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Communication

Light Traps to Study Insect Species Diversity in Soybean Crops

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Abstract: We aimed to monitor the species diversity and the dynamics of the number of soybean pests using light traps with an original design to develop protection systems against the main phytophages. Traps lured 44 species of insects from eight orders and 27 families. The capture of 15 species of economically important phytophages was recorded—representatives of various orders and families: order Lepidoptera—Noctuidae, Crambidae, Erebidae, and Geometridae; order Hemiptera—Flatidae; order Coleoptera—Elateridae, etc. Insect identification was carried out via morphological methods. Over the study period (93 days), 4955.41 insect specimens were caught on average per one trap. Most of the attracted insects belong to harmful entomofauna: namely the cotton bollworm (*Helicoverpa armigera*, Hübner)—58.9%, the beet webworm (*Loxostege sticticalis*, L.)—12.74%, the nutmeg moth (*Anarta trifolii*, Hufnagel)—6.5%, the European corn borer (*Ostrinia nubilalis*, Hübner)—2.68%, and some other species—19.2%. In addition to economically significant phytophages, we registered some indifferent and beneficial species. The summer dynamics of the cotton bollworm and the nutmeg moth were obtained for the entire research period. Then, we calculated the values of the indices of biodiversity and the dominance of insect species. An analysis of the index values allows us to conclude a balanced entomocomplex at the research site.

Keywords: soybean; insects; monitoring; biodiversity; pest control; light traps

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1. Introduction

Soy is the most valuable protein and oil crop. It is unparalleled among other field crops in terms of the quantity and quality of the useful substances contained in soybean grain. Soy contains up to 40–45% protein; therefore, it can help to resolve the pervasive problem of protein malnutrition. In addition to complete protein, soybean grain contains 20–25% oil with a favorable fatty acid composition, the same amount of carbohydrate compounds, mainly in soluble forms, and a large set of minerals and vitamins [1].

Soy grain's rich and diverse chemical composition predetermines its wide and comprehensive use and high national economic significance [2]. However, soybeans are vulnerable to a wide range of pests due to their excellent biochemical composition. Pests can cause 2–60% yield losses during epidemics [3–5]. Insects cause a variety of types of damage to the seedlings, leaves, stems, and generative organs of the plant. The growing season for soybean varieties in Krasnodar Krai ranges from 95 to 125 days. This is one of the main reasons for the accumulation of pests from different taxonomic groups on crops. Soybean provides substratum for more than 200 species of insects [6–8].

In the Asian region, 220 species of insects are collected from this crop. Thirty of them cause economic damage. The decrease in yield, depending on the area, is 20–60% [9]. The stink bugs *Nezara viridula* L. and *Piezodorus lituratus* Fabr. And the caterpillars *Leguminivora glicinivorella* Mats., *Etiella zinckenella* Tr., and *Matsumuraeses phaseoli* Mats. Are the most damaging [10]. In India, 48 to 100 species of insects belonging to various orders have been registered. The cutworm *Plusia* acuta Walker is considered the most harmful [11].

In Ukraine, Russia, Asian countries, and the United States, 68 harmful species have been noted, the most harmful of which are the following: the bean seed fly (*Delia platura* Meigen) [12], soy aphid (*Aulocorthum pelargonii* Kalt.), two-spotted spider mite (*Tetranychus urticae* Koch.), and various types of thrips, scoops, moths, and beetles [12–15]. In the steppe regions of Ukraine, the pulse pod borer moth (*Etiella zinckenella* Tr.) incurs the greatest harm to soybeans, with the caterpillars sometimes even eating up the seeds in the beans completely. In some years, the yield damage is 40–70% [16].

More than 60 phytophages were have been registered fromon soybean crops cultivated in the south-east of Kazakhstan. Of these, the following species cause economically significant damage: the Turkmen spider mite *Tetranychus turkestani* Ug.et Nik., the leg-ume Aphis fabae Sc. And melon aphid Aphis gossypii Gl., and weevils *(Sitona crinitus* Hbst.) belonging to the genus Coleoptera, the most common being the pea weevil (*Sitona linellus* Bansd.), three species of beetles from the family Bruchidae: pea weevil (*Bruchus pisarum* L.), bean grain beetle (*Acanthoscelides altectus* Sag.) and the cowpea weevil (Cal-losebruchus maculates Fabricius).The European tarnished plant bug (*Lygus rugulipennis* Popp.) causes the greatest harm to soybeans. The turnip moth (*Agrotis segetum* Schiff.) and the cotton bollworm (*Heliothis armigera* Hübner) from the order Lepidoptera are considered to be most damaging [17].

