Sunflower Seed Damage and Economic Injury Level of the European Sunflower Moth (Lepidoptera: Pyralidae) in the Republic of Azerbaijan[1]

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Abstract Injury to sunflower blossoms by the European sunflower moth, *Homoeosoma nebulella* Denis & Schiffermüller, significantly diminishes the harvest of sunflower seeds per hectare in commercial production in the Ganja-Ghazakh crop-growing region of the Republic of Azerbaijan. Annual seed losses of ~460 kg/ha can occur. Economic thresholds (ET), at which time insecticides or other remedial actions should be used to avoid exceeding the economic injury level (EIL), were determined for each of the two generations of *H. nebulella* that occur annually. The EIL was five to six eggs or large (≥third instar) larvae per blossom for the first generation, or about one egg or small (first or second instar) larvae per blossom for the second generation. The ET for adults caught in pheromone traps was 25.7 per day for the first generation and 3.7 per day for the second generation. Results also indicate that preventative or remedial actions should be used against the second generation of this pest, but such actions do not appear necessary to limit damage caused by the first generation.

Key Words Azerbaijan sunflowers, economic threshold, European sunflower moth, *Homoeosoma nebulella*

Increasing demand for quality sunflower seeds for human consumption, especially in the confectionary industry, has caused a rapid increase in farmland area cultivated for this crop in the Republic of Azerbaijan. Currently, approximately 2,350 ha are planted with sunflower, *Helianthus annuus* L. var. *qiqant*, in the Ganja-Ghazakh crop-growing regions of Azerbaijan. The increasing number of sunflower plantings on small farms is attractive to the European sunflower moth, *Homoeosoma nebulella* Denis & Schiffermüller, the most common, widespread, and economically damaging pest of this crop in Azerbaijan.

Early instars feed on different parts of the sunflower plants, but mostly on florets and petals. Large, late instars prefer seeds and hulls. Bryantsev (1966) noted that many last-instar larvae pupated in late autumn and served as the overwintering stage. He also observed that last-instar larvae pupating in early autumn emerged to

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begin a second generation during that same growing season. Furthermore, the last-instar larvae descend to the soil where they pupate (Bryantsev 1973). Adult emergence in the spring coincides with the opening of sunflower blossoms that provide an ovipositional substrate for adult moths and a food source for neonate larvae. Lukomech et al. (2008) also confirmed that the pupal stage is the overwintering phase and that, in early spring, adults emerge to seek ovipositional sites and food resources. Females oviposit 200 to 300 eggs each. Oviposition and larval feeding and development can occur on several different local plant species in addition to sunflowers. A maximum of two generations occur each growing season. Inclement weather conditions can delay moth emergence and flight (Szabó et al. 2010).

Other insects are noteworthy pests of sunflowers grown in other areas of the world. Royer and Walgenbach (1987) reported that a single larva of the American sunflower moth, *Homoeosoma electellum* (Hulst), per plant causes seed yield weight losses between 0.47% and 0.55% in South Dakota. These losses might be partially mitigated by planting sunflower varieties with resistance to lepidopteran pests, including *H. nebulella* (Piven’ et al. 2004). Insecticides have also proven efficacious. Lukomech et al. (2008) reported that severe damage by *Homoeosoma electellum* can be avoided by initiating insecticide treatments at a threshold of three eggs per blossom.

Insect pests are major limiting factors to the production of sunflower in Pakistan (Mukhtar 2009). Knodel et al. (2015) list about 15 insect species that are perennial pests of sunflower grown in the United States and southern Canada. Among those are the red sunflower seed weevil (*Smicronyx fulvis* LeConte), the sunflower midge (*Contarinia schulzi* Gagné), the sunflower beetle (*Zygogramma exclamationis* [F.]), the banded sunflower moth (*Cochylis hospes* Walsingham), and the sunflower stem weevil (*Cylindrocopturus adpsersus* [LeConte]). *Homoeosoma electellum* is only a sporadic pest in Canada and the northern parts of the United States (Knodel et al. 2015); however, it is the main pest of sunflowers grown in more southern areas of the United States (Charlet and Brewer 2009). Knodel and Charlet (2007) recommended planting sunflowers later in the season to avoid economic damage by lepidopteran pests in the United States. Alston (1996) discusses decision-making and economic injury concepts.

