Chapter 4

Moths of Economic Importance in the Maize and Sugar Beet Production

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Additional information is available at the end of the chapter

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Abstract

Maize and sugar beet productions are often threatened by various pests, causing high yield losses. Economically, most important maize pest is European corn borer, while sugar beet moth and noctuid moths cause serious damage on the sugar beet. This chapter highlights an introduction to several case studies representing long-term field research results on these pests. Depending on the pest, each study investigated the population level, dynamics of emergence or flight, damage levels and possibilities of forecasting on different localities in Croatia. The results could be of great importance in management of these pests. The European corn borer management depends mainly on timely conducted control, but the damage level also depends on maize hybrid and climatic conditions of investigated area. Damages caused by sugar beet moth depend on the population level and on locality's specific climate in a particular year. Sugar beet moth population and flight dynamics can be monitored by using pheromones, while pheromone application in forecasting and control showed to be disputable. Noctuid moths feed on the sugar beet foliage, causing high damages, especially on young plants. The damage level depends on the climatic conditions of the research area, and visual inspections of caterpillars are necessary for forecasting and control decision.

Keywords: maize, sugar beet, *Ostrinia nubilalis*, FAO maturity groups, *Scrobipalpa ocellatella*, flight dynamics, pheromones, forecasting, noctuid moths

1. Introduction

Maize is one of the most important field crops worldwide. In Europe, it is sown on almost 14 million of ha and in Croatia depending on the year, on between 250,000 and 300,000 ha [1].

Maize is usually attacked by a range of different pests, but the main pests in Europe are wireworms (family Elateridae), western corn rootworm (WCR) (*Diabrotica virgifera virgifera* LeConte) and European corn borer (ECB) (*Ostrinia nubilalis* (Hùbner)).

The sugar beet is grown from subtropical areas to the northern regions of Scandinavia and originated near the Mediterranean Sea and Atlantic Ocean. Globally, 4.76 million hectares are sown with sugar beets every year, predominantly in the Russian Federation, Ukraine, USA, Germany, France, Turkey and Poland. The world's largest producer is France, with 32 million tons or 13.6% of total production [2]. In Croatia, the sugar beet has been sown since 1905. The area under sugar beet is approximately around 20,000 ha. In the past 3 years, the area sown by sugar beet has decreased up to 15,500 ha [3]. During the emergence of plants, sugar beets can be attacked by a large number of pests [4, 5]. Sugar beet seeds are treated with insecticides during seed processing, so in the early stages of germination and emergence, crops are protected from soil pests and some pests attacking young plants for 6 weeks if neonicotinoid insecticides are applied [6]. Sugar beet development extends through May, June, July and August. During vegetation, sugar beets are, due to favorable climatic conditions, increasingly attacked by a variety of pest species throughout Europe. Out of all species attacking sugar beet during this period, the species belonging to the order Lepidoptera are the most numerous. Čamprag [7] described 36 species from the order Lepidoptera that can cause serious damage to sugar beet crops. The most numerous family of harmful species is Noctuidae, which includes 29 species grouped in nine genera. Out of these 29 species, the most important species from the cutting species group are the black cutworm, *Agrotis ipsilon* Hufnagel, and the turnip moth, *Agrotis segetum* Denis & Schiffermüller [8]. From the surface-feeding species group, the most important are the cabbage moth *Mamestra brassicae* L., the bright line brown eye moth, *Lacanobia oleracea* L., and the silver Y moth, *Autographa gamma* L. [7, 9]. Besides the noctuid species, the beet moth, *Scrobipalpa ocelatella* Boyd (Lepidoptera: Gelechiidae) is shown to be growing problem in sugar beet production in neighboring countries (Serbia) [10] as well as in some years in Croatia [5].

The latest assessment by the United Nations Environment Programme and World Meteorological Organization-supported Intergovernmental Panel on Climate Change (IPCC), released in late 2014 concluded that climate change is already showing effects on many communities, with far greater impacts to come [11, 12]. The impacts of climate change on insect communities encompass changes impact on species life cycles [13, 14] or impacts on synchrony between host plant and herbivore [15].

The increasing pest population in particular region is very often correlated with climate change. This fact leads to the conclusion that the pest life cycle has to be investigated even though the data from the past already exist. This will allow us to record the changes in life cycle caused by climate change. These changes could result with increasing the importance of the particular pest.

1.1. European corn borer

The European corn borer (ECB) is the most important pest in Croatian agriculture [16, 17]. Maceljski [16] estimates the annual loss due to ECB to be 6–25%, while Ivezić and Raspudić [18] report average infestations of 50% during the period of 10 years. Despite significant damage, control of ECB has been attempted only in sweet corn and seed corn, while potential losses in commercial maize have not yet been addressed. Since sweet corn is meant for use in the fresh stage or for canning/freezing, control of ECB is absolutely necessary.

To achieve successful control of ECB, different alternative control methods have to be employed prior to the insecticide application. Agro technical methods (crop rotation, deep plowing, proper choice of sowing time), mechanical control and sowing resistant or tolerant varieties are very important. Since ECB larvae overwinter in the corn stalks, it is extremely important to mechanically destroy (cut) the corn stalks before the deep plowing in autumn. In Croatia, on some fields, corn stalks are left during the winter and this is enabling ECB larvae to successfully overwinter and increase the population level.

