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# APPLICATION OF DIFFERENT INSECTICIDES BY DRIP IRRIGATION METHOD AGAINST EUROPEAN CORN BORER ON CORN CROPS

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Key words: corn, European corn borer (ECB), mass flight, caterpillar, phytophagous, insecticides, drip irrigation, insectigation.

Abstract

The peculiarities of the development and dynamics of the population density of European corn borer (ECB) on corn crops under irrigation were studied in 2019–2021 in conditions of Steppe of Ukraine. Field investigations were conducted according to generally accepted methods. The size of the experimental plots in the field experiments was 50 $m^2$ (10.4 x 4.8 m), the replication was 4 times. Allocation of plots was randomized. The beginning of the first adults flight was observed in the 1st decade – in the middle of June at average. Mass laying of eggs and the flight of more than 50% of the butterfly population occurred in the $3^{rd}$ decade of June, which coincided with the phase of pollen shedding of corn plants. Mass flight of the butterfly (flight of more than 75% of the population) was observed at the end of the $3^{rd}$ decade of June – the beginning of the 1st decade of July. The revival of caterpillars began in the third decade of June and continued until the end of July. The average population density of European corn borer caterpillars in 2019–2021 were 1.6 and 1.8 specimens per stem on corn crops. The European corn borer is a dangerous pest of corn in the Steppe zone of Ukraine, where it's caterpillars damage 34.5–37.8% stems and ears of this crop. Application of Coragen 20 KS, Calypso 480 SC and Actara 25 WG at higher from recommended rates against the ECB contributed to the reduction of plants damage in 8–15 times, compared to untreated crops.

## Introduction

The yield formation of agricultural crops in agrocenosis depends on the influence of many factors (pests, weeds and diseases). The anthropo-

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genic factor has a direct impact on the functioning of the agrocenosis. First of all, it is the choice of the *agricultural producer* in the application of certain elements of crop cultivation technology. Applying of the agricultural technology and the use of chemical measures of protection against harmful objects are related to all elements of the agrocenosis structure and significantly affected its productivity. From the point of view of plant protection to obtain a qualitative yield of a specific crop (including corn) is to reduce the number of harmful organisms to the level of their economic threshold (DÖRING at al. 2012).

The corn planting area in Ukraine exceeds 5 million hectares in 2021. Crop productivity is a complex factor that depends on the relationship between non-biological, biological factors and various components of plants structure. The yield of corn grain varies from 7.9 to 12.2 t $ha^{-1}$ from year to year. As known, the corn can reach potential yield in 15–18 t $ha^{-1}$ in different climatic zones of Ukraine. Unfavorable hydrothermal conditions of the vegetative seasons observed in recent years may be among the main reasons for crop losses (up to 30%). Low reserves of productive moisture in the one-meter layer of soil under crop determine the insufficient moisture supply of corn plants in the most critical phases of their growth and development, that leads to problems with grain filling (KLISHCHENKO at al. 2006, LAVRYNENKO et al. 2014).

Abnormally high temperatures during the development of the generative organs of this crop, in particular during the tasseling – pollen shedding at the absence of effective precipitation, starting from mid-June, determine the main reasons for the loses of corn grain yield: drying of pollen, insufficient pollination. Plants are the most sensitive to heat between the appearance of cob silks and milky kernel maturity. Four days of severe heat stress during this period can lead to a loss of 40–50% yield of the crop (ROMASHCHENKO at al. 2015, USHKARENKO et al. 2015, SHATKOVS'KYY 2018, LYKHOVYD at al. 2019).

Unsatisfactory phytosanitary condition of the corn agrocenosis is not less important factor for obtaining a low level of yield and its quality. Thus, yield losses can reach up to 40% at insufficiently effective and untimely control of corn pests. Therefore, in order to save grain from potential losses, it is extremely important to pay increased attention to the insecticide protection of this crop against harmful organisms. Spraying corn crops by insecticides ensures high biological and economic efficiency. But a small number of producers think about the consequences of such a wide use of chemicals. The selection of insecticides and the methods of their application should be rational and aimed to increase the delivering environmental safety of the agrocenosis in order to obtain environmentally safe products (MASON at al. 1996, TRYBEL′ at al. 2009, GARDNER at al. 2011, MELNICHUK at al. 2017).