To increase sunflower seed production in Azerbaijan, populations of *H. nebulella* must be managed below established economic injury levels (EILs). However, EILs for this pest are not well defined in Azerbaijan. Data were collected from 2007 through 2011. However, only 2008 growing season data and calculations are provided in this report. Multiyear results will be reported in the future as further evaluation and data analyses allow. This study was initiated to help define realistic EILs and economic thresholds (ETs) for *H. nebulella* on sunflower grown in the Ganja-Khazakh region of Azerbaijan. Our objective was to define action thresholds for eggs and larvae (first and second generation) on sunflower blossoms and for moths captured in nearby pheromone traps.

Materials and Methods

The study was conducted in four areas of Azerbaijan—Tovuz, Shamkir, Samux, and Goranboy—where sunflower (Qiqant) is grown commercially. The maximum distance between adjacent areas was 100 km. Each area was planted with 6 to 10 kg seed/ha in parallel rows with a spacing of 70 cm between adjacent rows. Field size was 1,888 ha in Tovuz, 1,048 ha in Shamkir, 369 ha in Samux, and 21 ha in Goranboy. Planting dates ranged from 20 March to 15 April 2008. One week before blooming, plots were established and plants were selected for uniformity of growth stage, size, and spacing within rows as per Royer and Walgenbach (1987). Plots of 5.6 m^2 were established within each field in a completely random design with three plots (treatments) per field (Toutenburg and Shalabh 2009**)**. One trap baited with female *H. nebulella* sex pheromone was positioned at blossom height within each plot in each of the four research areas ($n = 12$) to monitor moth activity. Traps were operated from mid-April through late September 2008, which overlapped the known adult flight periods for the first and second generations of *H. nebulella* in those areas.

The natural pheromone used in field traps was extracted from female moths in the laboratory and prepared according to techniques described by Mavraganis et al. (2010). Field-collected larvae were reared to adults in the laboratory. As pupae, males and females were separated prior to emergence. Upon emergence, moths were placed in cubical Plexiglas® cages (25 × 25 × 25 cm) provisioned with hydrolyzed yeast (ICN Biomedicals, Inc., Irvine, CA) mixed with sugar (1:3 ratio) and moistened with water. Rearing was conducted under 25 ± 2°C, 65% relative humidity, and a 12:12-h (light:dark) photoperiod. Resulting groups of 400 female virgin moths had their sex pheromone extracted three times with 20 ml of diethyl ether, and were then kept for 24 h in 20 ml of a methanol and dichloromethane two-solvent system (1:9 ratio). Pheromone was further extracted another two times using 20 ml of the two-solvent system. The diethyl ether and the two-solvent extracts from five batches (i.e., ~2,000 moths) were combined and concentrated by evaporation to 4,000 μl using a stream of helium gas (Mavraganis et al. 2010). Cotton wicks were then soaked with 2–3 ml of pheromone concentrate, which were then used to inoculate inside surfaces of noncommercial, laboratory-fabricated, deltoid-shaped sturdy paper insect traps. Inside walls of the traps were coated with Pestifix® adhesive (Flora Plants Co., Tartu, Estonia). These isosceles-triangular cross-section traps measure 19-cm-long by 13-cm-wide across the base, with two equal 11-cm-wide side walls meeting at the top and enclosing the length of the trap. This trap configuration is similar to a Pherocon® VI Trap (Trécé 2015) or Scentry® L P Delta Trap (Scentry 2006).

From 1 May to 15 September, randomly selected blossoms within each plot were examined several times weekly for *H. nebulella* larvae. At the same time, the outer layers of the floral bracts were examined for eggs using magnification. Depending on the variation of seed damage observed, 28 or 64 blossoms were examined in each plot.

The area of the top surface of each blossom was calculated using the commonly accepted formula, $A = \pi r^2$, for a circle with the radius derived from the blossom diameter, excluding petals, determined by averaging two measurements taken at 90° angles across the center of the blossom (Filchakov 1973, Knowles 1978). The horizontal inside surface area of a single seed was calculated using the formula, $A = \pi ab$, for an ellipse, where $a =$ the horizontal long axis of the seed base and $b =$ the short axis width of the seed base, on the bottom inside flat end surface of the seed that approximates the form of an ellipse. The number of seeds produced on a blossom was estimated by dividing the surface area of the blossom by the surface area of the seed. Mean seed weight was calculated from the total weight of seeds harvested, and the total weight of seeds per blossom was subsequently estimated by multiplying estimated weight of individual seeds by the estimated number of seeds per blossom.

Differences in larval numbers and seed condition had been noted over the sunflower growing season in the region; therefore, efforts were made to determine loss in seed productivity due to the first generation. Sunflowers selected to be examined in the study were numbered in each plot, and damaged seeds were collected with tweezers and counted in the laboratory to determine the percentage of seed loss. After insect-feeding damage to seeds was first observed within each plot and randomly selected plants were numbered, all investigations and evaluations were then conducted only on the numbered plants.