Resilience to the ECB is nowadays common with commercial maize hybrids. About 90% of 400 maize hybrids on market have shown a certain degree of resistance in vegetative phases of development [19]. Alongside resistance, modern maize hybrids are tolerant to a great degree to the damage caused by the ECB. Tolerance is the ability of a maize plant to withstand a certain population density of the insect without economic loss of yield or quality [19, 20]. The development of tolerant maize hybrids with a strong, robust stalk contributes immensely to reducing yield loss as a consequence of the damage caused by the ECB [21].

The main precondition for success in controlling ECB is correctly estimating the time when the insecticide should be applied [22]. According to Bažok et al. [22], the timing of ECB moth flights in Croatia has changed considerably since previous years. Bažok et al. [22] suggested using pheromones to demarcate the period of maximum moth incidence and to determine the percent of infested plants or the number of egg clusters on plant leaves by visual inspections carried out at the time of maximum incidence.

Therefore, the goal of research conducted in Croatia in 2017 was to establish the overwintering population level and dynamic of adult emergence of the European corn borer in North West Croatia. Additional goal was to estimate the differences between hybrids of different FAO maturity groups grown in areas with different climatic condition in terms of intensity of attack in vegetative maize growing stage (first ECB generation) and on maize cob (second ECB generation).

1.2. Moths on sugar beets

Surface-feeding noctuid moths are the most damaging pests in sugar beet, including the cabbage moth *Mamestra brassicae* L., the bright line brown eye moth, *Lacanobia oleracea* L., and the silver Y moth, *Autographa gamma* L. [7]. These species all have the potential to remove a majority (or all) of the above-ground foliage from young sugar beet plants, dramatically affecting plant growth and development. Cabbage and the bright line brown eye moth have two generations per year. They overwinter in pupae stage in the soil in the fields where the caterpillars lived. The butterfly eclosion starts at the end of May and early June. The second generation of adults flies in late July and early August. During the flying season, butterflies prefer planted areas for oviposition [23]. They lay eggs on sugar beet, but also on cabbages and other cultures and weeds. The first generation of caterpillar appears at the end of June and July, and the second generation appears at the end of August. The caterpillars are hygrophilic, preferring moisture areas in sugar beet crop. The maximum population level appears from the second half of June to the end of September. Silver Y moth is a migratory species partly developing population in our area, but most of the population comes from the southern regions. The butterfly eclosion in Croatia or arrival (from south) is similar to that of the previous two species, though the silver Y moth develops more generations per year (3–4), and it is possible that these generations overlap [23]. According to Čamprag [7], the economic thresholds established for the cabbage and the bright line brown eye moth are 10–12 caterpillars per m^2. For silver Y moth, precise threshold is not known, but 25% of the leaf area loss has been suggested as alternative economic threshold [24]. The population abundance and damages on sugar beet leaves are substantially impacted by air and soil temperature, as well as rainfall [7, 25–27]. Sugar beet seeds are treated with insecticides (often neonicotinoids) during seed processing and so, in the early stages of germination and emergence, crops are protected from pests for a short time [28]. Later in vegetation, sugar beets are increasingly attacked by a variety of pests as a result of favorable weather conditions. In this "unprotected" sugar beet period pheromone traps comprise one of the most effective methods for monitoring the seasonal flight dynamics of adult male moths [29–31]. These traps are often used to detect the presence of pests by season and location within a facility and to monitor apparent changes in the size of pest population over time [32]. However, the number of adult moths in pheromone traps is not always a direct indicator of the number of larvae, the life stage that damages the plants [33, 34]. Lemic et al. [28] established a strong positive correlation between captured male noctuid moths and the level of damage in sugar beet crop, and extreme relation of population density and weather conditions. However, for precise forecasting and decision about insecticide application in sugar beer field, visual inspections of moth damages are required [5, 7].

The sugar beet moth (*Scrobipalpa ocellatella* (Boyd) has been recorded in Croatia for the first time in 1947 in Slavonia region, and only 3 years later, it was mentioned as a pest present in almost all sugar beet growing area [35]. Sugar beet moth develops 4–5 generations in one vegetation season. It overwinters in last year sugar beer fields as adult caterpillar or in pupae stage [8, 16]. Since sugar beet moth has more generations and overwinters in different stages, often its generations overlap and all stages are present in sugar beets. For its reproduction, sugar beet moth prefers dry and warm weather, early spring and long autumn. In the sugar beet fields, Fajt [36] recorded that the attack starts at the field edges. Mines can be detected in the leaves and leaf stems, a distortion in the growing shoot with leaves spun tightly together are evidence of a larva within [35]. The danger increases in the second half of summer due to the increase in pest numbers in the second and subsequent generations. Economic threshold of damage: in the phenophase 6–8 leaves - 0.5 caterpillar per plant; at the beginning of the formation of root crops - 0.8–1 caterpillar per plant; at the beginning of the withering away of leaves - 2 caterpillars per plant. Sugar beet moth is a pest which appearance is irregular and systemic monitoring using pheromones allows occurrence detection in time [5].

The goal of the two studies carried out in Croatia in the period between 2012 and 2016 was to establish the dynamic of the flight and population level of sugar beet moth in Croatia and to establish the possibilities for beet moth forecasting by pheromone traps and visual inspections. Additionally, the goal was to establish the attack by various caterpillars (both moths and noctuids) in sugar beet fields planted in regions with different weather conditions.

