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# Modeling of the immature stages of the species of Noctuidae associated with *Physalis peruviana* L.

UNIVERSIDAD NACIONAL DE COLOMBIA

## Modelación de estados inmaduros de especies de Noctuidae asociados a *Physalis peruviana* L.

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## ABSTRACT

**Keywords:**
*Copitarsia decolora*
Generalized linear models
Golden berry
*Heliothis subflexa*
Solanaceae

*Physalis peruviana* L. is currently the second fruit crop more exported of Colombia; however, the pests associated with the culture have been little studied which is important considering that some Noctuidae can cause a decrease of 20% in its production. In this research, the Noctuidae species related to P. peruviana were studied in three farms of La Unión, Antioquia, Colombia. Twelve sampling units, with 30- and 45-day transplanted plants, were distributed throughout the farms and sampled biweekly from March 1$^{st}$ to August 29$^{th}$ of 2014. In the plant canopy and the planted area, immature stages were registered, and statistic models were built in order to describe their trend. The taxonomic identification of adults was made by comparing with the Noctuidae collection of Museo Entomológico Francisco Luis Gallego at Universidad Nacional de Colombia – Sede Medellín, and by using taxonomic keys. Nine Noctuidae species were found in total. Six models were built, four oviposition models for *Agrotis ipsilon* and *Spodoptera* spp., *Copitarsia decolora* and *Heliothis subflexa*, *Megalographa biloba*, and *Peridroma saucia*; a model for larvae and pupae stages was built. The oviposition model for *P. saucia* was the more adjusted, with a Root mean squared predictive difference (RMSPD) of 0.84. The other studied models were suitable to describe the trend of the immature stages; except for *M. biloba* model. This research revealed the ecological characteristics of the Noctuidae species associated with the golden berry crop that affect its productivity.

## RESUMEN

**Palabras clave:**
*Copitarsia decolora*
Modelos lineales generalizados
Uchuva
*Heliothis subflexa*
Solanaceae

*Physalis peruviana* L. es actualmente el segundo cultivo frutícola más exportado de Colombia; sin embargo, las plagas asociadas con el cultivo han sido poco estudiadas, lo cual es importante ya que algunos nóctuidos pueden causar una reducción del 20% en su producción. En esta investigación se estudió las especies de nóctuidos asociadas a *P. peruviana* en tres fincas del municipio de La Unión, Antioquia, Colombia. Doce unidades de muestreo, con plantas entre 30 y 40 días de trasplantadas, fueron distribuidas en las fincas y muestreadas quincenalmente, del primero de marzo al veintinueve de agosto de 2014. En el dosel de la planta y el área plantada se registró el total de estados inmaduros y se construyeron modelos estadísticos con el fin de describir su tendencia. La identificación taxonómica de adultos se hizo por comparación con la colección de Noctuidae del Museo Entomológico Francisco Luis Gallego de la Universidad Nacional de Colombia – Sede Medellín, y mediante el uso de claves taxonómicas. En total se encontraron nueve especies de nóctuidos. Se construyeron seis modelos, cuatro de oviposición para las especies *Agrotis ipsilon* y *Spodoptera* spp, *Copitarsia decolora* y *Heliothis subflexa*, *Peridroma saucia*, y *Megalographa biloba*; uno para larvas y otro para pupas. El modelo de oviposición de *P. saucia* fue el más ajustado con una Diferencia Cuadrática Media de Predicción (RMSPD *por sus siglas en inglés*) de 0,84. Los otros modelos estudiados describen adecuadamente la tendencia de los estados inmaduros, excepto el correspondiente a *M. biloba*. Esta investigación reveló características ecológicas de las especies Noctuidae asociadas al cultivo de uchuva que afectan su productividad.

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In Colombia, *Physalis peruviana* L., known as golden berry, is a fruit of exportation that has had a good reception in the European international market. The crop has increased from 221 cultivated hectares in 1999 (Sanabria, 2005) to more than 1,000 ha in 2009 (Agronet, 2015), and by 2005 it was considered the second more exported fruit after banana (Fischer *et al.*, 2005). Nowadays, it has been consolidated as the second most exported fruit product of the country, and in 2016 its total exports were 5.2 million t which represent a value of 23,600 million dollars (López, 2018). Most of the production is obtained by small farmers from the Colombian departments of Cundinamarca, Boyacá and Antioquia (Fischer *et al.*, 2014; Zapata *et al.*, 2002).