Irrigation is one of the main factors for the intensification of the agriculture in areas with insufficient and unstable natural moistening. That is why artificial watering became widespread in the 20$^{th}$ century. Currently, in the world more than 270 million hectares are under irrigation. And irrigated lands provide more than 40% of the world crop production, including only 18% of the area of agricultural land (DUDKA 2013).

In arid regions the irrigation is an important factor that guarantees high corn yields. It affects not only on the conditions of plant growth, but also on the development of all living organisms in the soil, plants, and in the vegetation zone. During irrigation, the microclimate of the surface layer of the soil and atmosphere changes significantly. Irrigation creates more favorable conditions for the most pests of hydrophilic and mesophilic ecological groups (ELLERS at al. 2018). The last ones in all stages of their development are not associated with the soil and live in the zone of the plant layer. Pests whose numbers increase at irrigation also include the European corn borer (*Ostrinia nubilalis* Hübner, 1796).

Drip irrigation is a method of watering in which water is moving directly to the root feeding zone of each plant in accordance with its biological and age peculiarities. The main principle of providing plants with water is to moisten only a definite volume of soil in which the root system is located. The volume of drip irrigation usage began to grow rapidly only at the beginning of the 90s of the XX century. Because it became clear in practice that drip irrigation, in addition to saving water resources, is also significantly increasing the yield of agricultural crops. The particularly dynamic development of drip irrigation was observed in the early 2000s, when the areas of drip irrigation in Ukraine grew up to 30–70% every year (ELANGO and NISHA PRADEEPA 2017).

Despite the overall success of foliar spraying by insecticides for controlling harmful insects, there are several negative moments, including risks to human health and the environment. That is why insectigation (the use of insecticides together with water by the method of drip irrigation) is becoming more and more widespread worldwide (GHIDIU et al. 2009).

Systemic insecticides applied by drip irrigation enter directly into the root zone of plants, where they are absorbed by the roots and moved to various plant tissues. Since insecticide residues located in the vascular system of plants and not on their surface, only insects that feed directly on the plant are affected. Therefore, this method is considered as safer for non-target organisms in agricultural fields, such as entomophages or bees. Beside with the effectiveness of insecticides for target objects, their safety for the main components of agrocenoses is actual. So, it is important to evaluate the action of insecticides of several chemical classes recommended for the protection crops against pests, to identify among them active ingredients that are safe to beneficial arthropods of agrocenoses (UMETSU and SHIRAI 2020).

**Analysis of recent research and publications.** The aim of improvement of the insecticides range is to increase their environmental safety in agrocenosis, in particular – to reduce the toxic load. Insecticides of a new class of chemical compounds – neonicotinoids appeared on the world market at the end of the 20$^{th}$ century. Their active ingredients were obtained based on natural toxins of plant (nicotine) and animal (anabasin) origin (PREETHA and STANLEY 2012).

The most suitable insecticides for use together with irrigation water are active ingredients from the class of neonicotinoids (such as thiamethoxam, thiacloprid, imidacloprid, acetamiprid) and anthranilic diamides (such as cyantraniliprole, chlorantraniliprole, lambda-cyhalothrin). Neonicotinoids have a systemic effect. They can move to the plant from the soil through the root system (root-systemic acropetal action), so they can be applied with drip irrigation. Neonicotinoids have a high level of mobility in the vascular system together with nutrients mainly in the leaves, but practically do not enter the grain and fruits. The duration of the protective effect of these insecticides is up to 6 weeks, and their effectiveness does not depend on changes in temperature and humidity (PEI-CHEN at al. 2013).

