 = Y \times Pr$, where:

V_0 = value of tomato production without pest attack (US$·ha^{-1}); Y = average yield of tomato crops without pest attack (t·ha^{-1}) and; Pr = average price of tomato fruit received by farmers (US$·t^{-1}).

The yield (t·ha^{-1}) of commercial tomato crops in which there was no pest attack was used. Subsequently, a survey of the average price (US$·t^{-1}) of tomato fruit received by farmers in the main tomato growing regions in Brazil from 2012 to 2019 (AGROLINK, 2019).

Subsequently, the percentage of losses caused by *N. elegantalis* when its density reaches the economic injury level was calculated using the formula (3):

(3) $PP_i = (C_i \times 100) \div (V_o \times k)$, where:

PPi = percentage of losses caused by the pest when its density reaches the economic injury level according to insecticide method of spray i (1 = hand sprayer, 2 = tractor, and 3 = aircraft); Ci = costs (US$·crop^{-1}) for managing *N. elegantalis* as previously determined; V_0 = tomato production value without pest attack (US$·ha^{-1}); k is the control efficiency coefficient (k = 0.8), it was adopted k = 0.8 because this is the minimum efficiency required for insecticide registration in Brazil (Pedigo et al., 1986; MAPA, 1995; Gordy et al., 2019; Glover et al., 2019; Lopes et al., 2019;).

The economic injury levels for *N. elegantalis* in tomato fields were determined using formula (4):

(4) *EILij = (PPi × NFSj) ÷ 100, where:*

EILij = economic injury level (number of fruits with eggs of *N. elegantalis* in the sample unit) as a function of insecticides spray method i (1 = hand sprayer, 2 = tractor, and 3 = aircraft) and plant stage j (1 = plants at the FSI and 2 = FSII); PPi = percentage of losses caused by the pest when its density reaches the economic injury level as a function of the spray method i; NFSj, = average number of fruits in the sample j [plants at FSI (5.16 fruits·sample^{-1}) and plants at FSII (10.19 fruits·sample^{-1})].

The evaluation of the number of fruits per sample was performed in 20 crops at both plant stages, FSI, and FSII. In each crop, around 180 plants were selected randomly. In each of these plants, the number of fruits per sample was evaluated. In the plants at FSI, this evaluation was performed in the last cluster, whereas in those at the FSII, this evaluation was conducted in the 2nd and 3rd clusters from the top of the plant canopy (Fig. 1).

2.2. Sequential sampling plans determination for *N. elegantalis*

The sequential sampling plans were determined according to Wald's sequential probability ratio test and validated through Resampling for Validation of Sample Plans software (RVSP) using *N. elegantalis* density data from commercial tomato crops (Wald, 1947; Naranjo and Hutchison, 1997). To make these sequential plans, Tally threshold = 1 because just one egg can cause damage on tomato fruit, minimum number = 10 samples, error α, and β = 0.1, upper limit (m_1) = EIL and lower limit (m_0) = 0.5 x EIL. These values are generally used for making sequential sampling plans (Cocco et al., 2015; Naranjo and Hutchison, 1997; Paula-Moraes et al., 2011).

The densities of *N. elegantalis* used in these determinations were obtained from 20 fields at each FSI and FSII. In each area, around 180 plants were evaluated equidistantly to eliminate possible directional tendencies (Rosado et al., 2014; Pinto et al., 2017).

Therefore, six sequential sampling plans (2 fruiting plant stage x 3 spray methods) were determined according to the phenological plant stage (FSI and FSII) and method for insecticide spray (hand sprayer, tractor, and aircraft). The lower and upper decision-making limits of these sampling plans were determined using the formulas (5) and (6):

(5) $LBn = h_0 + S \times n$,

(6) $UBn = h_1 + S \times n$, *where:*

LBn = lower limit of decision; h_0 = intercept on the y-axis of the lower decision boundary curves; S = curves inclination; n = number of samples; UBn = upper limit of decision and h_1 = intercept on the y-axis of the upper decision boundary curves.

2.3. Sequential sampling plan validation

In this part of the study, *N. elegantalis* density was evaluated in 180 commercial tomato fields. These 180 field crops were divided into two groups according to the fruiting stage of the tomato plants: FSI (90 fields) and FSII (90 fields). In each of these groups, the fields were subdivided into three subgroups. In each subset of 30 crops, the validation of one of the six sequential sampling plans was determined. In the areas of subgroups 1, 2, and 3, the validation of sequential sampling plans for plants at the FSI was performed for the use of hand sprayers, tractor, and aircraft applications, respectively. In the fields of subgroups 4, 5, and 6, validation of sequential sampling plans was performed for plants at the FSII for hand sprayer, tractor, and aircraft applications, respectively.

In each field, the average density of *N. elegantalis* obtained by the conventional sampling plan, the number of samples needed to make a decision, and the type chosen (control or non-control) for the methods was determined. The conventional sampling plans used in this validation process were established previously (Silva et al., 2019). In these conventional sampling plans, 42 plants at FSI or 36 plants at the FSII were to be evaluated per field. The percentage of correct decisions, and the time saved by the use of the sequential sampling plans was calculated using formulas (7) and (8), respectively (Pereira et al., 2017; Moura et al., 2018; Lima et al., 2019).

(7) PH = 100 (DSm ÷ TCp), where:

PH = percentage of correct decisions (%) when adopting the sequential plan; DSm = number of sequential plan decisions equal to conventional sampling plan and; TCp = total number of crops evaluated (Pereira et al., 2017; Moura et al., 2018; Lima et al., 2019).

(8) Ec = 100 (NCv - NSq) ÷ NCv, where:

Ec = time saving when adopting the sequential sampling plan (%), NCv = number of samples from the conventional sampling plan and; NSq = number of samples to decide on a sequential sampling plan.

3. Results

3.1. Economic injury levels

The control costs of *N. elegantalis* were 600.12, 518.88, and 525.72 US$·ha^{-1} in tomato crops for hand sprayer, tractor, and aircraft, respectively (Table 1). The crop production value without the pest attack was 31,960.00 US$·ha^{-1}. The economic injury level to *N. elegantalis* varied according to the stages of the plants and the insecticide spray method. When the plants were at the FSI, the economic injury levels were: 0.121, 0.105, and 0.106 fruits with pest eggs per sample for hand sprayer, tractor, and aircraft spraying methods, respectively. When the plants were at the FSII, the economic injury levels were: 0.239, 0.207, and 0.209 fruits with pest eggs per sample for hand sprayer, tractor, and aircraft spraying methods, respectively (Table 2).