*Physalis peruviana* (physalis = bladder) have numerous common names according to the country/or regions such as Cape gooseberry (South Africa), Inca berry, Aztec berry, Golden berry, giant ground cherry, African ground cherry, Peruvian ground cherry, Peruvian cherry, pokpok (Madagascar), rasbhari (India), poha aguaymanto poha aguaymanto (Peru), uvilla (Ecuador), uchuva (Colombia), harankash (Egypt), amur en cage (France), and physalis (United Kingdom) (Afsah, 2015). The mechanical, physicochemical, nutritional, and medicinal properties, so as its functionality, associated with this fruit have been described by Puente *et al.* (2011). Its genetic diversity and population structure have been studied by molecular markers (Garzón *et al*., 2015). *Physalis peruviana* is the object of several research in order to take advantage of its secondary metabolites, which exhibit extensive biological properties that could have a potential pharmacological, medicinal, and insecticidal use (Aguirre-Ráquira *et al*., 2014; Cirigliano *et al*., 2008).

However, there have not been developed technological programs or studies for the crop management. Therefore, the losses rise to around 13% (Sanabria, 2005). The studies of insect pests associated with this plant are incipient (Afsah, 2015). In the Noctuidae family, some polyphagous species that affect several organs at different stages of the *P. peruviana* phenology such as *Spodoptera* sp., *Agrotis* sp. and *Feltia* sp., known as cutworms. The larvae is the only harmful stage which can cut the seedling at ground level and can feed on branch, roots, leaves, and shoots (Benavides and Mora, 2005).

The damage caused by these cutworms is not harmful enough to the *P. peruviana* crop, as the damage made by the species that pierce the fruit like *Heliothis subflexa* and *Copitarsia decolora*, the former is considered the most important phytophagous of *P. peruviana* (Zapata *et al*., 2002). The caterpillars pierce the sepals and feed on the fruit in any of its stages, which could reduce the production to 20% according to the climatic condition and the alternative hosts; after the damage, some fruits can fall to the ground or stay in the plant, but in both cases the fruit loses its market value (Benavides and Mora, 2005).

Noctuidae has been the source of many types of researches, with the aim of understanding its behavior, life cycle, and mainly to find ways to control its populations. However, the researches in *P. peruviana* are incipient. The aim of this work was to determine the Noctuidae species associated with *P. peruviana*. The fluctuation of the immature stages according to the development of the plant, and spatial and climatic variables were studied in three farms from the municipality of La Union-Antioquia-Colombia, with the aim of building statistical models to describe the growing trend as a tool for pest management.

Twelve species of Noctuidae were found; cutworm and leaf eaters included *Agrotis ipsilon*, *Megalographa biloba*, *Peridroma saucia* and four species of *Spodoptera* (*S. albula*, *S. eridania*, *S. frugiperda* and *S. ornithogalli*); and two fruit borer, *Copitarsia decolora* and *Heliothis subflexa*. Six models clustering ecological and biological similarities of the species were built, having into account climatic, spatial and temporal variables. Four oviposition models were built for the species *A. ipsilon* and *Spodoptera* spp.; *C. decolora* and *H. subflexa*; *M. biloba*; and, *P. saucia*; besides, larvae and pupae models, without regards of the species. All models, except that of *M. biloba*, are important for predicting purposes in pest management programs.

## MATERIALS AND METHODS

### Location

The study included 12 sampling units distributed throughout three producer farms of *P. peruviana* in the municipality of La Unión, Antioquia, Colombia. The geographic coordinates of the first farm are 461186.23 m longitude W and 659246.13 m latitude N, the second farm with 460238.06 m longitude W and 659604.24 m latitude N, and the third farm with 459443.45 m longitude W and, 660349.50 m latitude N, with WGS 84 UTM 18N coordinate system, and 2.509 m mean altitude. The study was performed with plants between 30 and 45 Days After Transplant (DAT) and the sampling were made biweekly, from March 1st to August 29th of 2014. Before the *P. peruviana* was planted, the farms had different covers, which is a critical factor concerning the presence of phytophagous insects and the diseases. The previous cover for the farm 1 was *P. peruviana*, for the farm 2 was stubble low, and for the farm 3 was *Solanum tuberosum*.

## Sampling

Every sampling unit corresponded to 10 plants, in each plant the soil under the canopy and the canopy divided into three fractions (top, mid and low) were sampled. The soil under the canopy was flipped to collect the pupae and caterpillars of noctuids. In each fraction of the canopy, the beam, the underside of 20 leaves as the minimum, and the fruits were inspected, looking for the immature stages of noctuids. All the stages were collected in plastic glasses of 16 ounces, covered with a mesh and marked with the number of the plant, the fraction, the metamorphosis stage and the date. The glasses were put in boxes and carried to the laboratory of the Museo Entomológico Francisco Luis Gallego (MEFLG).

## Taxonomic identification

The eggs were placed on moistened paper with water until larvae hatching. The larvae were fed daily with leaves of *Ricinus comunis* until the adult emerged to be identified. The pupae were left in soil moistened with water until the imago emerged. The moths were put in a lethal chamber with ethyl acetate, to be mounted in an entomological pin. The moths were identified by comparing with the Noctuidae collection of the MEFLG with the curator guide (John Albeiro Quiroz-Gamboa), also comparisons with the taxonomic key of Angulo *et al.* (2008) were performed. Besides, the lepidopteran specialist of the United States Department of Agriculture (USDA) (Columbus, Ohio) Steven C. Passoa identified two of the species of larvae from this study.