During the first series of counts, seven plants per plot were evaluated. This number was too few for the most reliable statistical analysis, thus the number of plants evaluated was increased to 28 in each of 10 plots, and 64 in each of two plots. These increased sample numbers improved the standard errors of the statistical analyses and regression calculations and thus increased the validity of the resulting counts (Lakin 1990). Data were subjected to analysis of variance with t tests used to separate means ($P = 0.05$). Equal numbers of noninfested "control" blossoms per plot were used for comparison with infested blossoms (Toutenburg and Shalabh 2009).

EILs for egg, larval, and adult stages for the first and second generations were estimated using the formula of Pedigo and Higley (1992): $\mathrm{EIL} = \mathrm{C}/[\mathrm{V} \times \mathrm{D}' \times \mathrm{K}]$, where C = insecticide application cost in US$, V = market value per production unit in US$ per unit, D′ = percentage of weight loss/single pest/flower (seed weight loss, g/larva), and K = proportional reduction in injury when management is employed (0.80). The ET was calculated as $\mathrm{ET} = [0.80 \times \mathrm{EIL}]$.

Results and Discussion

Two generations of *H. nebulella* occurred in the plots of all four research areas (Fig. 1). Within each generation, there were no statistically significant differences among the research areas with respect to damage and yield. Therefore, data from all field research areas were combined for statistical analyses.

A statistically significant relationship ($t = 0.79 < t_{10;0.05} = 2.23$) between seed weight (y) and larval density (x), described by the regression equation $y = 43.38 - 0.11x$ ($r^2 = 0.36$), occurred in the first generation. Furthermore, the regression equation $y = 35.17 - 0.77x$ ($r^2 = 0.72$), where y = seed yield and x = larval density per blossom, indicates that a single larva can cause a significant loss of 0.77 g of seed weight ($t_{\mathrm{calculated}} = 3.21 > t_{10;0.05} = 2.23$) in the first and second generations (Lakin 1990; Figs. 2, 3). Although not significantly different among fields or regions, the larval infestations and, thus, the seed yield losses were significantly greater in the second compared with the first moth generation ($F = 0.06, 4.09$; df = 3, 8; $P \leq 0.05$; Table 1; Fig. 2).

Based on a market value of ~$0.0972/blossom, with pest management costs of $0.044/blossom, and ~40,816 blossoms/ha with 48.6 g seeds/blossom, a minimum of 898 kg seeds/ha must be produced to compensate for production of the crop

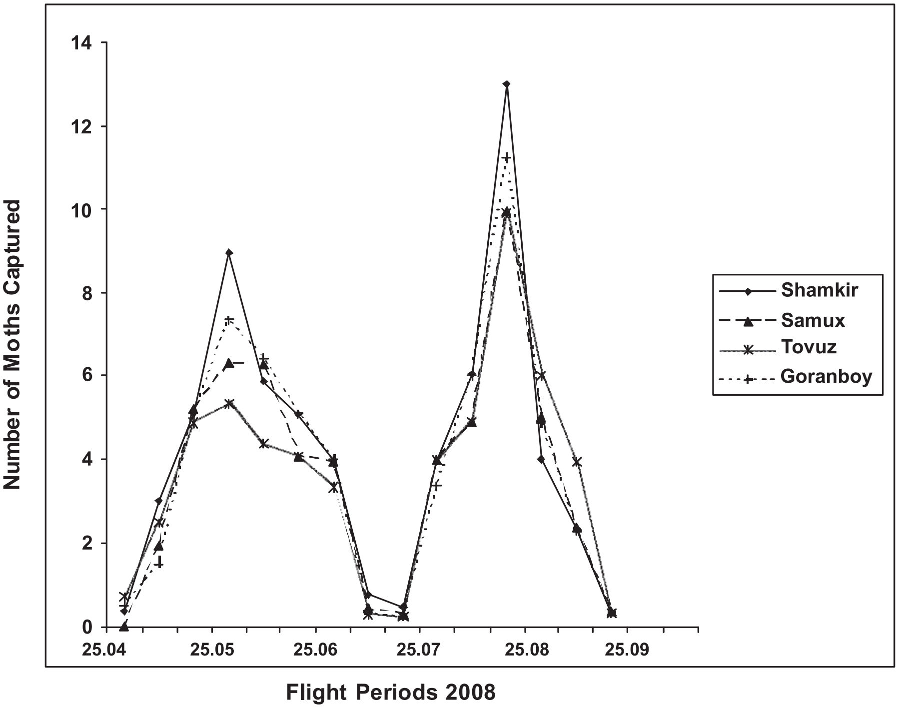

Fig. 1. First generation: 25 April–2 July 2008. Second generation: 25 July–20 September 2008. Average number of adult moths captured per day per pheromone trap, and peak flight periods.