3.2. Sequential sampling plans

For plants at the FSI the lower (m_0) and higher (m_1) decision-making limits were m_0 = 0.0605, 0.053, and 0.053 and m_1 = 0.121, 0.105, and 0.106 for hand sprayer, tractor, and aircraft insecticide spraying methods, respectively. When the plants were at the FSII, the lower and upper decision-making limits were m_0 = 0.119, 0.104, and 0.104 and m_1 = 0.239, 0.207, and 0.209 for hand sprayer, tractor, and aircraft insecticide spraying methods, respectively. When the plants were at the FSI the lower (h0) and upper (h_1) intercepts and the slope (S) of sequential sampling plans were h_0

= -2.892, h_1 = 2.892, and S = 0.088; h_0 = -2.969, h_1 = 2.969, and S = 0.076 and h_0 = -2.927, h_1 = 2.927, and S = 0.077 for hand sprayer, tractor, and aircraft insecticide spraying methods, respectively. When the plants were at the FSII, the lower and upper intercepts and the slope of sequential sampling planes were h_0 = -2.604, h_1 = 2.604, and S = 0.174; h_0 = -2.711, h_1 = 2.711, and S = 0.151 and h_0 = -2.689, h_1 = 2.689, and S = 0.152 for hand sprayer, tractor, and aircraft insecticide spraying methods, respectively. The minimum number of samples necessary to make control decisions for *N. elegantalis* according to this sequential sampling plan were ten samples (Fig. 2). However, the minimum number of samples needed to decide for no control decisions were different among the sampling plans. For hand sprayer insecticide application, the minimum number of samples for deciding not to control the pest were 34 and 16 when the plants were at the FSI and FSII, respectively (Fig. 2A). For insecticide sprays using a tractor, the minimum number of samples were 39 and 19 when the plants were at the FSI and FSII, respectively (Fig. 2B). Finally, for aircraft insecticide sprays, the minimum number of samples to decide on not controlling the pest were 39 and 18 when the plants were at the FSI and FSII, respectively (Fig. 2C).

3.3. Sequential sampling plans validation

In 99 of the 180 fields sampled, the pest was at a higher density than the economic injury level. In comparison, in 81 of these crops, the pest density was lower than the economic injury level (Tables 3, 4, and 5). In 100% of the 60 fields sampled for hand sprayer insecticide application, the sequential and conventional sampling plans made the same decisions. Also, the sequential sampling plan allowed scouting time savings of 65.40% and 55.46% in crops at the FSI and FSII, respectively, in comparison to the conventional sampling plan (Table 3 and Fig. 3).

In 58 of the 60 crops (96.67%) sampled for tractor insecticide application, the sequential and conventional sampling plans made the same decisions. In one crop, the conventional sampling plan decided not to control, while the sequential method chose to control the pest. In another crop, the inverse happened. In these crops, the use of the sequential sampling plan made it possible to save 39.12% and 46.76% of the scouting time when the plants were at the FSI and FSII, respectively, in comparison to the conventional sampling plan (Table 4 and Fig. 3).

For aircraft insecticides applications, in 59 of the 60 crops (98.33%) sampled, the sequential and conventional sampling plans made the same decisions. In only one of these crops (1.67%), the conventional sampling plan decided not to control the pest, while the sequential sampling plan chose to control the pest. In these crops, the use of the sequential program made it possible to save 37.76% and 48.98% of the scouting time when the plants were at the FSI and FSII, respectively, in comparison with the conventional sampling plan (Table 5 and Fig. 3).

4. Discussion

Decision-making systems of *N. elegantalis* presented here add great value for tomato growers. This study generates sequential sampling plans and EILs of *N. elegantalis* eggs during the tomato fruiting season and makes more accurate and fast decisions according to a grower's spray methods. Besides that, these decision-making systems exhibited a favorable cost-benefit ratio for growers. The control costs represent only 1.71% of the production value. This can be seen by comparing the pest control cost, which is considered low (547.5 US$·ha^{-1}) with the tomato crop production value (31,960 US$·ha^{-1}).

Regarding pest control cost, insecticides and adjuvants accounted for more than 70% of this cost. It happened due to the large number of sprays targeting *N. elegantalis* and pesticide cost (e.g., cartap and diamides). In addition, the pest control cost varied according to the insecticide spray method. Operations cultivating small areas generally use hand sprayers, which increases control costs because this equipment efficiency (up to 0.9 ha per worker a day) is lower than tractor and aircraft sprays (Alencar, 2010; Matthews et al 2014).

N. elegantalis economic injury levels were considered low, ranging from 0.105 to 0.239 fruits with pest eggs per sample. It suggests that if plants at FSI have one fruit attacked in an average of 49.14 fruits sampled (2.03%) the control is required. In the case of plants at FSII, if one fruit is attacked in an average of 42.65 fruits sampled (2.34%) the control is required. EILs were low because *N. elegantalis* feeds directly on the tomato fruits, which also has a high market value. Lower EILs are common to insects damaging the part of the plant to be sold or when they are vectors of pathogens (Wegbe et al., 2003; Costa et al., 2019; Ramos et al., 2019).

The EILs varied according to plant stage (FSI and FSII), and pesticide spray methods. At the FSI, only one cluster of fruit per plant is evaluated (5.16 fruits·sample^{-1}). In contrast, at the FSII, two bunches of fruit per plant are evaluated (10.19 fruits sample^{-1}) as the EILs are proportional to the number of fruits per sample, and EILs are highest at FSII. Besides, at the FSI, tomato plants have larger-size fruit and, therefore, better commercial value. As the EIL is inversely proportional to the crop production value, it is expected that the EILs for *N. elegantalis* would be lower at the FSI than FSII. In concerning of pesticide spray methods, EILs are proportional to control costs, as hand sprayer cost is the most expensive, and EILs are higher in crops managed with hand sprayer than those operated with tractor or aircraft sprayers (Higley and Pedigo, 1993; Pedigo et al 1986).

In 180 fields sampled for the validation process, about half of them (49.50%) were below the EIL, the other half were above the EIL (50.50%), and the sequential sampling plan took both control and no control decisions with high precision. Then, the validation process was a success because, on average, 98.33% of the crops sampled in the sequential sampling plans made the same decision as the conventional sampling plan. The fact that in 99% of the situations with a high *N. elegantalis* population, the sequential sampling plans have led to control decisions is important to prevent this pest from causing economic damage. Moreover, in about 98% of the fields with a low *N. elegantalis* population, the sequential sampling plans have decided not to control the pest, which reduces unnecessary insecticide applications.