## Statistical analysis

The response variable corresponded to the information of the Noctuidae species that were grouped according to features of the immature stages like pupae, larvae, and oviposition (Table 1). These were correlated with eleven climatic variables, five spatial variables, and a temporal variable. The climatic variables were related to temperature, relative humidity and precipitation, during eight days before sampling, each climatic variable was partitioned according to its features (Table 2). The spatial variable corresponded to the slope and sampling location, north latitude, west longitude, and altitude coordinates. The temporal variable corresponded to the week, correlated with the development phases of the plant as well as the agricultural practices (Table 3). The climatic information was provided by the Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia (IDEAM), and the spatial information was taken with a Global Position System (GPS) *Garmin e-trx 10®* and analyzed by the software *Arcgis 10.2®*.

**Table 1.** Response variables of the immature stages of Noctuidae species associated with *Physalis peruviana*.

| Type of oviposition | | | | Larvae | Pupae |
|---|---|---|---|---|---|
| Gregarious oviposition on the leaf beam (G***OLB***) | Gregarious oviposition underside of the leaf (***GOUL***) | Isolated oviposition on the leaf beam (***IOLB***) | Isolated oviposition underside of the leaf (***IOUL***) | | |
| *P. saucia* | *S. albula* | *C. decolora* | *M. biloba* | Larvae | Pupae |
| | *S. eridania* | *H. subflexa* | | | |
| | *S. frugiperda* | | | | |
| | *S. ornithogalli* | | | | |
| | *A. ipsilon* | | | | |

**Table 2.** Explanatory variables: Climatic variables recorded eight days before sampling.

| Minimum temperature | | | Mean temperature | | | Rainfall | | Relative humidity | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Lower | Mean | Higher | Lower | Mean | Higher | Mean | Cumulative | Lower | Mean | Higher |
| *Mitl* | *Mitm* | *Mith* | *Metl* | *Metm* | *Meth* | *Rm* | *Rc* | *Rhl* | *Rhm* | *Rhh* |

**Table 3**. Explanatory variables: Spatial and temporal variables.

| Explanatory variables | | | | | |
|---|---|---|---|---|---|
| Slope | X coordinate corrected | Y coordinate corrected | Z coordinate corrected | Sampling unit | Elapsed week |
| *S* | *Xc* | *Yc* | *Zc* | *Su* | *Wk* |
| % | WGS 1984, UTM Zone 18N (m) | WGS 1984, UTM Zone 18N (m) | m.a.s.l. | Distributed throughout three producer farms (1 to 12) | Week of the year |

The statistical analysis was made with the Tinn-R® software by using Generalized Linear Models (GLM). GLM is a statistical model for a large family of probability distributions known as the exponential family, that includes important distributions as the Gaussian, Gamma, Chi-squared, Beta, Bernoulli, Binomial and Poisson distributions in order to find statistical differences (Schabenberger and Pierce, 2001). The Poisson distribution was used because the data presented this kind of trend and was of low magnitude. Nevertheless, as there are variables with bigger magnitudes, it was required to get an adjusted model by using Akaike function (AIC) through the step command of Tinn-R®. For the statistical test, it was used the Root Mean Square Predictive Difference (*RMSD*) that provides a higher sameness to validate the prediction model.

Having into account that projected coordinates have a large scale, it was necessary to apply a correction to avoid masking other explanatory variables, as shown below:

$$Cc = (Ci - Cm)$$

*Cc:* Coordinate corrected

*Ci:* Coordinates *ith*

*Cm:* Coordinate minimum

## RESULTS AND DISCUSSION

In total, nine Noctuidae species were found. They were distributed in the subfamilies Acronyctinae, Noctuinae, Plusiinae and Cuculiinae. The Acronyctinae included the species: *Spodoptera albula* (Walker, 1857), *S. eridania* (Cramer, 1782), *S. frugiperda* (Abbot and Smith, 1797) and *S. ornithogalli* (Guenée, 1852). These species showed gregarious oviposition covered with the protection of silk and squamae made by the female (Vélez-Ángel, 1997), mainly laid on the leaf underside, in the middle and low fraction of the *P. peruviana* canopy.

The Noctuinae species were *Agrotis ipsilon* (Hüfnagel, 1766), *Heliothis subflexa* (Guenée, 1852) and *Peridroma saucia* (Hübner, 1808). *A. ipsilon* has gregarious oviposition mainly on the leaf underside in the middle and low fraction of *P. peruviana* canopy as well as the *Spodoptera* species. *P. saucia*, except for this species also have oviposition on the leaf beam of *P. peruviana* canopy. Finally, *H. subflexa*, previously classified in Heliothinae (Matthews, 1991), has isolated oviposition mainly on the leaf beam, in the middle and top of the canopy or close to the reproductive organs like branches or fruits of *P. peruviana*.