Investigating the dynamics of the decomposition of thiamethoxam and lambda-cyhalothrin in plants, degradation to undetermined amounts was established on 14$^{th}$ day after treatment. An active ingredient lambda--cyhalothrin degraded on the 28$^{th}$ day after treatment, and the concentration of its metabolites continued to decrease. Redistribution of the chlorantraniliprole in the plant occurs due to its translaminar movement through the cells of the stem epidermis and the conducting xylem vessels, which contributes to the entry of this active ingredient into the new growth. A high level of protective effect of chlorantraniliprole with drip application against the European corn borer was noted in foreign studies. As a result of research conducted with the use of an insecticide containing chlorantraniliprole to protect corn crops, it was established the presence of residual amounts of the insecticides active ingredient mainly in plants, not in the soil (LEPESHKYN at al. 2015, HLADIK et al. 2014, SANCHEZ-BAYO and GOKA 2014, SCHAAFSMA at al. 2015).

**Relevance of research.** The combination of using insecticides together with meliorated water using the drip irrigation method has advantages compare with traditional spraying due to the rational use of irrigation water and pesticides to save the crop yield. The active ingredients of insecticides from the classes of neonicotinoids and anthranilic diamides are fit for use in drip irrigation systems. Because they have excellent solubility in water and, accordingly, quickly reallocate into the roots, further moving through the vascular system of the plant. Also, during insectigation, dependence on high air temperatures is eliminated.

The purpose of our research was to clarify the peculiarities of the ECB development and to study the effectiveness of application insecticides from the classes of neonicotinoids and anthranilic diamides together with irrigation water by drip irrigation to limit the development of this pest and control its number on corn crops in the Steppe zone of Ukraine.

## Materials and Methods

Field investigations were conducted on corn crops according to generally accepted methods (Trybel' at al. 2001) during 2019–2021 in the conditions of the Kherson Region, State Enterprise Experimental Farm 'Brylivske' of the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine (coordinates 46.404028° N latitude, 33.112361° E longitude).

The emergence of the imago and, accordingly, the beginning and mass flight of the ECB on the fields were recorded using fermental traps with molasses and pheromone traps. According to the pest development cycle, the female eggs on plants were counted. To do this, 10 plants from two parallel rows were observed in 10 places of the field, calculating their average number per 1 square meter.

The size of the experimental plots in the field experiments was 50 $m^2$ (10.4 x 4.8 m), the replication was 4 times. Allocation of plots was randomized. Corn hybrid is P8816 (FAO 280). The technical efficiency of insecticides was determined by the reduction in the number of caterpillars in corn stems during the harvest period and damage of stems, selecting 50 plants from each plot (5 in 10 places). Corn stems were cut lengthwise, and the number of caterpillars was counted.

Investigated insecticides were used according to the experiment scheme (Table 1). Most of studied active ingredients are not registered for use by drip irrigation in Ukraine.

Table 1
Scheme of the trial on corn crops under different application rates of insecticides and irrigation systems (2019–2021)

| Preparation name | Active ingredient | Type of irrigation | |
|---|---|---|---|
| | | sprinkler | drip |
| | | rate [l $ha^{-1}$] | |
| Control | (treatment by water) | – | – |
| Coragen 20 SC | chlorantraniliprole, 200 g $l^{-1}$ | 0.4 | 0.6 |
| Actara 25 WG | thiamethoxam, 250 g $kg^{-1}$ | 0.3 | 0.6 |
| Mospilan 20 SP | acetamiprid, 200 g $kg^{-1}$ | 0.05 | 0.1 |
| Calypso 480 SC | thiacloprid, 480 g $l^{-1}$ | 0.375 | 0.5 |
| Confidor 200 SL | imidacloprid, 200 g $l^{-1}$ | 0.25 | 0.6 |

Insecticides were applied by sprinkler irrigation and drip irrigation, depending on their physical and chemical properties (solubility in water and mobility in the soil). Some preparations were added into irrigative water in the first third, others in the second third of the volume of water provided for irrigation. The mother solution of the insecticide was prepared in a container connected to the irrigation system (volume is 200 l) and application was started. After using the insecticide, the system must be washed with the amount of clean water equal to the volume of the whole irrigative system. Execution of this condition will ensure the distribution of the full insecticide dose on the experimental plot and will prevent the accumulation of its unused residues in the irrigation system.