Another advantage of this sequential sampling plan is the scouting time and cost savings. In the conventional sampling plans for *N. elegantalis*, 42 or 36 samples were required for decision making in fields at the FSI and FSII, respectively (Silva et al., 2019). However, with the sequential sampling plans, it was possible to make control decisions with a minimum of 10 samples, generating time-saving between 37.76 to 65.40%. Therefore, the sequential sampling plans determined in this research allow faster and more affordable decision making.

In this study, sequential sampling plans were determined for the same tomato production system adopting different spray methods. However, it is important to point out the limitations of this study regarding the tomato production system. The fields studied here are aimed at fresh market consumption which would not expect to have any damage to the tomato fruit. However, if the tomato production system was for industrial processing, more fruit damaged by the pest would be tolerated, and therefore, the EIL determined would be higher. In regard to the limitations, the adoption of the type of IPM tool developed in this study requires training to be used, including the identification of the pest eggs and the use of sequential sampling plan monitoring tables (Supplementary material appendices A, B, and C).

In conclusion, the decision-making systems for *N. elegantalis* developed in this research are the first to determinate EILs and sequential sampling plans based on *N. elegantalis* eggs according to plant stage and spray methods. Adopting these decision-making systems would prevent unnecessary insecticides application, reduce production costs, and minimize negative impacts on the environment. The next step could be developing a smartphone application for IPM tomato crops in which the grower could input personal crop information and obtain more specific decision-making.

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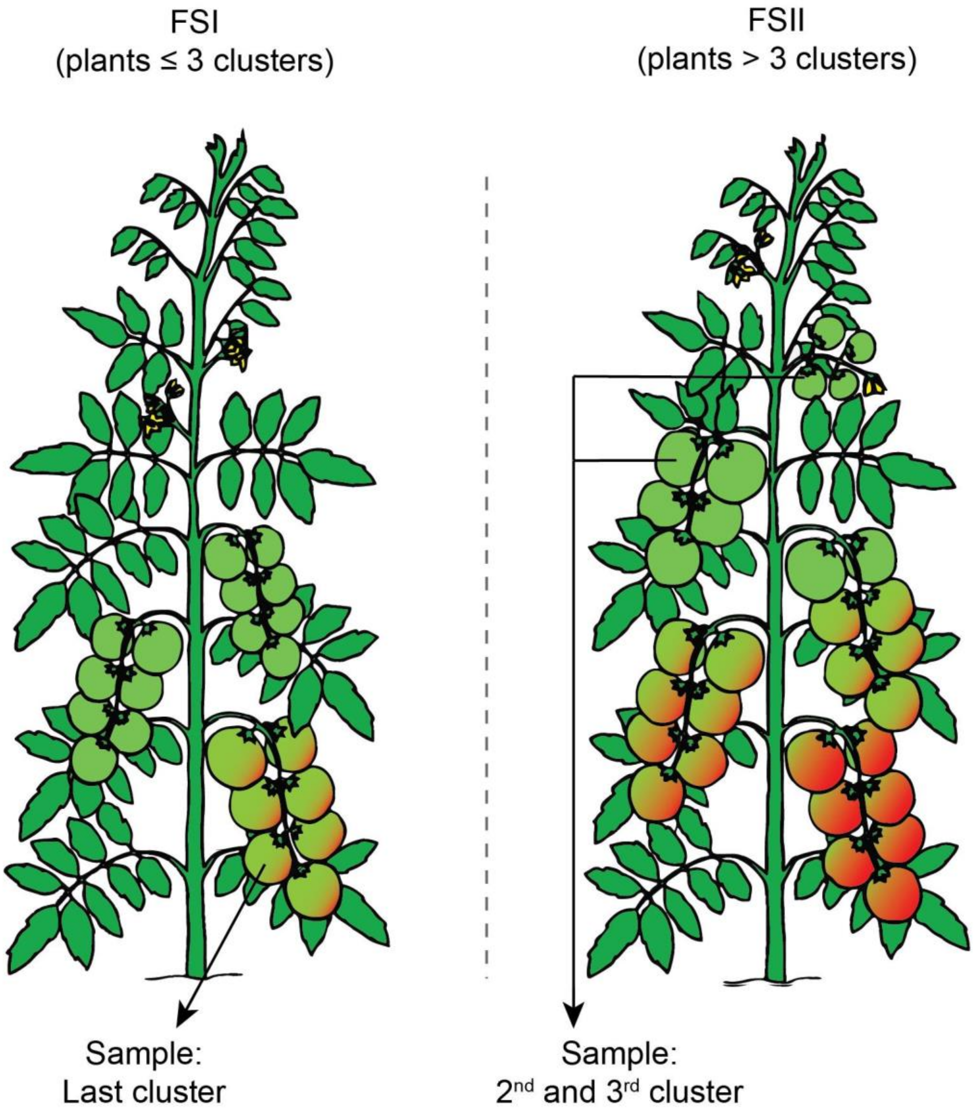

Fig. 1. Samples used to evaluate the intensity of *Neoleucinodes elegantalis* attack as a function of tomato plants stage.

Table 1. Costs (US$ ha^{-1}) of insecticides, adjuvants, equipment, and application for *Neoleucinodes elegantalis* manage in tomato crops as a function of the insecticide application method.