The only Plussinae species was *Megalographa biloba* (Stephens, 1830), with isolated oviposition mainly on the leaf underside and in the middle fraction of the *P. peruviana* canopy. The Cuculiinae species found was *Copitarsia decolora* (Guenée, 1852), with isolated oviposition mainly on the leaf beam, in the middle and top of the canopy or close from reproductive organs like branches or fruits of *P. peruviana* as well as *H. subflexa*. *C. decolora* and *H. subflexa* could be considered more important species than the other seven reported in this work because they both feed on the fruits because if the fruit is exported with small larvae and quality flaws could be baned. *C. decolora* and *H. subflexa* were present mainly at the crop reproductive phase, while the other seven species that feed on leaves were present in all the development phases, mainly in the vegetative stage.

### The Modelling

The GLM built for each response variable showed the estimated trend for the different immature stages, considering the explanatory variables that more affected the model. Table 4 shows the statistical significance of the variables that describe the model trend and the Akaike index (AIC) that allow inferring if each model is suitable to estimate the trend of the immature stages.

**Table 4.** Statistical significance of explanatory variables.

| Explanatory Variables | $\beta_0$ | Wk | Su | S | Xc | Yc | Zc | *Mitl* | *Mitm* |
|---|---|---|---|---|---|---|---|---|---|
| Pupae | <0.001 | - | <1 | - | - | - | - | - | - |
| Larvae | <1 | <0.001 | <0.001 | <0.1 | - | - | . | <0.001 | <0.001 |
| *H. subflexa* and *C. decolora* | <0.001 | <0.001 | <0.05 | - | <0.001 | <0.001 | - | <0.001 | <0.001 |
| *P. saucia* | <0.05 | <0.01 | <0.001 | - | <0.01 | - | - | - | - |
| *M bibloba* | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| *A. ipsilon* and *Spodoptera* spp. | <0.001 | - | <0.01 | <0.001 | - | - | <0.05 | <0.01 | |

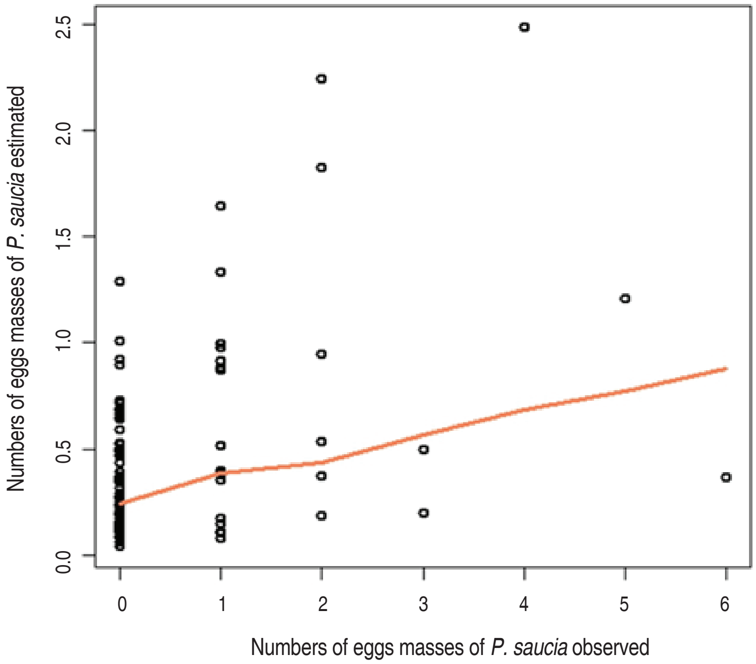
| Explanatory Variables | *Mith* | *Metl* | *Metm* | *Meth* | *Rm* | *Rc* | *Rhl* | AIC | RMSPD |
|---|---|---|---|---|---|---|---|---|---|
| Pupae | - | <0.001 | - | - | <0.05 | <0.05 | - | 382.72 | 1.406 |
| Larvae | - | <0.001 | <0.001 | <0.001 | - | <0.001 | <0.001 | 623.57 | 2.733 |
| *H. subflexa* and *C. decolora* | <0.01 | <0.001 | <0.1 | <0.001 | <0.05 | <0.001 | - | 953.87 | 5.414 |
| *P. saucia* | - | -- | <0.01 | - | - | <0.001 | <1 | 214.54 | 0.837 |
| *M bibloba* | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 217.25 | 0.928 |
| *A. ipsilon* and *Spodoptera* spp. | <0.001 | | | <0.001 | - | . | <0.001 | 422.01 | 1.714 |

- Without statistical differences.

Before describing each model, it is noteworthy that the most complex model, considering it was affected by 12 of the 17 variables studied, was the oviposition model of *C. decolora* and *H. subflexa* (Table 4). It could be explained because their eggs are laid individual and located from the middle to the upper part of the canopy, therefore they are more exposed and sensitive to most of the variables. On the other hand, the simplest model was the pupae one, only affected by four variables, suggesting that the states of Noctuidae located underground are less susceptible to most of the variables studied. Besides, it should be highlighted that the *GOLB* model of *P. saucia* oviposition had an index closer to zero.