2. Materials and methods

2.1. European corn borer

2.1.1. Study fields

Research was carried out in 2017 on four locations in Croatia: Šašinovečki Lug (45°51′00″ N, 16°10′01″ E), Vrana (43°56′45″ N, 15°26′53″ E), Tovarnik (45°13′28″ N, 19°21′38″ E) and Gola (46°1′44″ N, 16°33′13″ E). Besides these fields, at the location Šašinovečki Lug, eclosion and overwintering population of ECB was investigated on one unplugged maize field (45°51′21″ N, 16°10′17″ E).

2.1.2. Weather

Automatic weather stations were set up next to the cornfields on each location (Šašinovečki Lug, Vrana, Gola and Tovarnik), to collect data on average daily air temperature and daily amount of rainfall.

2.1.3. European corn borer moth eclosion and overwintering population

Samples of overwintering maize stalks (hybrid Bc 282) were collected on March 23, 2017. Twenty random stalks were collected from 15 rows. A total number of 300 maize plants were collected. The collected plants were 100 cm long. At the Department of Agricultural Zoology Faculty of Agriculture in Zagreb all plants were examined for shot holes from larval feeding. Maize stalks were cut into 20 cm pieces and placed in 15 entomological cages. Entomological cages were used for the purpose of rearing ECB larvae which overwintered in maize stalks. The eclosion of the moths out of the stalk was monitored every 7 days until May 29, 2017, when the final number and the gender of the enclosed moths were determined.

2.1.4. Estimating attack of first and second larval generation

In May 2017 on each of the four locations, 32 maize hybrids from four FAO maturity groups (300, 400, 500 and 600) were sown by permuted block randomization scheme. In total, on each location, 128 maize plots were planted, with each hybrid planted in four rows (4 m in length) and in four replications. The intensity of first ECB generation attack was estimated between June 28 and July 17, 2017. Damages on the plants (distinctive leaf holes, shot holes on stalks) were identified on two inner rows of every replication and recorded as the percent of the plants attacked by ECB. After all hybrids have been harvested (in September), 10 maize cobs were randomly selected from each replication and examined for second ECB generation damages and recorded as the percent of cobs infested by second ECB generation larva. For each FAO maturity group yield was recorded after harvesting.

2.1.5. Data analysis

In order to determine the difference in the intensity of the ECB attack (first and second ECB generation) among different FAO maturity groups, data on the percent of damaged maize plants and cobs on hybrids were submitted to two-way variance analysis (ANOVA). Averages were compared by Tukey's honestly significant range test. All differences were considered statistically significant at P = 0.05. Statistical evaluation of data was performed by the data management software ARM 9® GDM software, Revision 2018.2. [37].

2.2. Moths on sugar beets

Investigation of moths on sugar beets has been carried out in two separate studies.

2.2.1. Sugar beet moth

2.2.1.1. Study fields

To monitor the seasonal dynamics of sugar beet moth, a field trial was conducted in three growing seasons, from 2012 till 2014. Monitoring was performed from the early May to late August (18th to 35th week of the year) in Tovarnik (45°13′28″ N, 19°21′38″ E) in two sugar beet fields. In 2012, sugar beets were sown in fields of 45.89 ha and 4.82 ha; in 2013, sugar beets were sown in fields of 4.51 ha and 1.03 ha; and in 2014, sugar beets were sown in fields of 1.14 ha and 2.09 ha. The fields were approximately 5 km distanced.

2.2.1.2. Weather conditions

Prevailing weather conditions (i.e., mean air temperature and daily amount of precipitation) were collected from the two closest meteorological stations (Vukovar and Gradište) for all 3 years with the help of the Croatian Meteorological and Hydrological Service for each year of the period of investigation.

2.2.1.3. Monitoring of the moths and damage estimation

Pheromone traps (VARL + Csalomon®, Plant Protection Institute, Budapest, Hungary) were fixed on wooden sticks approximately 1.5 m above the ground and placed in the middle of the sugar beet fields. To catch the maximum number of specimens, the pheromone dispensers were changed at 6-week intervals as recommended by the manufacturer. Inspections on trapped moths were performed every 7 days.

Visual inspections of plants to detect damage caused by moth larvae were performed as described by Čamprag [23] in the Manual of the Reporting and Forecasting Service. Randomly, 10 × 10 sugar beet plants diagonally across the field were selected to detect damage on sugar beet leaves caused by larval feeding. In visual surveys, percentage of plants damaged by moths has been established as well as the number of caterpillars on the plants.

2.2.1.4. Data analysis

The moth monitoring results for the selected intervals are presented as the total number of males caught per trap per week. The average percent of damaged plants is presented as a function of the cumulative capture of moths in pheromone traps. Values were determined from the 18th until the 35th week of the year.

Data on moth abundance, percent of damaged plants and number of caterpillars on the plants, as well as meteorological data, were compared among years by ANOVA, and the mean separation was estimated using Tukey's HSD test [37]. The statistical software ARM 9® [37] was used to calculate correlation coefficients and to conduct regression analyses between the cumulative capture of male moths on pheromone traps and the percentage of plants damaged by larvae. The correlation coefficients were established, regression lines were described, and the coefficient of determination was calculated.

2.2.2. Noctuid moths

2.2.2.1. Study fields

The research was conducted during 2015 and 2016 on two distinct locations of Croatia, in Lukač (45°52′26″ N 17°25′09″ E) in Virovitica-Podravina county, and in Tovarnik (45°09′54″ N 19°09′08″ E) in Vukovar-Sirmium county. Untreated sugar beet (Artus in 2015 and Jelen in 2016) was sown at each location on 1000 m^2. In 2015, sowing was done on April 9 in Lukač and on April 11 in Tovarnik. In 2016, sowing was done few days earlier, that is, in Lukač on April 1 and on March 26 in Tovarnik.