Inputs	Chemical group	Unit	U.C (US$)	Quantity (ha^{-1})	S.C (ha^{-1})
Insecticides:					
Novaluron 100 EC	Benzoylurea	L	34.57	0.700[a]	24.20
Methomyl 215 SL	Carbamate	L	10.77	1.000[a]	10.77
Cyantraniliprole 100 OD	Diamide	L	89.47	0.450[a]	40.26
Chlorantraniliprole 200 SC	Diamide	L	198.9	0.200[a]	39.78
Flubendiamide 480 SC	Diamide	L	172.82	0.175[a]	30.24
Cartap 500 SP	Nereistoxin analogue	kg	49.55	1.250[a]	61.94
Chlorpyrifos 480 EC	Organophosphate	L	6.22	1.500[a]	9.33
Bifenthrin 100 EC	Pyrethroid	L	29.78	0.075[a]	2.23
Lambda-cyhalothrin 250 CS	Pyrethroid	L	25.37	0.088[a]	2.23
Spinetoram	Spinosyn	kg	524.47	0.075[a]	39.34
(1.1) Insecticide average cost per application (US$)					26.03
Adjuvant					
(1.2) Mineral oil 756		L	7.84	1.25[a]	9.80
(1) Insecticide + Adjuvant (1.1 + 1.2)					35.83
Cost of insecticide application by hand sprayer					
Personal protective equipment (PPE)			19.12	0.008[b]	0.15
Hand sprayer		day	0.06	1	0.06
Time work		h	1.94	7.20[c]	13.97
(2) Subtotal:					14.18
(2.1) Cost of one spray (1) + (2)					50.01
(2.2) Total control cost (2.1) x 12 application per crop					600.12
Cost of insecticide application by tractor					
PPE			19.12	0.008[b]	0.15
Tractor spray*		h	39.90	0.182[c]	7.26
(4) Subtotal					7.41
(4.1) Cost of one spray (1) + (4)					43.24
(4.2) Total control cost (4.1) x 12 application per crop					518.88
Cost of insecticide application by aircraft					
Aircraft Spray**			ha	1.00[c]	7.98
(5) Subtotal					7.98
(5.1) Cost of one spray (1) + (5)					43.81
(5.2) Total control cost (5.1) x 12 application per crop					525.72

-U.C= unit cost (US$).
-S.C= Spray cost (US$ ha^{-1}).
-a Insecticide and adjuvant recommended dose value according to their labels.
-b Value obtained according to the durability of the PPE and hand sprayer.
-c Value obtained according to spray efficiency.
-* Operational cost of tractor + bar sprayer + labor + social charges.
-** Operational cost of aircraft + bar sprayer + labor + social charges.

Table 2. Yield, fruit price, production value of tomato crops, and economic injury levels for N*eoleucinodes elegantalis* (number of tomato fruits with pest eggs per sample) as a function of plant stage FSI= plants with ≤3 clusters and FSII= plants with >3 clusters, and insecticide application method.

Attribute		Value
Crop Yield (t ha^{-1})		68.00
Tomato price (US$ t^{-1})		470
Production Value (US$ ha^{-1})		31,960.00
Insecticides spray methods	Economic injury levels	
	FSI	FSII
Hand sprayer	0.121	0.239
Tractor	0.105	0.207
Aircraft	0.106	0.209

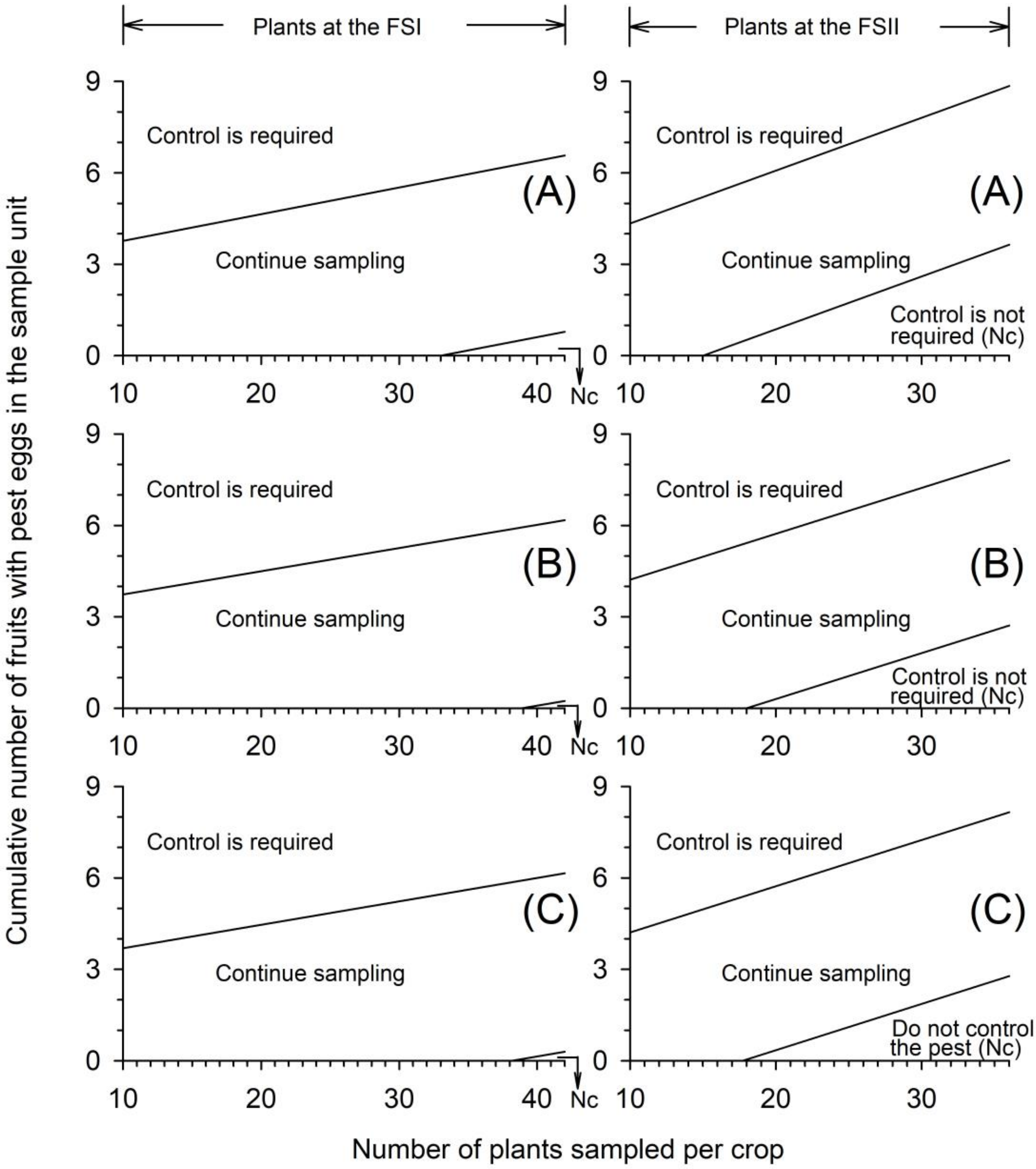

Fig. 2. Decision-making limits of sequential sampling plans for *Neoleucinodes elegantalis* as a function of tomato stage plants FSI= plants with ≤3 clusters and FSII= plants with >3 clusters and insecticides spray method: (A) hand spray, (B) tractor spray and (C) aircraft spray.