### *Peridroma saucia* oviposition model

The gregarious oviposition of *P. saucia* on the leaf beam (*GOLB*) in *P. peruviana* showed a model with a *RMSPD* of 0.84, close enough to zero, and all variables had a *P*<0.05, thus the confidence interval was higher than 95%, so it could be used to estimate the oviposition trend of this moth (Figure 1). This kind of model could be used as a tool for integrated pest management, especially if it is complemented with a development model (Choi and Kim, 2014) to predict the time of the larvae first instar, as the proposed for *Ascostis selenaria* (Denis et Schiffermüller) (Lepidoptera: Geometridae). Allowing an effective spraying time, since the egg and the first instar are the most vulnerable to insecticides (Park *et al*., 2014). The equation suggested that the oviposition of *P. saucia* was influenced negatively by the week (*Wk*) and by the lower relative humidity (*Rhl*).




$$Y' = -16.3308 - (0.0965\,Wk) + (1.1886\,Metm) + (0.0234\,Rc) - (0.0629\,Rhl) + (0.3107\,S) + (125.8787\,Xc) \quad (1)$$

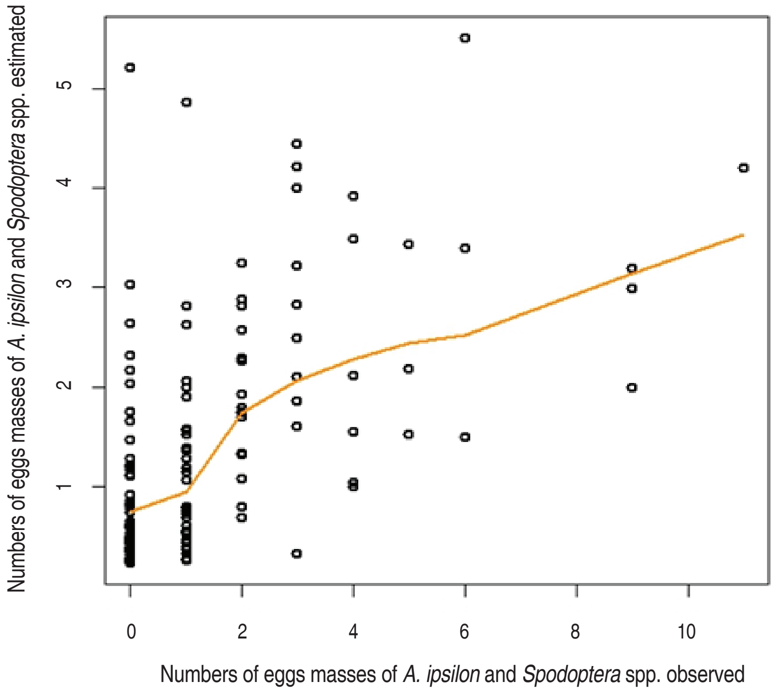
**Figure 1.** *Peridroma saucia* oviposition model.

The variable *Wk* could be related to *P. peruviana* phenology as well as the agronomic activities because the plant development was matching with chemical pest management to avoid damages in leaves and fruits of *P. peruviana*. The relative humidity and temperature affected the developmental stages of *P. saucia*. The relative humidity and mean temperature were 79.79% and 15.13 °C, respectively, thus the equation model was affected negatively by the lower relative humidity. Moreno-Fajardo and Serna-Cardona (2006b) found that the stages are shorter under a relative humidity of 82.93% and a temperature of 23.97 °C than 65.96% and 17.72 °C. On the other hand, mean temperature (*Metm*), the rain cumulative (*Rc*), the sampling unit (*Su*) and the East corrected (*Ec*) had a positive effect in the oviposition model of *P. saucia*.

### ***Agrotis ipsilon*** **and** ***Spodoptera*** **spp. oviposition model**

The oviposition model of *A. ipsilon* and *Spodoptera* spp., corresponding to the gregarious oviposition on the leaf underside (*GOUL*) (Figure 2)., had a RMSPD of 1.7142 with a *P*<0.05 for all the variables. It described closely the oviposition trend of the *Spodoptera* species found in *P. peruviana* crop: *S. ornithogalli, S. albula, S, eridania* and *S. frugiperda*, as well as *Agrotis ipsilon.* The oviposition of these species showed similar features because they were found mainly in the mid and low canopy of *P. peruviana*, and the eggs usually were gregarious and covered with silk and flakes (only those of *Spodoptera* spp).