The technological process of applying plant protection products, fertilizers and chemical reagents with irrigation water in drip irrigation systems is regulated by the State standard of Ukraine 7937:2015 *Irrigation. Bringing of fertilizers with water in systems of microirrigation. General requirements*. This normative document is active from 2016 and was developed by the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences together with the National University of Life and Environmental Sciences of Ukraine and the National Scientific Center 'Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky'.

Hydrothermal coefficient of Selianinov (HTC) calculated by the formula:

$$K = R \cdot 10/\Sigma t,$$

where:
$R$ – the sum of precipitation in millimeters for a period with temperatures above +10°C
$\Sigma t$ – the sum of temperatures in degrees Celsius [°C] for the same time.

The lower the HTC, the drier the area (Ushkarenko et al. 2014, Meladze and Meladze 2017, Stoyanova and Georgiev 2017, Lykhovyd 2019).

The degree-days were calculated using the formula for the average daily temperature, calculated from the daily maximum and minimum temperatures, minus the development threshold (baseline temperature) (Herms 2004, Musayeva and Yaxyayev 2020). Temperature +10$^{o}$C was taken as development threshold for ECB.

## Results and Discussion

Constant monitoring of the pest number during the growing season was provided for the planning and timely implementation of crop protective measures from the caterpillars of the ECB. Therefore, during 2019–2021, we observed the flight dynamics of adults and recorded the dates of egg laying by the females and the appearance of caterpillars.

The development of the ECB in the conditions of the Kherson region took place in two generations. At the same time, the development of the second facultative generation was noted at the end of August – September. Monitoring of fermental traps with molasses, as well as pheromone traps in 2019 showed that the flight of the first adults of the ECB occurred in the middle of the first decade of June (369.2 GDD) – Table 2.

Table 2

Biological features of the European corn borer

| Stage of ECB development | Date of stage beginning (GDD) | | |
|---|---|---|---|
| | 2019 | 2020 | 2021 |
| Beginning of flight first adults of ECB. Start of egg laying | 06.06 (369.2) | 16.06 (374.8) | 21.06 (379.5) |
| Mass egg laying | 11.06 (435.1) | 21.06 (441.5) | 25.06 (442.0) |
| Mass flight (> 50% of population) | 18.06 (536.5) | 28.06 (543.0) | 01.07 (532.1) |
| Mass flight (> 75% of population) | 23.06 (621.4) | 03.07 (624.9) | 08.07 (623.5) |

The increase in the density of the phytophagous population occurred at increasing of air temperature. An activity of the imago flight increased with significant warming, and its mass flight was observed at the end of the second decade of June (536.5–621.4 GDD).

The flight of the first adults of the ECB in 2020–2021 was observed in mid-June (374.8–379.5 GDD). The mass laying of eggs and flight of more than 50% of the butterfly population occurred in the third decade of the month (441.5–543.0 GDD), which coincided with the phase of pollen shedding by corn tassels. The mass flight of the butterfly (flight of more than 75% of the population) was observed at the end of the 3rd decade of June – the beginning of the 1st decade of July (624.9–623.5 GDD). The revival of caterpillars began in the third decade of June and lasted until the end of July.

Analyzing the meteorological conditions of the research period, we noted that the sum of active temperatures in 2019–2020 exceeded the long-term indicator by 205–220°C (Table 3). The vegetation period of 2019 and 2021 was characterized by sufficient moisture supply (HTC – 1.26–1.41), while in 2020 it was dry (HTC – 0.70). The dynamics of the butterfly's population over the years depended on weather conditions. A large amount of precipitation without heavy rains was favorable for the massive reproduction of the pest. While dry weather limited its number, at the same time speeding up the phases of growth and development of corn plants.

Table 3

Meteorological conditions of the vegetative season

| Weather indicator | 2019 | 2020 | 2021 | Long-term average |
|---|---|---|---|---|
| Sum of active temperatures (SAT) for IV–IX months [°C] | 3470.3 | 3455.5 | 3208.9 | 3250.0 |
| Sum of effective temperatures (SET) for IV–IX months [°C] | 1780.3 | 1765.5 | 1618.9 | 1527.0 |
| Sum of precipitation for IV–IX months [mm] | 437.8 | 242.0 | 452.8 | 247.0 |
| HTC | 1.26 | 0.70 | 1.41 | 0.76 |

Protection against the ECB is quite complicated. So it is important to determine the correct time of spraying with a very extended period of the butterfly's flight. As can be seen from Table 2, time duration is almost 20 days from the appearance of the first adults to the flight of 75% of the pest population. Caterpillars of older and younger instars were found at the same time at observations and scores. In addition, for the larvae's is native a hidden lifestyle, and therefore they become not available for the action of insecticides.