Table 3. (D) *Neoleucinodes elegantalis* densities (number of fruits attacked in the sampling unit), number of samples in the sequential sampling plan (NSq), Decisions making for conventional (Cv) and sequential (Sq) plans (Ct = decision of pest control and Nc = decision of do not control the pest) and time-saving (Ec) of the sequential sampling plan in relation to the conventional plan in 30 tomato crops for hand sprayer application of insecticides on plants in two stages.

Plants at the FSI= ≤3 clusters (conventional plan = 42 samples)						Plants at the FSII= >3 clusters (conventional plan = 36 samples)					
Crops	D	NSq	Decision		Ec	Crops	D	NSq	Decision		Ec
			Cv	Sq	(%)				Cv	Sq	(%)
1	0.28	34	Ct	Ct	19.05	1	0.06	27	Nc	Nc	25.00
2	0.24	23	Ct	Ct	45.24	2	0.28	23	Ct	Ct	36.11
3	0.33	15	Ct	Ct	64.29	3	0.00	16	Nc	Nc	55.56
4	0.17	32	Ct	Ct	23.81	4	0.00	16	Nc	Nc	55.56
5	0.13	25	Ct	Ct	40.48	5	0.06	28	Nc	Nc	22.22
6	0.63	10	Ct	Ct	76.19	6	0.00	16	Nc	Nc	55.56
7	0.22	39	Ct	Ct	7.14	7	0.08	16	Nc	Nc	55.56
8	1.20	10	Ct	Ct	76.19	8	0.06	27	Nc	Nc	25.00
9	0.89	10	Ct	Ct	76.19	9	3.89	10	Ct	Ct	72.22
10	0.65	10	Ct	Ct	76.19	10	4.86	10	Ct	Ct	72.22
11	0.67	10	Ct	Ct	76.19	11	5.67	10	Ct	Ct	72.22
12	0.61	11	Ct	Ct	73.81	12	6.00	10	Ct	Ct	72.22
13	0.65	10	Ct	Ct	76.19	13	5.31	10	Ct	Ct	72.22
14	1.07	10	Ct	Ct	76.19	14	4.89	10	Ct	Ct	72.22
15	1.48	10	Ct	Ct	76.19	15	3.61	10	Ct	Ct	72.22
16	1.72	10	Ct	Ct	76.19	16	2.69	10	Nc	Nc	72.22
17	0.54	10	Ct	Ct	76.19	17	0.11	16	Nc	Nc	55.56
18	0.48	10	Ct	Ct	76.19	18	0.06	16	Nc	Nc	55.56
19	0.35	10	Ct	Ct	76.19	19	0.14	27	Nc	Nc	25.00
20	1.09	10	Ct	Ct	76.19	20	0.03	16	Nc	Nc	55.56
21	1.35	10	Ct	Ct	76.19	21	0.03	21	Nc	Nc	41.67
22	0.67	10	Ct	Ct	76.19	22	0.08	21	Nc	Nc	41.67
23	0.67	10	Ct	Ct	76.19	23	0.08	33	Nc	Nc	8.33
24	1.11	10	Ct	Ct	76.19	24	0.00	16	Nc	Nc	55.56
25	0.83	10	Ct	Ct	76.19	25	4.25	10	Ct	Ct	72.22
26	0.96	10	Ct	Ct	76.19	26	4.92	10	Ct	Ct	72.22
27	0.61	13	Ct	Ct	69.05	27	4.08	10	Ct	Ct	72.22
28	0.89	10	Ct	Ct	76.19	28	7.17	10	Ct	Ct	72.22
29	1.76	10	Ct	Ct	76.19	29	3.83	10	Ct	Ct	72.22
30	0.00	34	Nc	Nc	19.05	30	0.00	16	Nc	Nc	55.56

- [a] Accuracies on decisions using the sequential plan = 100%
- [b] Economics to use sequential plan in crops at the FSI = 65.40%
- [b] Economics to use sequential plan in crops at the FSII = 55.46%.

[a] Value obtained from a comparison between conventional and sequential plans decisions.
[b] Values derived from the average of economies (Ec) on each plant stage.

Table 4. (D) *Neoleucinodes elegantalis* densities (number of fruits attacked in the sampling unit), number of samples in the sequential sampling plan (NSq), Decisions making for conventional (Cv) and sequential (Sq) plans (Ct = decision of pest control and Nc = decision of do not control the pest) and time-saving (Ec) of the sequential sampling plan in relation to the conventional plan in 30 tomato crops for tractor sprayer application of insecticides on plants in two stages.

Plants at the FSI= ≤3 clusters (conventional plan = 42 samples)						Plants at the FSII= >3 clusters (conventional plan = 36 samples)					
Crops	D	NSq	Decision		Ec	Crops	D	NSq	Decision		Ec
			Cv	Sq	(%)				Cv	Sq	(%)
1	0.05	42	Nc	Nc	0.00	1	0.06	32	Nc	Nc	11.11
2	0.24	10	Ct	Ct	76.19	2	0.28	19	Ct	Ct	47.22
3	0.05	42	Nc	Nc	0.00	3	0.00	19	Nc	Nc	47.22
4	0.00	39	Nc	Nc	7.14	4	0.00	19	Nc	Nc	47.22
5	0.05	42	Nc	Nc	0.00	5	0.06	32	Nc	Nc	11.11
6	0.00	39	Nc	Nc	7.14	6	0.00	19	Nc	Nc	47.22
7	0.07	42	Nc	Nc	0.00	7	0.08	19	Nc	Nc	47.22
8	0.05	42	Nc	Nc	0.00	8	0.06	32	Nc	Nc	11.11
9	3.76	10	Ct	Ct	76.19	9	3.89	10	Ct	Ct	72.22
10	4.64	10	Ct	Ct	76.19	10	4.86	10	Ct	Ct	72.22
11	5.48	10	Ct	Ct	76.19	11	5.67	10	Ct	Ct	72.22
12	5.88	10	Ct	Ct	76.19	12	6.00	10	Ct	Ct	72.22
13	4.95	10	Ct	Ct	76.19	13	5.31	10	Ct	Ct	72.22
14	4.71	10	Ct	Ct	76.19	14	4.89	10	Ct	Ct	72.22
15	3.69	10	Ct	Ct	76.19	15	3.61	10	Ct	Ct	72.22
16	2.60	10	Ct	Ct	76.19	16	2.69	10	Ct	Ct	72.22
17	0.10	13	Nc	Ct	69.05	17	0.11	36	Nc	Nc	0.00
18	0.05	42	Nc	Nc	0.00	18	0.06	33	Nc	Nc	8.33
19	0.14	42	Ct	Nc	0.00	19	0.14	36	Nc	Nc	0.00
20	0.05	42	Nc	Nc	0.00	20	0.03	25	Nc	Nc	30.56
21	0.02	42	Nc	Nc	0.00	21	0.03	25	Nc	Nc	30.56
22	0.07	42	Nc	Nc	0.00	22	0.08	25	Nc	Nc	30.56
23	0.07	42	Nc	Nc	0.00	23	0.08	36	Nc	Nc	0.00
24	0.00	39	Nc	Nc	7.14	24	0.00	19	Nc	Nc	47.22
25	4.26	10	Ct	Ct	76.19	25	4.25	10	Ct	Ct	72.22
26	4.90	10	Ct	Ct	76.19	26	4.92	10	Ct	Ct	72.22
27	3.95	10	Ct	Ct	76.19	27	4.08	10	Ct	Ct	72.22
28	6.64	10	Ct	Ct	76.19	28	7.17	10	Ct	Ct	72.22
29	3.95	10	Ct	Ct	76.19	29	3.83	10	Ct	Ct	72.22
30	0.05	39	Nc	Nc	7.14	30	0.00	19	Nc	Nc	47.22