only. This “gain-yield” (G-Y) threshold is based on the 0.80 factor in the ET formula above, meaning that pesticide applications at the beginning of the second generation will increase seed yield by 80% compared with nontreated fields (Pedigo and Higley 1992). The G-Y threshold is calculated by the formula, G-Y threshold (kg seed yield/ha) = (\$0.044/\$0.0972) $\times$ (40,816 blossoms/ha $\times$ 0.0486 kg seeds/blossom) = 898 kg seeds/ha.

Therefore, to realize a profit while paying for management costs, yield must exceed 898 kg seeds/ha in Azerbaijan sunflower fields. During the first generation, an average of 1,760 kg seeds/ha were produced from field plantings, exceeding the G-Y threshold by 862 kg/ha. In addition, seed yield was reduced by 23.4% during the second generation compared with the first generation losses (Table 1). When first and second generation yields per blossom were compared with noninfested blossom yields, losses were −11.3% for the first generation and −32.0% for the second generation. If 80% of second generation losses can be mitigated with pesticide applications, then a grower must consider pesticide use at the beginning of the second flight period (Fig. 1).

First generation larvae mainly feed on petals, whereas second generation larvae prefer seeds. Therefore, first generation seed weight losses were 0.11 g (0.23%) per larva, compared with second generation greater seed weight losses at 0.77 g

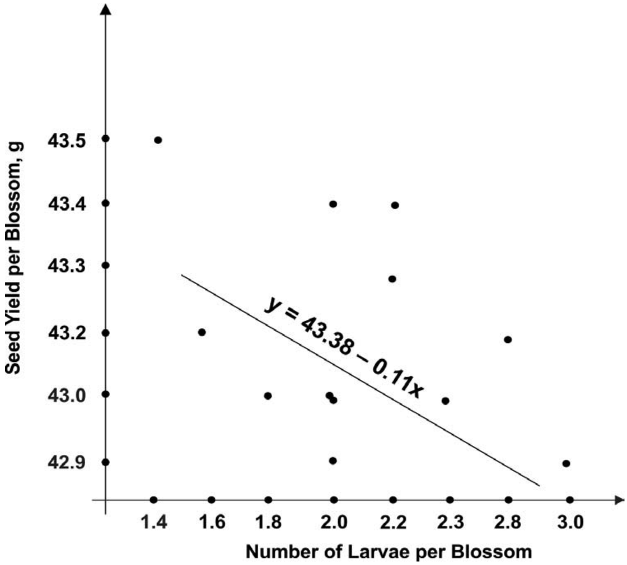

Fig. 2. Relationship between single sunflower blossom seed yield (g) and mean number of first generation *Homoeosoma nebulella* larvae (1–5) per blossom on four field locations ($n = 12$). $R^2 = 0.36$.

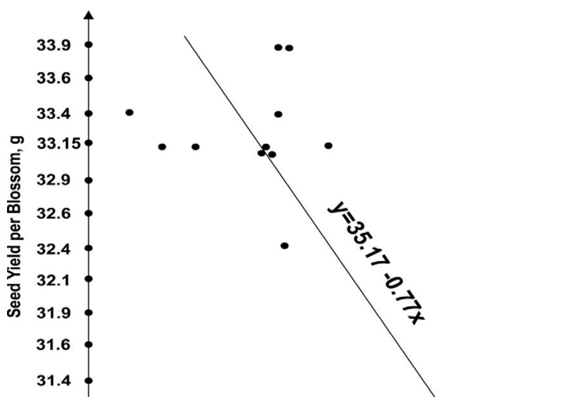

Fig. 3. Relationship between single sunflower blossom seed yield (g) and mean number of second generation *Homoesoma nebulella* larvae (1–5) per blossom on four field locations ($n = 12$). $R^2 = 0.72$.

Table 1. Seed yield per sunflower blossom at the end of the first and second generations of *Homoeosoma nebulella* larvae, mean ± SEM.