2.2.2.2. Visual inspections and data analyses

Visual inspections of plants were performed as described by the Manual of the Reporting and Forecasting Service [23] to detect damage on leaves caused by noctuid larvae. Larval attack and damage on leaves was followed weekly on both locations in both years on randomly selected 4 rows of 20 m long starting form emergence of plants (i.e., May 6, 2015 and May 18, 2016) till root harvest (i.e., September 14, 2015 and September 7, 2016). Percentage of infected plants by moth larvae was recorded. Percentage of damage was calculated using the Townsend-Heuberger [38] formula. Data on percent of damaged plants as well as meteorological data were compared among years by ANOVA [37], and the mean separation was estimated using Tukey's HSD test. Where appropriate, data were $\sqrt{(x + 0.5)}$ transformed.

3. Results and discussion

3.1. European corn borer

In our survey, weather conditions during maize growing season varied among the investigated locations (**Table 1**). According to the data collected by weather stations, locality Vrana was characterized as having an extremely hot vegetation season. Locality Tovarnik was medium warm but had the lowest amount of rainfall (only 201 mm). By contrast, localities Šašinovečki Lug and Gola were characterized with high total amount of rainfall, especially locality Šašinovečki Lug which had more than 490 mm of rain. The weather conditions obviously could have an influence on the European corn borer population level and damages of first and second larval generation attack.

Locality	Average monthly temperature (°C)	Total amount of rainfall (mm)
Šašinovečki Lug	20.43	494.2
Tovarnik	21.12	201.6
Gola	20.00	399.5
Vrana	23.06	340.6

Table 1. Prevailing weather conditions during the vegetation season of maize in 2017 (May–September).

3.1.1. Overwintering population

After hibernation, ECB larvae developed into moths, whose eclosion out the stalk was monitored. The first enclosed moth was recorded on May 1, 2017. According to Kraljević Župić [39], the first moths were recorded on entomological lamps in location Sinj 31 day later, whereas in entomological cages with severed maize stalks they appeared somewhat earlier, but still more than 2 weeks later than in this research. The appearance of the first ECB generation in the field depends on the temperature and relative air moisture [16]. First eclosion according to Maceljski [16] usually takes place in the middle of May, although the majority of moths appear in June. Deviation in this research can be explained by the fact that the moths in cages were recorded as soon as they emerged from the cocoon, while several days must pass in order to catch the moths in a trap. Additionally, climatic condition influence the eclosion and as it has been found by Bažok et al. [22] in a very warm year, in 2003, the maximum of ECB moth appearance on pheromones on localities close to investigation site in this research, was in middle May. In total, 32 ECB moths developed from overwintering larvae. Male moths were the first to emerge out of the stalk (protandry). The total number of adult males was 14 (44%), whereas the total number of female moths was 18 (56%), which is in accordance with the research by Fadamiro and Baker [40] who also recorded a lower number of males compared to females. Considering these numbers and the fact that 32 moths developed from 300 stalks, it was estimated that in 1 hectare of unplugged maize cca. 8000 moths overwinter (at sowing 75,000 maize plants per hectare). This number of moths could produce more than 4 million larvae of first generation (estimated at cca. 500 eggs per female moth).

3.1.2. ECB first and second larval generation attack

Intensity of the first generation of ECB larval attack varied between 1.01% in Šašinovečki Lug to 38.1% in Tovarnik (**Table 2**). Significant differences in the intensity of the first generation of ECB larval attack was estimated among localities in all FAO maturity groups. High attack on all hybrids has been established in Tovarnik and Vrana, and lower attack has been established in Gola and the lowest in Šašinovečki Lug.

However, significant differences in maize stalk damage were estimated between FAO maturity groups in Šašinovec (condition of low attack) and in Tovarnik (conditions of high attack). In Vrana and Gola, no significant differences were established due to the high variability in attack intensity in different hybrids.

Locality	FAO maturity group				Tukey's HSD, P = 0.05
	300	400	500	600	
Šašinovečki Lug	1.18d[*]B[**]	1.20 dAB	3.05 bA	1.45 dAB	2.24
Tovarnik	25.28 aB	27.59 aAB	31.57 aAB	38.1 aA	11.47
Gola	5.6 c	7.54 c	7.48 b	9.5 c	ns
Vrana	15.94 b	17.56 b	23.9 a	24.71 b	ns
Tukey's HSD, P = 0.05	3.36	3.69	5.07	4.89	/

[*]Means followed by the same small letter do not significantly differ among localities (i.e., columns) ($P < 0.05$; Tukey's honestly significant difference (HSD)).

[**]Means followed by the same capital letter do not significantly differ among FAO maturity groups (i.e., rows) ($P < 0.05$; Tukey's honestly significant difference (HSD)).

Table 2. Intensity of the first-generation ECB larval attack (%).

The intensity of the attack of the second generation of ECB was much higher comparing to the first generation, it ranged between 17.19 and 92.81% (**Table 3**). The differences among localities in the attack of each FAO maturity groups were significant. The highest attack on all FAO maturity groups has been established in Tovarnik, somewhat lower in Vrana moderate in Šašinovečki Lug and the lowest in Gola. This situation is very similar with those established for the first generation. The localities with higher attack of the first generation, Tovarnik and Vrana, had higher attack of the second generation too. The locality Šašinovečki Lug had the lowest attack of the first generation, but the attack of the second generation was moderate and higher comparing to the locality Gola. This is probably the consequence of the higher amount of rainfall received in July in Šašinovečki Lug comparing to Gola.

