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Economic damage levels and treatment thresholds for leafminer insects in *Solanum tuberosum* crops

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ABSTRACT

Integrated Pest Management (IPM) can only result in reduced insecticide use when treatments are applied when infestations reach economic thresholds (ET) determined from economic injury levels (EIL). The objective of this study was to determine the EIL and ET for *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) and *Liriomyza huidobrensis* (Burgess) (Diptera: Agromyzidae) in 8 and 11 fields of the potato cultivar 'Ágata', respectively. The EILs were calculated based on control costs, production values, control efficacy and injuries of each insect and the ETs were calculated by subtracting 20% from the EIL value, given that control measures must be undertaken before the pest populations reach the former level. The EIL for *L. huidobrensis* at 50 and 70 days after planting (DAP) ranged from 0.07 to 0.24 and from 0.09 to 0.32 mines per plant, respectively, and those of *P. operculella* at 50 DAP ranged from 0.07 to 0.24 mines per plant. The ET for *L. huidobrensis* at 50 and 70 DAP were 0.05–0.19 mines per plant, respectively, and those of *P. operculella*, 0.05 to 0.19 mines per plant at 50 DAP. These results suggest that management of these pests in potato crops should use the ET of 0.07 and 0.05 mines per plant for control decisions regarding *L. huidobrensis* and *P. operculella*, respectively.

1. Introduction

Insect pests cause financial losses in horticulture (Oerke and Dehne, 2004) and in potato crops are mainly controlled with chemical insecticides (Rondon, 2010; Mujica and Kroschel, 2013), which are often applied without considering pest and natural enemy densities (Richards et al., 2015). Insecticides can cause pest resistance, increase production costs, contaminate the environment and can be toxic to humans and non-target organisms (Okoth et al., 2014; Alyokhin and Miller, 2015). Insecticides such as organophosphates (malathion, chlorpyrifos and acephate), benzylates (bromopropylate), carbamates (kresoxim, thiodicarb) and cyclodienes (endosulfan) have been detected in potato tubers (Soliman, 2001; Rigueira et al., 2013; Ahmed et al., 2014).

Two of the most significant pests of *Solanum tuberosum* L. (Solanaceae) (Rondon, 2010; Alves et al., 2014) are *Liriomyza huidobrensis* (Burgess) (Diptera: Agromyzidae) and *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) generating losses of up to 100% in this crop (Rondon, 2010; Mujica and Kroschel, 2013). These pests destroy the leaf mesophyll and allow pathogen entry (Zoebisch and Schuster, 1987; Mujica and Kroschel, 2013). *Liriomyza huidobrensis* has been reported in Argentina, Chile, Costa Rica and Peru (Barea, 1994; Lopez et al., 2003; Larrain, 2004; Mujica and Kroschel, 2013) in several potato cultivars (Mujica and Kroschel, 2013). *Phthorimaea operculella* is a pest of worldwide significance that destroys potato leaves and tubers (Rondon, 2010). The potato cultivar Ágata, which comprises more than 60% of the area planted in Brazil, has a high market value due to its high yield, rapid budding and smooth, uniform, light yellow tubers (Fernandes et al., 2010). Determination of economic injury and economic thresholds is the first step towards Integrated Pest Management

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(IPM) with reduced production costs (Sharma et al., 2011; Batistela et al., 2012; Ellis et al., 2012).

The economic injury level (EIL) quantifies the costs and benefits of IPM pest control decisions for sustainable crop production (Ramsden et al., 2017). The EIL is the number of insects or injury level that would generate economic losses equal to control costs. This level varies according to factors such as control costs, production value, injury unit, damage and control efficiency (Fernandes et al., 2011; Brewer et al., 2013).

The economic threshold (ET) is often set at 80% of the EIL, allowing the time for control measures to be undertaken before the pest (numbers/density) reaches the former value (Mujica and Kroschel, 2013). The ET calculation is difficult because it requires of pest populations and damage in a large number of crops with insect populations at different population levels (Pedigo et al., 1986). Studies of ETs have been reported for *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) in *Allium cepa*, *Anticarsia gemmatalis* (Hübner) (Lepidoptera: Noctuidae) and artificial defoliation in soybean *Glycine max* (L. Merril) (Batistela et al., 2012) and *Meligethes aeneus* Fabricius (Coleoptera: Nitidulidae) in *Brassica napus* L. (Hansen, 2004), mainly using the EIL as for *L. huidobrensis* in potato (Kroschel, 1995).

The objective was to determine and validate EIL and ET values for *L. huidobrensis* and *P. operculella* management in the potato cultivar Ágata in Brazil.

2. Materials and methods

This study was conducted from September 2013 to April 2014 in 24 commercial potato fields (*S. tuberosum* cultivar 'Ágata') in the municipalities of Campos Altos, Carmo Paranaíba, Ibiá, Rio Paranaíba and São Gotardo, Minas Gerais, Brazil. The EILs and ETs for *P. operculella* and *L. huidobrensis* were validated in 8 and 11 of these 24 fields (Fig. 2A, Fig. 2B), respectively.