According to the research materials of Russian scientists from 1982, 78 species of insects that damage soybeans have been found in Primorsky Krai. The most common are Lepidoptera, with 48 species (60% comprising harmful fauna). They are noticeably inferior to bugs (9 species, or 11.5%), beetles (8 species, or 10%), and orthoptera (7 species, or 10%). The representatives of the three remaining orders (Homoptera proboscideans, thrips, and Diptera) account for no more than 10% of the harmful fauna. A.I. Mishchenko identified 45 out of the 78 species as soybean pests in the Far East [18,19].

In 1990–1992, Shabalta O.M. and Nguyen Thi Chat [20] identified 54 species of soybean phytophages in the North Caucasus. Twenty of these species were then included in the list of soybean pests found in Krasnodar Krai for the first time. The most numerous among those 54 species are Lepidoptera—20 species, Hemiptera—12 species, Coleoptera—8 species, Orthoptera—7 species, and Homoptera proboscideans and thrips—7 species. In addition, one species from the order Acarinae was identified.

Based on literary sources, many scientists are engaged in the study of the biodiversity of arthropods on soybeans. Because of this, the development of new devices and methods for monitoring soybean phytophages is an urgent topic that is inextricably linked to the development of basic methods of control, such as chemical, biological, and agrotechnical methods.

Recently, light traps of various designs have been increasingly used in agriculture to monitor the number of phytophages and to study the biodiversity of agroecosystems. They help to eliminate various types of arthropods. The use of the positive phototaxis of insects to attract them has long been known, and there exists a wide range of light traps based on tungsten lamps, incandescent lamps, and high-pressure fluorescent and mercury lamps [21].

The use of such devices has, however, a number of disadvantages: long-wave radiation, which reduces the effectiveness of attracting insects, invisible infrared radiation, high-energy consumption, limited-service life, and toxic mercury [22–24]. The widespread availability of LED light sources has opened up opportunities for research and development on insect attractants. Various designs of such light traps are considered as a means of monitoring and combating phytophages, making them applicable for the greening of agriculture. Researchers from different countries have experimentally proven the high efficiency of ultraviolet-spectrum LEDs in experiments using ultraviolet (UV)—405 nm, blue—470 nm, green—525 nm, and red—630 nm spectra [22–28].

The aim of this study is to monitor the species diversity and the dynamics of the number of soybean pests using light traps with an original design to develop protection systems against the main phytophages.

2. Materials and Methods

We conducted research on soybeans using light traps for 93 days: from 14 June to 15 September 2021, using soybeans planted in the central zone of Krasnodar Krai, Russian Federation, in the production fields of the OJSC Rassvet, Ust-Labinsky district. Over the course of the research, light traps were tested on soybeans.

The light traps were developed by the Federal Research Center of Biological Plant Protection (FRCBPP) [27–29]. The device is an autonomous, mobile tool for the monitoring and mass capture of arthropods with a positive phototaxis (Figure 1). The attractive element is UVA strip LEDs with a wavelength of 400 nm, an emission angle of 120°, a luminous flux density of 10 lm/m, and a supply voltage of 12 V. The diodes we used are 0.075 W (0.000075 mW) each. The trap uses 24 diodes, with a total power of 0.0018 mW.

Figure 1. Light trap with a conical design (FRCBPP, Krasnodar, 2021).

The stream of light attracts insects to the light emitter at night. Attracted insects collide with smooth transparent plates, are temporarily immobilized, and then, under gravity, fall on the inner surface of the cone and further into the cavity of the cylinder and subsequently into the insect collector. Various types of insect receptacles have been developed (for the continuous capture of attracted insects and for separating them). Insect receptacles for continuous catching fix all of the lured insects into the cavity of the insect receptacle. When entering the cavity of a separating receptacle, insects can escape if their size is smaller than or commensurates with the size of the cells of the separating element of the insect receptacle. The size of the cells is selected so that the target species of insects cannot penetrate through the receptacle. An additional light emitter located on a transverse bar attached to the walls of the cylinder makes it possible to keep insects in the cylinder and the insect receptacle at night. In the daytime, insects are concentrated in the lower part of the insect receptacle or on the inside between the bandage and the outer walls of the cylinder. The insect trap is powered by a small-sized battery with a voltage of 12 V and a capacity of at least 5 Ah. A feature of the light trap of the conical design is its 360° range for attracting insects.