The differences among the FAO maturity groups were significant at two localities, Šašinovečki Lug and Gola where the attack was low to moderate. In described conditions, FAO maturity

Locality	FAO maturity group				Tukey's HSD, P = 0.05
	300	400	500	600	
Šašinovečki Lug	1.18d[*]B[**]	1.20 dAB	3.05 bA	1.45 dAB	2.24
Tovarnik	25.28 aB	27.59 aAB	31.57 aAB	38.1 aA	11.47
Gola	5.6 c	7.54 c	7.48 b	9.5 c	ns
Vrana	15.94 b	17.56 b	23.9 a	24.71 b	ns
Tukey's HSD, P = 0.05	3.36	3.69	5.07	4.89	/

[*]Means followed by the same small letter do not significantly differ among localities (i.e., columns) ($P < 0.05$; Tukey's honestly significant difference (HSD)).

[**]Means followed by the same capital letter do not significantly differ among FAO maturity groups (i.e., rows) ($P < 0.05$; Tukey's honestly significant difference (HSD)).

Table 3. Intensity of the second-generation ECB larval attack (%).

groups 400 and 500 had higher attack comparing to FAO groups 300 and 600. According to available literature, the average intensity of ECB attack in Croatia varies and depends on the FAO maturity group, locality and year of investigation. Some authors have shown that with the increase of the length of vegetation period (i.e., maturity group) the intensity of the attack of ECB is increasing [17]. Our investigation cannot prove these findings because the FAO group 400 had the highest attack on the sites where the overall attack was lower (i.e., Šašinovečki Lug and Gola). The same time, on the sites where the overall attack of ECB was high (i.e., Tovarnik and Vrana) the attack of FAO 400 was high. This is in line with the results reported by Augustinović et al. [41] who reported the same time the lowest and the highest attack of FAO 400, depending on the site of investigation. Investigations conducted by Raspudić et al. [42] have not shown statistically relevant differences in attack intensity among the hybrids what is similar for our results obtained at the localities Tovarnik and Vrana.

Maize yield was recorded for each FAO maturity group on all localities and standardized (14% moisture) and is presented in **Table 4**. There is a great difference between locations, which was implied regarding the weather conditions, but no significant differences in yield between FAO maturity groups were found.

Previous research conducted on yield in maize hybrids of different FAO maturity groups shown that the significantly highest yield should be expected for the FAO 500 and 600 maturity groups [43–45]. It can be assumed that significantly higher ECB attacks (both generations) on medium-late FAO maturity groups have resulted in yield reduction and the yield was lower than expected for these FAO groups and did not differ from the yield of early to medium FAO maturity groups.

3.2. Moths on sugar beets

3.2.1. Sugar beet moth

In our survey, weather conditions during growing season varied among the investigated years (**Table 5**). According to the Croatian Meteorological and Hydrological Service in 2012, Croatia was characterized as having an extremely hot and dry year. By contrast, 2013 was characterized as a moderate year with average air temperatures, medium amount of total amount of rainfall, and 2014 was characterized as cold and moist. In 2012, the investigated

Locality	FAO maturity group			
	300	400	500	600
Šašinovečki Lug	7.3	7.5	7.6	8.2
Tovarnik	5.2	5.2	5.1	5.2
Gola	25.3	26.6	26.1	25.1
Vrana	14.6	16.9	14.0	15.0

Table 4. Maize field yield (t/ha) on four localities in 2017.

Year	Mean air temperature (°C) ± SD	Mean soil temperature (°C) ± SD	Total amount of rainfall (mm) ± SD
2012	22.26 ± 0.03 a*	24.75 ± 0.26 a	144.71 ± 30.26 b
2013	21.06 ± 0.08 b	23.59 ± 0.45 b	272.75 ± 31.32 ab
2014	19.99 ± 0.19 c	23.05 ± 0.5 b	400.50 ± 3.39 a
HSD P = 0.05	0.646	0.74	181.626

*Values followed by the same letter are not significantly different among columns (P > 0.05; Tukey's HSD).

Table 5. Characteristics of the climatic conditions prevailing in the years of investigation (from 18th till 35th week).

period was characterized by higher mean air temperatures (22°C) and mean soil temperatures at 10 cm depth (25°C). Consequently, the total amount of rainfall in the same period was significantly lower (144 mm), while 2013 was characterized as a moderate year with average air temperatures of 21°C and average soil temperatures of 24°C, with a total amount of rainfall of 272 mm. The investigation period in 2014 was characterized by lower mean air temperatures (19°C), lower soil temperatures (23°C) and a significantly higher amount of rainfall (400 mm) compared to 2012 and 2013. The weather conditions evidently had a great influence on the male moth population level and population dynamics.