- [a] Accuracies on decisions using the sequential plan = 96.67%
- [b] Economics to use sequential plan in crops at the FSI = 39.12%
- [b] Economics to use sequential plan in crops at the FSII = 46.76%

[a] Value obtained from a comparison between conventional and sequential plans decisions.
[b] Values derived from the average of economies (Ec) on each plant stage.

Table 5. (D) *Neoleucinodes elegantalis* densities (number of fruits attacked in the sampling unit), number of samples in the sequential sampling plan (NSq), Decisions making for conventional (Cv) and sequential (Sq) plans (Ct = decision of pest control and Nc = decision of do not control the pest) and time-saving (Ec) of the sequential sampling plan in relation to the conventional plan in 30 tomato crops for aircraft sprayer application of insecticides on plants in two stages.

Plants at the FSI= ≤3 clusters (conventional plan = 42 samples)						Plants at the FSII= >3 clusters (conventional plan = 36 samples)					
Crops	D	NSq	Decision		Ec	Crops	D	NSq	Decision		Ec
			Cv	Sq	(%)				Cv	Sq	(%)
1	0.05	42	Nc	Nc	0.00	1	0.03	31	Nc	Nc	13.89
2	0.24	10	Ct	Ct	76.19	2	0.28	19	Ct	Ct	47.22
3	0.05	42	Nc	Nc	0.00	3	0.00	18	Nc	Nc	50.00
4	0.00	39	Nc	Nc	7.14	4	0.00	18	Nc	Nc	50.00
5	0.05	42	Nc	Nc	0.00	5	0.03	31	Nc	Nc	13.89
6	0.00	39	Nc	Nc	7.14	6	0.00	18	Nc	Nc	50.00
7	0.07	42	Nc	Nc	0.00	7	0.10	18	Nc	Nc	50.00
8	0.05	42	Nc	Nc	0.00	8	0.03	31	Nc	Nc	13.89
9	3.76	10	Ct	Ct	76.19	9	3.69	10	Ct	Ct	72.22
10	4.64	10	Ct	Ct	76.19	10	4.48	10	Ct	Ct	72.22
11	5.48	10	Ct	Ct	76.19	11	4.86	10	Ct	Ct	72.22
12	5.88	10	Ct	Ct	76.19	12	5.62	10	Ct	Ct	72.22
13	4.95	10	Ct	Ct	76.19	13	4.90	10	Ct	Ct	72.22
14	4.71	10	Ct	Ct	76.19	14	5.14	10	Ct	Ct	72.22
15	3.69	10	Ct	Ct	76.19	15	3.79	10	Ct	Ct	72.22
16	2.60	10	Ct	Ct	76.19	16	2.86	10	Ct	Ct	72.22
17	0.10	13	Nc	Ct	69.05	17	0.10	36	Nc	Nc	0.00
18	0.05	42	Nc	Nc	0.00	18	0.07	18	Nc	Nc	50.00
19	0.14	42	Nc	Nc	0.00	19	0.10	36	Nc	Nc	0.00
20	0.05	42	Nc	Nc	0.00	20	0.03	25	Nc	Nc	30.56
21	0.02	42	Nc	Nc	0.00	21	0.00	25	Nc	Nc	30.56
22	0.07	42	Nc	Nc	0.00	22	0.1	25	Nc	Nc	30.56
23	0.07	42	Nc	Nc	0.00	23	0.07	36	Nc	Nc	0.00
24	0.00	39	Nc	Nc	7.14	24	0.00	18	Nc	Nc	50.00
25	4.26	10	Ct	Ct	76.19	25	4.00	10	Ct	Ct	72.22
26	4.90	10	Ct	Ct	76.19	26	5.38	10	Ct	Ct	72.22
27	3.95	10	Ct	Ct	76.19	27	3.72	10	Ct	Ct	72.22
28	6.64	10	Ct	Ct	76.19	28	5.55	10	Ct	Ct	72.22
29	3.95	10	Ct	Ct	76.19	29	3.69	10	Ct	Ct	72.22
30	0.00	39	Nc	Nc	7.14	30	0.00	18	Nc	Nc	50.00

- [a] Accuracies on decisions using the sequential plan = 98.33%
- [b] Economics to use sequential plan in crops at the FSI = 37.76%
- [b] Economics to use sequential plan in crops at the FSII = 48.98%

[a] Value obtained from a comparison between conventional and sequential plans decisions.
[b] Values derived from the average of economies (Ec) on each plant stage.