During the production stage the potato plants were spaced 80–87 cm between rows and with 12–15 stems per linear meter. The potato fields selected had areas between 10 and 35 ha with leafy plants mined by *L. huidobrensis* and *P. operculella*.

The evaluations were carried out randomly in the potato fields at 15, 25, 50 and 85 days after planting (DAP) for *P. operculella* and at 35, 50 and 70 DAP for *L. huidobrensis*. The total number of mines with live caterpillars was evaluated for all leaves of the plants sampled.

The EIL, for *P. operculella* and *L. huidobrensis*, was calculated with the control cost (\$ ha^{-1}), average yield (t ha^{-1}), production value (\$ ha^{-1}), injury unit, damage and control efficiency (K). The EIL was defined as the damage that would justify the cost of artificial control measures (Higley and Pedigo, 1996; Pedigo and Rice, 2009). EIL = CC/V x I x D x K (formula 1), where EIL = economic damage level; CC = management cost per unit production; V = market value per production unit; I = injury per pest equivalent; D = damage per unit injury; K = coefficient of control efficiency. The ET value was 20% of the EIL, since control measures should be undertaken prior to the population reaching the EIL (Pedigo et al., 1986; Mujica and Kroschel, 2013). The ET varies according to environmental conditions, pest reproduction and other non-controllable factors (Pedigo et al., 1986). Low EIL and ET values indicate a low loss-benefit relationship, not justifying pest control measures (Bueno et al., 2011).

2.1. Management cost per unit production (CC)

Management costs per unit production (\$ ha^{-1}) were calculated taking into account the sprayer rental per insecticide application as \$142.25 ha^{-1}. In the Alto Paranaíba region the control of *P. operculella* and *L. huidobrensis* during the potato cycle requires three applications of insecticide. For this reason, this value was multiplied by three. The cost of the commercial insecticide applications of abamectin, chlorfenapyr, chlorantraniliprole, spinosad, lambda-cyhalothrin and novalurom, against *P. operculella* and *L. huidobrensis*, was calculated. The doses (L ha^{-1}), to control these pests, were multiplied by the unit price of the insecticide.

2.2. Market value per production unit (V)

The production value was estimated based on the value the average yield (t ha^{-1}) multiplied by the selling price of the potato (low, medium and high) (\$ t^{-1}). These prices were estimated as average monthly values from 2005 to 2014 and adjusted by the IGP-DI as of August 2014 (Cepea, 2014).

2.3. Unit of injury and damage (I and D)

Damage per injury unit (D) was obtained by adjusting the linear regression model of yield (t ha^{-1}) as a function of the number of mines per plant. The injury per pest equivalent (I) was determined by the curve inclination of the linear model adjusted between the number of active mines per plant per sample unit (Paula-Moraes et al., 2013).

2.4. Control efficiency coefficient (K)

The control efficiency coefficient (K) was 0.80, corresponding to the 80% control, recommended by the Brazilian Ministry of Agriculture and Livestock (Paula-Moraes et al., 2013; MAPA, 2014).

2.5. The ET validation

The ET was validated according to the number of *P. operculella* and *L. huidobrensis* mines per plant with 100 plants per hectare, sampled in 8 and 11 potato fields with the cultivar Ágata, respectively (Fig. 2A and B). The number of mines per plant in each field was compared with the ET values per insect miner.

3. Results

The control costs for *L. huidobrensis* and *P. operculella* were of US\$511 and US\$499 ha^{-1}, respectively. A total of 83.6% and 85.5% of this cost for *L. huidobrensis* and *P. operculella* are due to operational costs and 16.5% and 14.6% to that of the three insecticide applications, respectively (Table 1). Production values for *L. huidobrensis*, with a yield of 26.1 t ha^{-1} ranged from 2493 to 8849 \$ ha^{-1} and for *P. operculella* to 28.3 t ha^{-1} from 2695 to 9567 \$ ha^{-1} (Table 2).

The slope of 1.07 (Fig. 1A) and 0.81 (Fig. 1B) at 50 and 70 DAP and 0.98 mines per plant at 50 DAP (Fig. 1C) shows the relationship between yield and the number of *L. huidobrensis* and *P. operculella* mines, respectively (Fig. 1). The relationships between yield and the number of *P. operculella* mines per plant after 35 and 70 DAP and for *L. huidobrensis* after 35 DAP were not significant ($P > 0.05$).

The EIL values for *L. huidobrensis* at 50 and 70 DAP ranged from 0.07 to 0.24 and from 0.09 to 0.32 mines per plant, respectively, and those for *P. operculella* at 50 DAP of 0.07–0.24 mines per plant (Table 3). The ETs for *L. huidobrensis* at 50 and 70 DAP varied from 0.05 to 0.19 and from 0.07 to 0.25 mines per plant, respectively, and those for *P. operculella* at 50 DAP from 0.05 to 0.19 mines per plant (Table 3).

The number of *P. operculella* and *L. huidobrensis* mines per plant increased from the 25 DAP, with ET reaching 0.05 mines per plant in most potato fields. One of the eight evaluated fields showed a lower *P. operculella* mine density than the ET at 50 DAP and therefore did