The caterpillars of the ECB are very dangerous phytophagous of corn during the period of pollen shedding and grain formation. Afterwards its damage of stems and ears will cause a significant threat of yield reducing. Taking this into account, insecticides were applied by sprinkling and drip application to control the pest number and its harmfulness. The preparations were used in the phase of the beginning of pollen shedding by corn tassels. At dissecting plant stems, the number of pests on the control variants was 1.8 specimens per stem at sprinkling and 1.6 specimens per stem at drip application.

The results showed the effectiveness of all insecticides reached 77.2–94.2% by decreasing damage of plants by caterpillars at the level of 2.0–8.6%. In particular, the insecticides Coragen 20, KS, Calypso 480 SC and Actara 25 WG at higher rates contributed to the reduction of phytophagous plant damage to 2.0–4.5%, which is 8–15 times less compare to the control (Table 4). Damage of corn stems on the control variant was at average 34.5–37.8%.

Table 4

Effectiveness of the insecticides application on corn against the European corn borer at different application rates and irrigation systems (average for 2019–2021)

| Variant | Application rate [l $ha^{-1}$, kg $ha^{-1}$] | Damage of plants [%] | | Efficiency [%] | |
|---|---|---|---|---|---|
| | | sprinkler | drip | sprinkler | drip |
| Control | – | 37.8 | 34,5 | – | – |
| Coragen 20 SC | 0.4 | 3.2 | 2.8 | 91.5 | 91.9 |
| | 0.6 | 2.4 | 2.3 | 93.7 | 93.3 |
| Actara 25 WG | 0.3 | 4.5 | 4.1 | 88.1 | 88.1 |
| | 0.6 | 2.8 | 2.0 | 92.6 | 94.2 |
| Mospilan 20 SP | 0.05 | 8.6 | 6.1 | 77.2 | 82.3 |
| | 0.1 | 4.7 | 4.6 | 87.6 | 86.7 |
| Calypso 480 SC | 0.375 | 4.4 | 4.2 | 88.4 | 87.8 |
| | 0.5 | 2.8 | 2.4 | 92.6 | 93.0 |
| Confidor 200 SL | 0.25 | 6.4 | 4.5 | 83.1 | 87.0 |
| | 0.6 | 3.3 | 2.6 | 91.3 | 92.5 |
| LSD (at $p < 0.05$) | – | 1.2 | 1.04 | 2.7 | 2.49 |

The maximum protection of the crop against the ECB was noted for the drip application of insecticides at two application rates. Thus, insecticides based on the active ingredients of thiamethoxam, thiacloprid and chlorantraniliprole controlled the pest, significantly reducing its number. Insecticide Actara 25 WG reliably decreased the damage of corn plants by caterpillars with an efficiency of 88.1–94.2%. The somewhat lower efficiency was obtained at applying by drip irrigation method of the insecticide Coragen 20 SC with the application rates of 0.4–0.6 l $ha^{-1}$ – 91.9–93.3%. The lowest control of the number of caterpillars of the ECB was noted at application of the insecticide Mospilan 20 SP (active ingredient acetamiprid). Its level of protection was 82.3–86.7%.

The data obtained during the harvesting of the yield also indicate significant level of protection by the tested insecticides applied against this pest (Table 5). Thus, a significant reducing of density of stems was found (62.3–65.2 thousand ha$^{-1}$) on control. Corn plant stems were broken because of caterpillar's damage. This led to a lack of yield of corn grain due to the inability of the grain-harvesting header to pick up the ears that fell on the soil surface. Before harvest, plant density was in 1.2–1.35 times higher on the insecticide-treated plots compared to the control.