The presence of sugar beet moth has been established through the whole vegetation period in 2012 and in 2014, while in 2013, the moths were captured on the traps until week 26 (**Figure 1**). Later on, male moth captures have not been observed. The reason could be found in the very high prevailing temperatures in the whole second part of the vegetation season in 2013. During the period of 8 weeks in 2013 (from mid of July to mid of September), the average weekly temperatures were over 24°C, and the amount of rainfall was extremely low. In spite of the fact that sugar beet moth prefers dry and hot years for its reproduction [10], the prevailing conditions in 2013 were not very favorable for moth development. It is difficult to state how many generations sugar beet moth developed in 1 year. There are four peaks of the flight in 2012 and 2014, but the number of moths caught was too low to

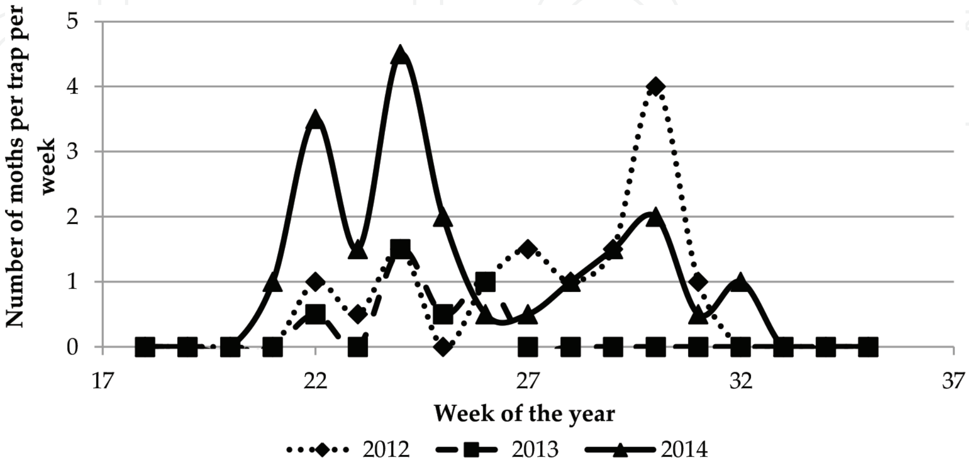

Figure 1. Total moths capture per pheromone trap per week (from 18th till 35th) in Tovarnik, Croatia, 2012–2014.

conclude that the moth developed four generations as it is stated by Maceljski [16] and Čamprag et al. [10]. Based on our results, which confirm previous surveys of Čamprag et al. [10], by the use of pheromones, we can predict the abundance of the first generation of moth which happens in 21st and 22nd week of the year. In subsequent years, the flight dynamics has similar patterns in the first 6 weeks of the moth appearance. In the second part of the vegetation season (week 27 till week 35), flight dynamic patterns depended very much on the prevailing weather conditions.

Sugar beet moth can cause important damage during the vegetation season of sugar beets. The surface-feeding larvae are foliage-feeding pests, but their later generation enters into the sugar beet root so they can be extremely harmful due to the destruction of leaf mass as well as due to the damaging the sugar beet roots and opening the floor to the infections with different pathogens [7, 16], which has a negative effect on sugar accumulation in the root [43]. Thus, possible damage forecasting and thresholds for suppression based on male moth captures on pheromone traps can be of great importance in the management of sugar beet pests.

We observed a correlation between male moth captures and plant damage in all investigated years in spite of the differences in weather conditions, which directly caused differences in population dynamics and differences in the total capture of moths on pheromones (**Figure 2**). The correlation coefficients were high for 2012 and 2013 and could be described as full positive correlations and medium in 2014 and could be described as positive correlation [46]. The coefficients of determination (r^2) were also high for both species groups, and the regression curves had similar tendencies and were linear (**Table 6**).

Moth population growth during the vegetation period increased the damage to sugar beet plants. In warm and dry years (e.g., 2012 and 2013), 10 collected sugar beet male moths caused

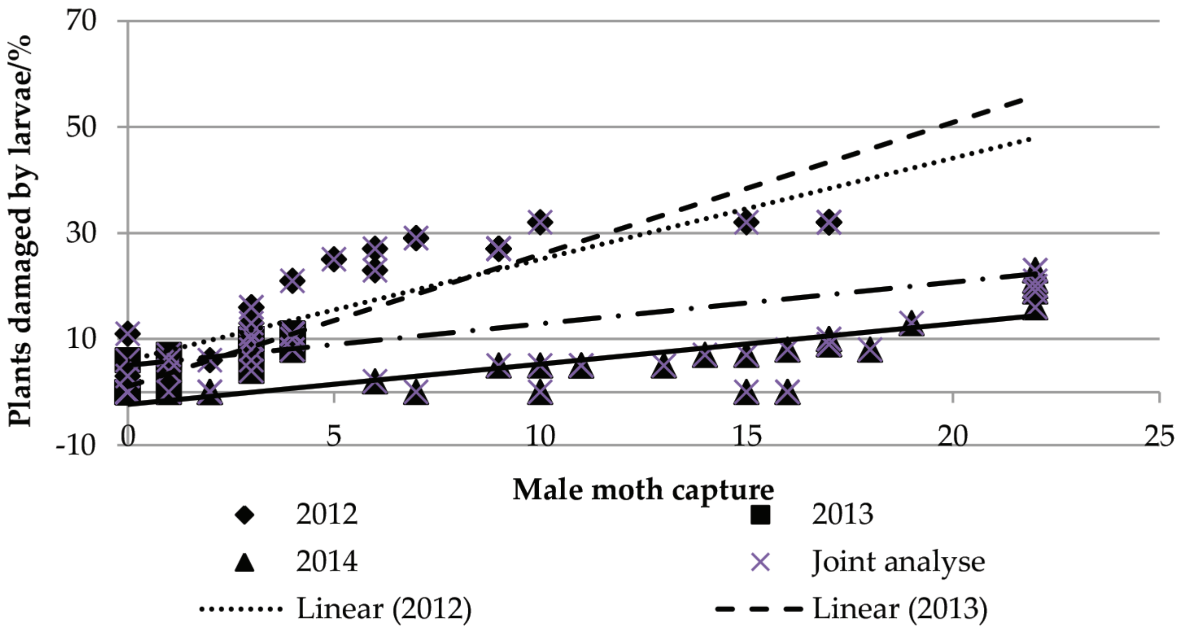

Figure 2. Regression analysis of the cumulative capture of sugar beet male moths on pheromone traps (x) versus the percentage of plants damaged by moth larva (y), Tovarnik, Croatia, 2012–2014.