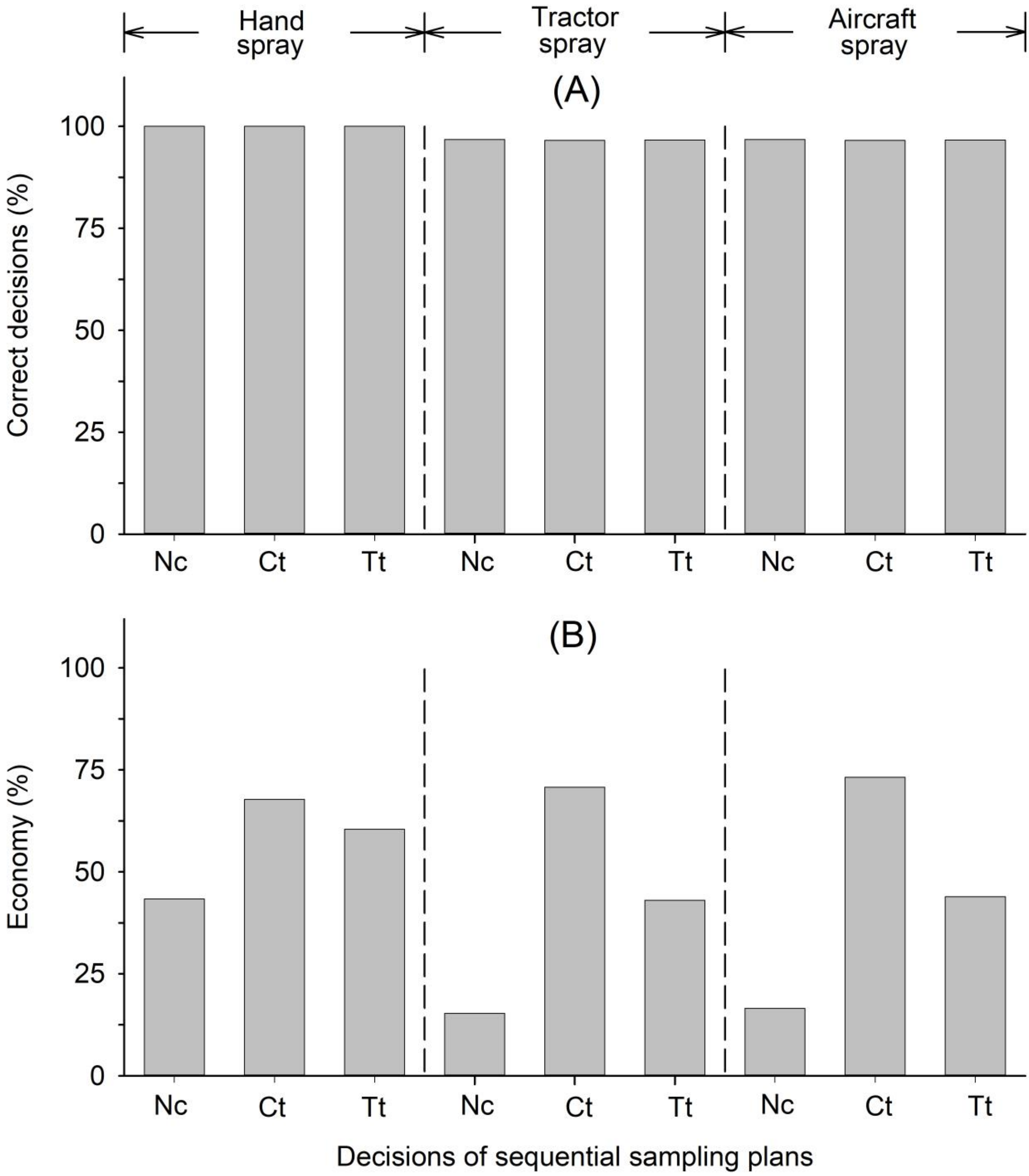

Fig. 3. (A) Correct decisions of non-control (Nc), control (Ct) and total (Tt) and (B) time savings with the use of sequential sampling plans for *Neoleucinodes elegantalis* in tomato crops as a function of the insecticide spray methods (hand spray, tractor or aircraft).

7. Supplementary material

Instructions for the use of sequential sampling tables of *Neoleucinodes elegantalis* in tomato crops.

Tables in appendices A, B, and C show the sequential sampling plans for *Neoleucinodes elegantalis* in tomato crops for the application of manual, tractor, and aircraft insecticides. Appendix A shows the pest sequential sampling plan for farmers using hand sprayers. Appendix B shows the pest sequential sampling plan for farmers using a tractor. Finally, appendix C shows the pest sequential sampling plan for farmers using aircraft.

Each sequential sampling table is divided into two parts. The first part is for sampling the pest in the tomato plants at the FSI (up to three clusters), and the sample unit is the most basal cluster of the plants. The second part is for sampling the pest at the tomato FSII (more than three clusters). At this stage, the sample unit is the joint evaluation of the 2nd and 3rd top clusters in the tomato plants. In the sample units, the number of fruits with eggs of *N. elegantalis* should be counted (Fig. 1).

There are six columns in each sequential sampling table for *N. elegantalis*. The first column represents the number of samples (NS) to be evaluated in each crop. The second column represents the decision of do not control the pest. The third column represents the lower limit of decision making (LL). In the fourth column should be made the cumulative count of fruits with *N. elegantalis* eggs (CNFE). The fifth column represents the upper limit of decision making (UL). The sixth column represents the decision to control the pest (appendices A, B, and C).

In the first plant sampled in a tomato crop, the number of fruits with *N. elegantalis* eggs in the sample unit should be counted. This number will be noted in the CNFE column of the sequential sampling table. Since the second sampled plant should be noted the number of fruits with eggs cumulatively. For example, if in the first sample (plant 1), two fruits with pest eggs are observed, this number will be noted on the 1st line the

CNFE column of sequential sampling table. If in the next sample (plant 2) one fruit with pest eggs is found, the number 3 (2 fruits from the 1st plant + 1 fruit from the 2nd plant) will be annotated in the 2nd row of the column CNFE and so on. The no control decision will be taken when CNFE <LL. The pest control decision will be made when CNFE ≥ UL.

7.1 Appendix A

Sequential sampling table for *Neoleucinodes elegantalis* in tomato crops for hand sprayer insecticides applications on plants at the FSI and FSII.