Table 5
The effect of the application of insecticides and their rates on productive indicators of corn under different types of irrigation (average for 2019–2021)

| Variant | Application rate [l ha$^{-1}$, kg ha$^{-1}$] | Plant density before harvesting [thousands ha$^{-1}$] | | Yield [t ha$^{-1}$] | | ± To control [t ha$^{-1}$] | |
|---|---|---|---|---|---|---|---|
| | | sprinkler | drip | sprinkler | drip | sprinkler | drip |
| Control | – | 62.3 | 65.2 | 13.0 | 13.9 | – | – |
| Coragen 20 SC | 0.4 | 78.3 | 83.0 | 16.7 | 17.4 | 3.7 | 3.5 |
| | 0.6 | 84.1 | 84.4 | 17.3 | 17.8 | 4.3 | 3.9 |
| Actara 25 WG | 0.3 | 78.5 | 83.0 | 16.4 | 17.6 | 3.4 | 3.7 |
| | 0.6 | 83.3 | 84.5 | 17.0 | 18.1 | 4.0 | 4.2 |
| Mospilan 20 SP | 0.05 | 80.5 | 81.5 | 15.9 | 16.8 | 2.9 | 2.9 |
| | 0.1 | 83.3 | 83.5 | 16.6 | 17.2 | 3.6 | 3.3 |
| Calypso 480 SC | 0.375 | 77.3 | 79.5 | 15.9 | 16.4 | 2.9 | 2.5 |
| | 0.5 | 80.3 | 83.0 | 16.7 | 17.3 | 3.7 | 3.4 |
| Confidor 200 SL | 0.25 | 81.8 | 83.5 | 16.2 | 17.3 | 3.2 | 3.4 |
| | 0.6 | 83.8 | 85.3 | 16.8 | 18.0 | 3.8 | 4.1 |

In the variant with the use of chemical protection, damage by the caterpillars of ECB to crop plants was reduced. This made it possible to save a significant share of the grain yield, compared to untreated plants. The highest level of yield (17.8–18.1 t ha$^{-1}$), compared to the control, was obtained on the plots with the use of higher rates of insecticides Coragen 20 SC, Confidor 200 SL and Actara 25 WG at applying them with irrigation water. Therefore, 3.9–4.3 t ha$^{-1}$ of grain was additionally obtained.

The use of insecticides together with irrigation water. in comparison with traditional spraying, helps to improve the ecological condition of the agrocenosis. Also it improves the sanitary and hygienic condition of the working area of employees, and at the same time allows to grow ecologically clean products. The disadvantage of this method is the limited list of registered active ingredients that can be used. So, the research of modern and new active ingredients of insecticides regarding the possibility of their application with water in irrigation systems is the promising direction of investigations.

## Conclusions

1. The beginning of the ECB first imago flight in 2019–2021 was observed in the 1$^{st}$ decade – mid-June (369.2–379.5 GDD). The mass laying of eggs and flight of more than 50% of the butterfly population occurred in the II–III decades of the month (435.1–543.0 GDD), which coincided with the phase of pollen shedding by corn plants.

2. The mass flight of the imago (flight of more than 75% of the population) was observed at the end of the 3rd decade of June – the beginning of the 1$^{st}$ decade of July (621.4–624.9 GDD). The revival of caterpillars began in the third decade of June and continued until the end of July. The average number of larvae of the European corn borer in 2019–2021 was 1.6 and 1.8 specimens per stem in corn crops.

3. The European corn borer is a dangerous pest of corn in the Steppe zone of Ukraine, where it's caterpillars damage 34.5–37.8% stems and ears of this crop. Application of Coragen 20 KS, Calypso 480 SC and Actara 25 WG at higher from recommended rates against the ECB contributed to the reduction of plants damage by the pests in 8–15 times, compared to untreated crops.

4. Due to the reduction of corn plants damage by ECB caterpillars before harvesting, the density of plants was 1.2–1.35 times higher in the areas treated with insecticides, compared to the control. Treatment corn crops with insecticides makes possible to save the corn grain yield share at the level of 3.9–4.3 t ha$^{-1}$.

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