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Year	n	Correlation coefficient (r)	Coefficient of determination (r^2)	Probability (p)	Regression equation
2012	36	0.7817	0.8841	0.0001	y = 1.0959x + 5.9892
2013	36	0.8283	0.9101	0.0001	y = 2.4935x + 2.0284
2014	36	0.6711	0.8192	0.0001	y = 0.762x − 2.3334
Joint analysis	108	0.2838	0.5327	0.0001	y = 0.7835x + 5.0267

Table 6. Correlation coefficients, coefficients of determination and regression equations for percent of plants damaged by sugar beet moth larvae (y) and cumulative capture male sugar beet moths on pheromone traps (x), Tovarnik, Croatia.

the damage on 25–30% plants. However, in the year in which weather conditions were not so hot and dry (e.g., 2014), the same number of male moths indicated the damage of 5% of damaged plants. In 2013, we did not record neither new male moth capture nor the additional damage on the plants, and analysis is based on the data from first part of the season when the climatic conditions were preferable for moth development. Later on, the climatic conditions were not favorable and moth population reduced so the larvae did not continue to cause the damage on the plants.

Although we established a strong correlation between the cumulative number of male moths caught on pheromone traps and damage on plants, we were not able to detect a threshold for decisive control because we used sex pheromone-baited traps in our investigations, which, while highly sensitive and selective, have the inherent weakness of attracting only male moths. Therefore, traps that attract female moths would potentially provide more valuable information for pest control decisions.

3.2.2. Noctuid moths

On locations Lukač and Tovarnik weather conditions during sugar beet growing season varied among the investigated years and locations (**Figure 3**). On both locations, year 2015 was characterized with higher air and soil temperatures and lower amount of precipitation comparing to the year 2016. In both investigation years, location Tovarnik was characterized by higher mean air temperatures comparing to location Lukač. Consequently, the total amount of rainfall in the same period was significantly lower (higher in Lukač). The weather conditions evidently had a great influence on the noctuid larval attack on sugar beet.

3.2.2.1. Visual inspections of leaf damage

The attack of harmful caterpillars was determined throughout the vegetation in both research years. A total of 22 visual inspections were performed (depending on the year). The percentage of caterpillar-damaged plants is shown in **Figure 4**. Although the plants were found to be damaged, caterpillars have been rarely found. In 2015, the maximum infestation was 0.45 caterpillars per plant, which is below the threshold. In 2016, the maximum infestation of caterpillars was even lower.

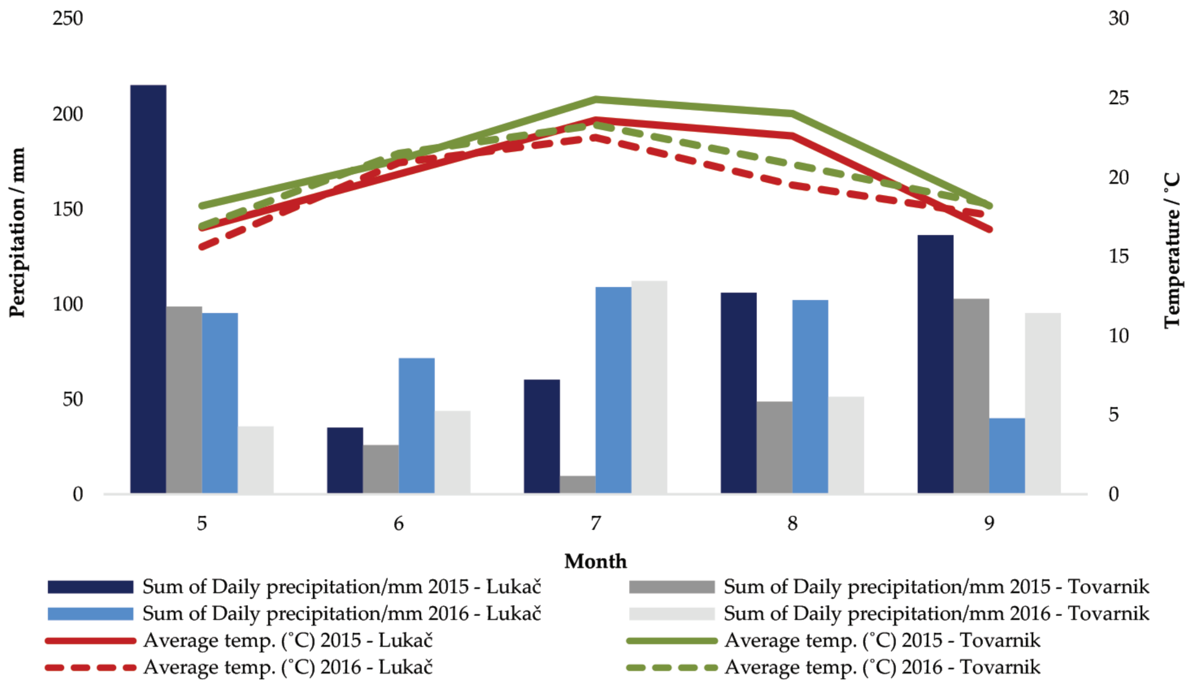

Figure 3. Weather conditions in two locations where research was conducted.