Although this model was not as close to zero as that of *P. saucia* (Figure 1), it could be used to estimate the presence of oviposition of these phytophagous to design a pest management program. The variable affecting the oviposition was the higher value of minimum temperature (*Mith*) with a mean value of 11.8 °C. According to Milano *et al.* (2008), the lowest temperature threshold of *S. frugiperda* is 15 °C and the highest is 35 °C; in both temperatures, the mating frequency is affected. In concordance with Méndez-Barceló (2009) who found that female might laid until 1,000 eggs, but if the temperature reaches 30 °C, the oviposition drops to 386 eggs.



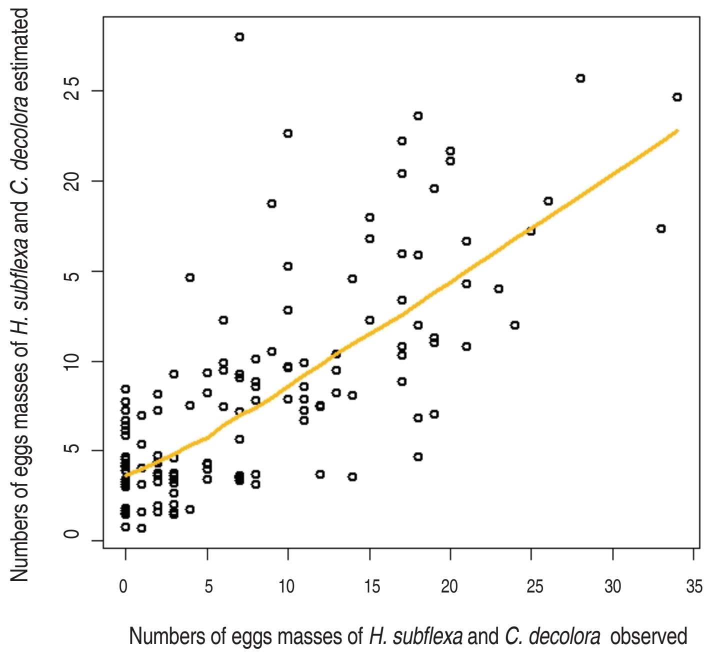

$$Y' = -39.07989 - (0.05482Su)+(0.06371Zc)+(2.07891Meth)+(0.30934Mitl)-(0.7397Mith)+(0.14596Rhl)-(0.05287S) \quad (2)$$

**Figure 2.** *Agrotis ipsilon* and *Spodoptera* spp. oviposition model.

Conversely, our model showed that the highest values of mean temperature (*Meth*), with a mean of 16.14 °C and the lowest value of minimum temperature (*Mitl*), with a mean of 8.2 °C had a positive effect in the *Spodoptera* spp. oviposition process. In this case, it is necessary to evaluate the exposition time for every level of temperature, since it may have a lower exposition time in *Meth* and *Mitl*, but for *Mith* had a higher time of exposition. On the other hand, the other variables that affected the model negatively were the slope (*S*) and the sample unit (*Su*), both corresponding to spatial variables. Therefore it can be inferred that there are micro clime and soil variables that are not favorable for the oviposition of *Spodoptera* spp.

### *Copitarcia decolora* and *Heliothis subflexa* oviposition model

The *C. decolora* and *H. subflexa* oviposition model, corresponding to the isolated oviposition on the leaf beam in *P. peruviana* (*IOLB*) (Figure 3), had a RMSPD of 5.414, with all the variables with a $P<0.05$, except for the mean of the mean temperature (*Metm*) with $P<0.1$. The highest value of RMSPD allowed inferring that there may be other variables that can explain better the oviposition behavior of piercing fruit moths; despite the statistical test is supported by a high confidence level in each variable. The GLM (Figure 3) is tight enough to describe the oviposition trend for both species; therefore, it could be used to know the immature stages trend of this species.




$$Y' = -1.189e{+}01-(3.632e{-}02\,Wk)+(5.512e{-}01\,Metl)+(9.936e{-}01\,Meth)-(1.749e{-}01\,Metm)+(5.094e{-}01\,Mitl)-(3.546\,Mith)-(6.945\,Mitm)-(8.790e{-}02\,Rm)+(1.992e{-}02\,Rc)-(4{,}268e{-}02\,Su)-(1.124e{-}02\,Xc)-(2.388e02\,Yc). \quad (3)$$