Research Region	First Larval Generation*		Second Larval Generation*	
	No. Larvae/ Blossom	Seed Yield, g	No. Larvae/ Blossom	Seed Yield, g
Tovuz	1.6 ± 0.1	43.2 ± 0.1 a	1.8 ± 0.2	33.2 ± 0.1 b
Shamkir	2.0 ± 0.0	43.1 ± 0.1 a	3.5 ± 0.5	32.3 ± 0.5 b
Samux	2.1 ± 0.05	43.2 ± 1.0 a	2.9 ± 0.2	33.6 ± 0.2 b
Goranboy	2.7 ± 0.2	43.0 ± 0.1 a	2.7 ± 0.1	33.1 ± 0.03 b
Average	2.1 ± 0.2	43.1 ± 0.03 a	2.7 ± 0.3	32.9 ± 0.2 b
Average loss, %**		−11.3%		−32.0%

* Numbers followed by the same letter in each row or column are not significantly different, $P = 0.05$. Within each generation, mean larvae numbers are not significantly different, $n = 3$ sampling plots (treatments) per each of four research regions. Number of larvae per blossom at the end of the first and second generations.
** A single nondamaged "control" blossom produces an average yield of 48.6 g seeds.

(1.58%) of seeds per blossom per larva. In this study, it was determined that a single seed-feeding larva destroyed an average of 7 to 10 seeds/blossom. Although the first and second generation larval numbers were similar (Table 1), first generation larvae feed on fewer seeds due to their preference for petals. Thus, first generation seed loss was equal to −0.48% per blossom (2.1 larvae/head), whereas the second generation seed loss was equal to −4.27% per blossom (2.7 larvae/blossom). These results are similar to those of Archer et al. (1983), in which they reported seed losses per larva ranged from −0.5% to −2.4% per blossom.

EILs were calculated as the number of *H. nebulella* eggs or larvae per blossom, or the number of adults trapped per 100 blossoms in the field using the formula of Pedigo and Higley (1992). Those EIL values ranged from 5.1 eggs or larvae/blossom and 2.06 adults/100 blossoms for the first generation to 0.73 eggs or larvae/blossom and 0.29 adults/100 blossoms for the second generation. ETs ranged from 4.1 eggs or larvae/blossom and 25.7 adults/pheromone trap/d for the first generation to 0.45 eggs or larvae/blossom and 3.7 adults/pheromone trap/d for the second generation (Table 2).

Note that EILs and ETs calculated from this study are based on only 1 yr of evaluation and could become modified when multiyear data are evaluated. Refined EIL and ET values can be determined after analyzing data from several growing seasons. Confidence in EIL and ET values increases when data from several growing seasons are used for calculations. Thus, the ETs from this study should be considered proposed initial "action thresholds" where insecticide applications and other sunflower moth management measures should be implemented.

In our study, egg, larval, and adult numbers (Tables 1, 2) and the flight periods and numbers of adults captured during both generations (Fig. 1) did not exceed ETs during the first generation. Therefore, pesticide applications would not have been appropriate before the early stages of the second generation. However, pesticide

Table 2. Economic injury and economic threshold level averages of *Homoeosoma nebulella* on sunflower: number of eggs or larvae per blossom; number of adult moths caught per pheromone trap per day. (Economic injury and economic threshold levels are based on 1-yr data. These numbers could change based on multiyear data analyses.)

Generation	Life Cycle Phase*	Economic Threshold (eggs or larvae/ blossom or adults/trap/d)	Economic Injury Level (eggs or larvae/ blossom; or adults/blossom)	Pesticide Treatment Cost (US$/ha)
First	Egg (larva)*	4.1	5.1	$1,796**
	Adult	25.7/trap	0.0206 (2.06/100 blossoms)	
Second	Egg (larva)*	0.45	0.73	$1,796
	Adult	3.7/trap	0.0029 (0.290/100 blossoms)	

* Eggs and larvae considered equal in number.
** Generally, insecticide applications during the first generation are not needed.

applications would have been warranted at the beginning of the second generation during the last week in July or first week in August 2008 (Fig. 1). With second generation ETs of 0.45 eggs or larvae/blossom and 3.7 adults/trap, ET thresholds were quickly exceeded after 25 July and within the first 2 weeks of August. Without pesticide applications, EILs would be reached early during the second generation and, without intervention, nonacceptable seed damage and yield loss would occur. Because peak flight and egg-laying periods could vary from year to year, sunflower moth numbers must be regularly monitored and their ETs and EILs calculated during each growing season. Pesticides should be used only when ETs are reached and will be exceeded. This planning will reduce production costs because pesticide applications will seldom, if ever, be economically feasible or required during the first sunflower moth generation. However, regular sampling for pest in sunflower fields is essential for successful management of *H. nebulella*.

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