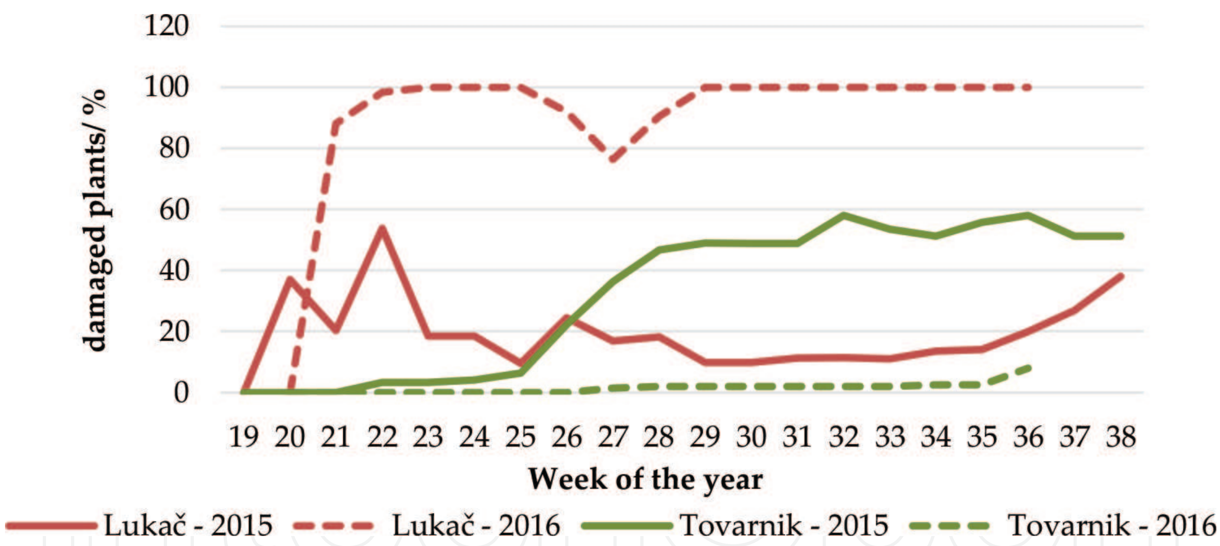

Figure 4. Noctuid moth larvae damage dynamics in sugar beet.

A warm summer with low humidity preceded higher egg mortality and a second generation of larvae in low numbers [47]. Indeed, damages on leaves from the second-generation larvae were not significantly higher. Warm and dry conditions in Tovarnik had a negative influence on the first generation of noctuid moth larvae, which directly caused lower damage dynamic in Tovarnik versus Lukač in whole investigation period. In 2015, the larval damage on sugar beet on both locations was lower. However, weather conditions in 2015 were favorable for noctuid moth development (lower temperature, higher precipitation; [28]) and, in 2016, a population recovery was observed which was visible from higher level of larval damage. These results confirm a previous survey by Vajgand [27] in which a decrease in the moth population and larval damages were caused by a very warm and dry vegetation period.

4. Conclusions

The results of the investigation could be of great importance in management of investigated pests, ECB and moths (sugar beet moth and noctuid moths) on sugar beet.

4.1. European corn borer

In North West Croatia, the eclosion of the European corn borer overwintering population monitored in cages happened about 2 weeks earlier (beginning of May) than previously recorded in the literature. Male moths emerged first (protandry), and in total population they were represented in lower numbers than female moths. Changes in timing of ECB moth flight and, consequently, changes in the period of maximum moth incidence have a great influence on the success of ECB control, as the insecticides must be applied in timely manner. Also, the intensity of the first and second ECB larval generation attack varied significantly among four FAO maturity groups and among four investigation sites in all FAO maturity groups, the latest presumably due to different weather conditions. Significant differences in maize stalk damage, caused by the first generation, were recorded between FAO maturity groups on two locations which differed in attack intensity. Similarly, the second-generation attack differed significantly among FAO maturity groups on two locations where the attack was low to moderate. Results confirmed that the damage of ECB is determined by the weather conditions rather than by FAO maturity group.

4.2. Moths on sugar beets

The seasonal dynamics for sugar beet moth has shown that, during the 3-year period, it appeared between 21st and 22nd week of the year, suggesting the pheromones could be used to predict the first generations abundance. After 27th week, the flight dynamics depended on the prevailing climatic conditions. Four peaks of flight were detected, but due to low moth number, we cannot conclude on number of generations per year. A strong correlation between male moth captures and plant damage suggested that moth population growth increased the damage on sugar beet. However, the same number of male moths did not cause the same level of damage in years with different climatic conditions. Given the fact we used sex pheromones, which attracted only moth males, we were not able to conclude on a threshold for decisive control; therefore, pheromones which also attract females could be useful in sugar beet moth forecasting and control decisions. Noctuid moth damages on sugar beet leaves, determined by visual plant inspections, showed that the damages depended on climatic conditions of the location and decreased in very warm and dry conditions.

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