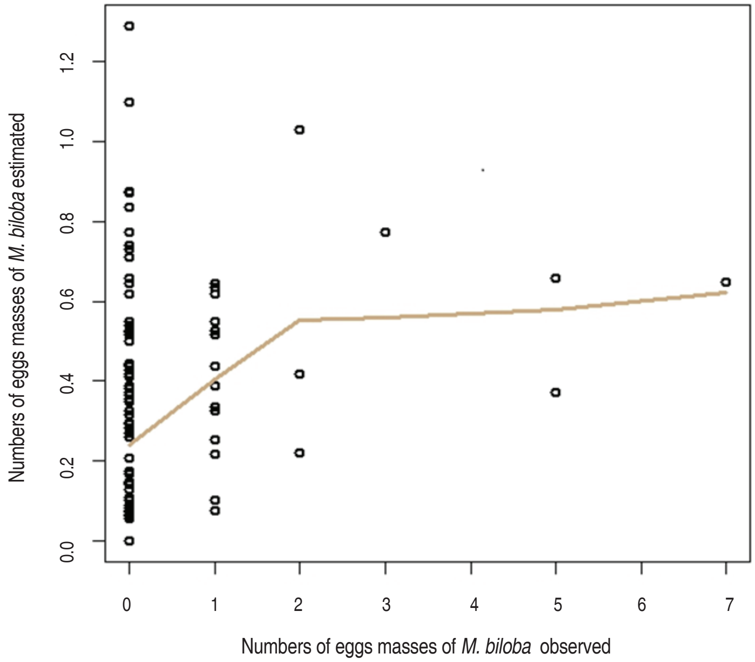
**Figure 3.** *Copitarsia decolora* and *Heliothis subflexa* oviposition model.

The equation of the model showed that there was a negative effect on the following variables, with $P<0.001$: *Wk*, *Mith*, *Mitm*, and *Ec*. Also, the following variables had a negative impact, with $P<0.05$: *Minth*, *Rm*, *Su*, and *Nc*. Moreover, the variable *Metm* had a negative effect in the model with a $P<0.1$. Four of the variables named correspond to the lower level of temperature because it could be the most important variable. Moreno-Fajardo and Serna-Cardona (2006a) consider that temperature could affect the number of generations in *C. decolora* and probably influence the behavior of this moth, like in *Alabama argillacea* (Lepidoptera: Noctuidae) (Mazza *et al*., 2006).

On the other hand, the spatial variables *Su* and *Nc*, related to the conditions and location of the sampling units, could be associated with soil and microclimatic conditions. Nevertheless, the lowest temperature minimum registered (*Mitl*), with a mean of 8.02 °C, was positive among the whole variables in this model such as in the *Spodoptera* model, indicating that there could be a relationship between this level of temperature and the behavior of oviposition in both species.

### *Megalographa biloba* oviposition model

The oviposition model of *M. biloba* that corresponded to isolate oviposition under the leaf of *P. peruviana* (*IOUL*) (Figure 4) had a RMSPD of 0.9281; the second model after *P. saucia* with the lowest value. Nevertheless, the P-value for all variables were close to 0.9 (Table 4) which means a confidence interval lower than 10% in the relationship between the variables studied and the oviposition observed. These results indicated that there is no confidence to estimate the oviposition trend of this species, although Figure 4 showed a good description. The variables studied did not explain the egg trend for *M. biloba* in the *P. peruviana* crop.




$$Y'=-1.144e02-(7.27e\text{-}01Wk)+(7.348e\text{-}02Metl)-(5.522Meth)+(15.09Metm)-(12.99Mitl)-(3.686Mith)+(22.77Mitm)-(8.57Rm)+(4.598e\text{-}01Rc)-(1.332Hrl)-(5.678e\text{-}02Su)-(4.115Xc)-(9.342Yc)-(5.590e\text{-}02Zc)-(2.318e\text{-}03S). \quad (4)$$

**Figure 4.** *Megalographa biloba* oviposition model.

**Larvae model**

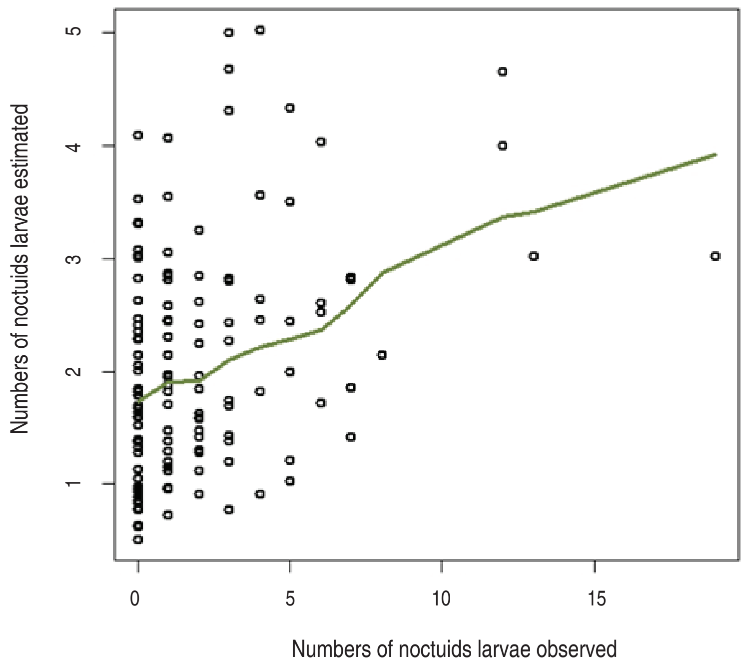
The larvae model of the nine species of noctuids collected in the *P. peruviana* crop had a RMSPD of 2.73252 that is a value relatively far from zero, with a $P<0.05$ for all the variables, except for the slope (*S*) that presented a $P<0.1$. Nonetheless, the model had a good trend description of Noctuidae larvae in the crop (Figure 5), turning it in a pest management tool; therefore, with the different variables evaluated it is possible to define a behavior of the Noctuidae larvae populations in *P. peruviana*.