Plants at the FSI
(number of clusters per plant ≤3)

NS	Decision	LL	CNFE	UL	Decision
1	Do not control the pest when CNFE < LL	-		-	Control the pest when CNFE ≥ UL
2		-		-	
3		-		-	
4		-		-	
5		-		-	
6		-		-	
7		-		-	
8		-		-	
9		-		-	
10		-		3.77	
11		-		3.86	
12		-		3.94	
13		-		4.03	
14		-		4.12	
15		-		4.21	
16		-		4.29	
17		-		4.38	
18		-		4.47	
19		-		4.56	
20		-		4.64	
21		-		4.73	
22		-		4.82	
23		-		4.91	
24		-		4.99	
25		-		5.08	
26		-		5.17	
27		-		5.26	
28		-		5.35	
29		-		5.43	
30		-		5.52	
31		-		5.61	
32		-		5.70	
33		-		5.78	
34		0.09		5.87	
35		0.17		5.96	
36		0.26		6.05	
37		0.35		6.13	
38		0.44		6.22	
39		0.52		6.31	
40		0.61		6.40	
41		0.70		6.48	
42		0.79		6.57	

Plants at the FSII
(number of clusters per plant >3)

NS	Decision	LL	CNFE	UL	Decision
1	Do not manage the pest when CNFE < LL	-		-	Control the pest when CNFE ≥ UL
2		-		-	
3		-		-	
4		-		-	
5		-		-	
6		-		-	
7		-		-	
8		-		-	
9		-		-	
10		-		4.34	
11		-		4.51	
12		-		4.69	
13		-		4.86	
14		-		5.03	
15		-		5.21	
16		0.17		5.38	
17		0.35		5.55	
18		0.52		5.73	
19		0.69		5.90	
20		0.87		6.07	
21		1.04		6.25	
22		1.21		6.42	
23		1.39		6.60	
24		1.56		6.77	
25		1.73		6.94	
26		1.91		7.12	
27		2.08		7.29	
28		2.25		7.46	
29		2.43		7.64	
30		2.60		7.81	
31		2.78		7.98	
32		2.95		8.16	
33		3.12		8.33	
34		3.30		8.50	
35		3.47		8.68	
36		3.64		8.85	

In the heading: NS = number of samples, LL = lower limit of decision making, CNFE = cumulative count of the number of fruits with *N. elegantalis* eggs in the sampling unit (Fig. 1) and UL = upper limit of decision making.

7.2. Appendix B

Sequential sampling table for *Neoleucinodes elegantalis* in tomato crops for insecticides tractor application on plants at FSI and FSII.

Plants at the FSI
(number of clusters per plant ≤3)

NS	Decision	LL	CNFE	UL	Decision
1	Do not control the pest when CNFE < LL	-		-	Control the pest when CNFE ≥ UL
2		-		-	
3		-		-	
4		-		-	
5		-		-	
6		-		-	
7		-		-	
8		-		-	
9		-		-	
10		-		3.73	
11		-		3.81	
12		-		3.88	
13		-		3.96	
14		-		4.04	
15		-		4.11	
16		-		4.19	
17		-		4.27	
18		-		4.34	
19		-		4.42	
20		-		4.49	
21		-		4.57	
22		-		4.65	
23		-		4.72	
24		-		4.80	
25		-		4.88	
26		-		4.95	
27		-		5.03	
28		-		5.11	
29		-		5.18	
30		-		5.26	
31		-		5.33	
32		-		5.41	
33		-		5.49	
34		-		5.56	
35		-		5.64	
36		-		5.72	
37		-		5.79	
38		-		5.87	
39		0.01		5.94	
40		0.08		6.02	
41		0.16		6.10	
42		0.24		6.17	

Plants at the FSII
(number of clusters per plant >3)

NS	Decision	LL	CNFE	UL	Decision
1	Do not control the pest when CNFE < LL	-		-	Control the pest when CNFE ≥ UL
2		-		-	
3		-		-	
4		-		-	
5		-		-	
6		-		-	
7		-		-	
8		-		-	
9		-		-	
10		-		4.22	
11		-		4.37	
12		-		4.52	
13		-		4.67	
14		-		4.82	
15		-		4.97	
16		-		5.12	
17		-		5.27	
18		-		5.42	
19		0.15		5.57	
20		0.30		5.72	
21		0.45		5.88	
22		0.60		6.03	
23		0.75		6.18	
24		0.91		6.33	
25		1.06		6.48	
26		1.21		6.63	
27		1.36		6.78	
28		1.51		6.93	
29		1.66		7.08	
30		1.81		7.23	
31		1.96		7.38	
32		2.11		7.53	
33		2.26		7.68	
34		2.41		7.83	
35		2.56		7.98	
36		2.71		8.14	

In the heading: NS = number of samples, LL = lower limit of decision making, CNFE = cumulative count of the number of fruits with *N. elegantalis* eggs in the sampling unit (Fig.1) and UL = upper limit of decision making.

7.3. Appendix C

Sequential sampling table for *Neoleucinodes elegantalis* in tomato crops for insecticides aircraft application on plants at the FSI and FSII.

Plants at the FSI
(number of clusters per plant ≤3)

NS	Decision	LL	CNFE	UL	Decision
1	Do not control the pest when CNFE < LL	-		-	Control the pest when CNFE ≥ UL
2		-		-	
3		-		-	
4		-		-	
5		-		-	
6		-		-	
7		-		-	
8		-		-	
9		-		-	
10		-		3.69	
11		-		3.77	
12		-		3.85	
13		-		3.92	
14		-		4.00	
15		-		4.08	
16		-		4.15	
17		-		4.23	
18		-		4.31	
19		-		4.38	
20		-		4.46	
21		-		4.54	
22		-		4.61	
23		-		4.69	
24		-		4.77	
25		-		4.84	
26		-		4.92	
27		-		5.00	
28		-		5.07	
29		-		5.15	
30		-		5.23	
31		-		5.30	
32		-		5.38	
33		-		5.46	
34		-		5.54	
35		-		5.61	
36		-		5.69	
37		-		5.77	
38		-		5.84	
39		0.07		5.92	
40		0.14		6.00	
41		0.22		6.07	
42		0.30		6.15	

Plants at the FSII
(number of clusters per plant >3)

NS	Decision	LL	CNFE	UL	Decision
1	Do not control the pest when CNFE < LL	-		-	Control the pest when CNFE ≥ UL
2		-		-	
3		-		-	
4		-		-	
5		-		-	
6		-		-	
7		-		-	
8		-		-	
9		-		-	
10		-		4.21	
11		-		4.36	
12		-		4.51	
13		-		4.66	
14		-		4.81	
15		-		4.97	
16		-		5.12	
17		-		5.27	
18		0.04		5.42	
19		0.20		5.57	
20		0.35		5.73	
21		0.50		5.88	
22		0.65		6.03	
23		0.80		6.18	
24		0.96		6.33	
25		1.11		6.48	
26		1.26		6.64	
27		1.41		6.79	
28		1.56		6.94	
29		1.71		7.09	
30		1.87		7.24	
31		2.02		7.40	
32		2.17		7.55	
33		2.32		7.70	
34		2.47		7.85	
35		2.63		8.00	
36		2.78		8.15	

In the heading: NS = number of samples, LL = lower limit of decision making, CNFE = cumulative count of the number of fruits with *N. elegantalis* eggs in the sampling unit (Fig. 1) and UL = upper limit of decision making.