According to the larvae model equation, the lower value of mean temperature (*Metl*), the mean of mean temperature (*Metm*), the mean of minimum temperature *(Mitm),* the rain cumulative (*Rc*), and the sampling unit (*Su*) had a negative effect on the larvae presence in the field. The temperature had a high incidence in the metamorphosis, while the rain cumulative suggests that soil water accumulation could affect the larvae behavior in the field. Also, the sampling unit is related to microclimatic conditions and is likely that soil features are correlated as well.

**Pupae model**

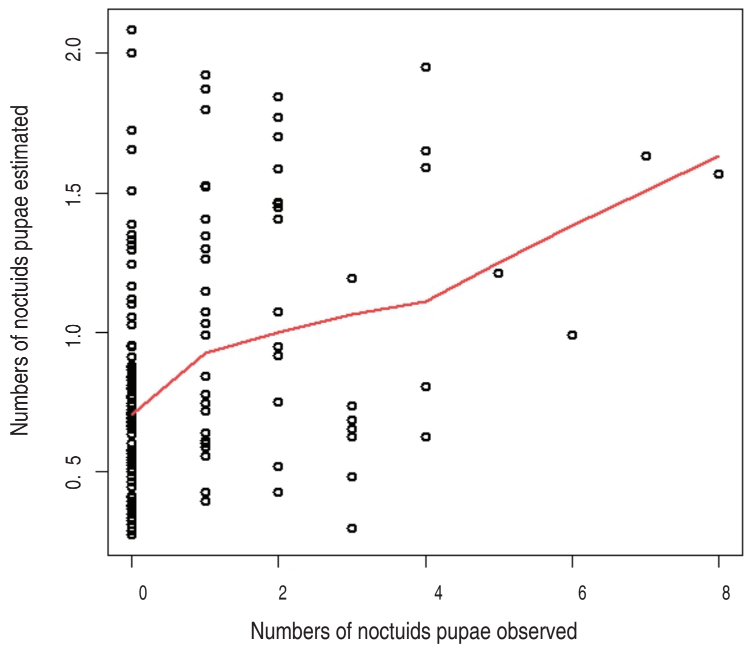
The pupae model of the nine species of noctuids collected in the soil had a RMSPD of 1.4056, which is a value relatively close to zero. The variables had a $P<0.05$, meaning a confidence interval higher to 95%. Therefore, the model had a great trend to describe the pupae of Noctuidae in the crop (Figure 6).

According to the pupae model equation, the mean of mean temperature (*Metm*), the rain cumulative (*Rc*), and the sampling unit (*Su*) had a negative effect in the pupae presence in the field, so as it was observed in the larvae model equation. Considering that the pre-pupae and pupae stages are carried out in the soil, it is important to highlight the possibility that some features of the soil,




$$Y' = -6.518644 + (0.108243\,Wk) - (1.04030\,Metl) + (1.9953\,Meth) - (0.9861\,Metm) + (1.523842\,Mitl) - (2.0938\,Mitm) - (0.021174\,Rc) + (0.14205\,Rhl) - (0.068996\,Su) + (0.015704\,S). \quad (5)$$

**Figure 5.** Larvae model.




$$Y' = 9.54905 - (0.63235\,Metm) + (0.14651\,Rm) - (0.02591\,Rc) - (0.04073\,Su) \quad (6)$$

**Figure 6.** The pupae model.

related to the rain cumulative and the sampling unit, are the reason of the negative effect in this model.

## CONCLUSIONS

In most cases, the more important explanatory variables to estimate the trend of noctuids immature stages in the *P. peruviana* crop were the temperature, rainfall cumulative and the elapsed week. The temperature is known as one of the most important variables because it determines the time for the development of the insects' immature stages, considering that they are ectothermic. Therefore, the kind of models built in this work, combined with Grades-Day (used to predict the most important thermal events of the insects), should be considered to reduce its populations, if it is necessary. The cumulative rain dropped the larvae populations and probably reduced the imago activity. Finally, the elapsed week of the crop, another crucial variable, should be considered for insect pest management.

The oviposition found for each noctuid species recorded, as well as each model built, constitutes a tool for integrated pest management. The noctuid oviposition agreed with the feeding preference of each species. Those species that feed on leaves laid their eggs frequently on the canopy middle and low part of the leaves, and those that feed on *P. peruviana* fruit, as *C. decolora* and *H. subflexa*, laid their eggs close to the reproductive organs or on it. These behaviors are important for Noctuidae sampling, monitoring and management.

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