In 2021, due to the need to identify and account for all insect of the species attracted by light traps, we took into account daily catches using a closed insect receptacle. When conducting daily counts, the captured insects were slightly damaged, but this did not interfere with determination. Weekly counts were also carried out (once every 7 days) using a separating insect receptacle.

To obtain reliable results, we used three light traps that were installed 50 m from the edge of the field and 100 m apart.

Insect identification was carried out by morphological methods using insect classifiers [19,30–32].

Statistical Analysis

The values of the confidence intervals and the correlation coefficients (r) were calculated using Statistica 10.0 and MS Excel. The values of the biodiversity indices were calculated in accordance with the procedure outlined in [33–37] using MS Excel.

3. Results

At different periods of vegetation, 44 species were attracted—representatives of eight orders and 27 families.

From the beginning of June to the end of July, during the growing season from phase V-2—the appearance of the second triple leaf—to R-2—full flowering, the traps contained representatives of the families Noctuidae, Pyraustidae, and Pyralidae. The pulse pod borer moth *Etiella zinckenella* (Treitschke) was found in the traps. This was explained by the presence of windbreaks in perennial legumes, namely false acacia (*Robinia pseudoacacia* L.). Weed forbs in the lower layer of false acacia are also a source of entomofauna atypical for soybeans; at the same time, it served as a reserve for soybean phytophages.

Over the entire research period (93 days), we recorded captures of the following phytophages: the cotton bollworm (*Helicoverpa armigera*, Hübner), the large yellow underwing (*Noctua pronuba*, L.), the silver Y moth (*Autographa gamma*, L.), the nutmeg moth (*Anarta trifolii*, Hufnagel), the dark sword-grass (*Agrotis ipsilon*, Hufnagel), the cabbage moth (*Mamestra brassicae,* L.), the spotted cutworm (*Xestia s-nigrum*, L.), the bright-line brown-eye (*Lacanobia oleracea*, L.), the beet webworm (*Loxostege sticticalis*, L.), the pulse pod borer moth (*Etiella zinckenella*, Treitschke), the European corn borer (*Ostrinia nubialis*, Hübner), the gypsy moth (*Lymantria dispar*, L.), the lackey moth (*Malacosoma neustria*, L.), the drinker (*Euthrix potatoria*, L.), the blood-vein (*Timandra comae*, Schmidt), the clay fan-foot (*Paracolax tristalis*, Fabricius), the spotted sulphur (*Emmelia trabealis*, Scopoli, L.), and the citrus flatid planthopper (*Metcalfa pruinosa*, Say).

As a result, 4955.41 insect specimens were caught on average per one trap. At the same time, the predominant majority of the lured insects were representatives of harmful entomofauna: namely the cotton bollworm, the beet webworm, the nutmeg moth, the European corn borer, etc. (Table 1).

Table 1. Arthropod species attracted by the light trap in amounts of more than 10 specimens during the research period. Central zone of Krasnodar Krai. 2021.

Species	Average Number of Insect Specimens per Trap	% of the Total Number of Attracted Insects
economically significant phytophages		
Helicoverpa armigera, Hübner	2923.33	58.99
Loxostege sticticalis, L.	631.35	12.74
Anarta trifolii, Hufnagel	323.37	6.53
Ostrinia nubialis, Hübner	132.87	2.68
Agrotis ipsilon, Hufnagel	110.16	2.22
Sitochroa verticalis, L.	95.33	1.92
Autographa gamma, L.	75.65	1.53
Etiella zinckenella, Treitschke	74.17	1.50
Lymantria dispar, L.	74.17	1.50
Halyomorpha halys, Stål	50.5	1.02
Xestia s-nigrum, L.	34.0	0.69

Table 1. *Cont.*

Species	Average Number of Insect Specimens per Trap	% of the Total Number of Attracted Insects
Noctua pronuba, L.	20.33	0.41
Mamestra brassicae, L.	12.33	0.25
	useful entomofauna	
Chrysopa perla, L.	28.17	0.57
Acontia candefacta, Hübner	24.67	0.50
Harmonia axyridis, Pallas	19.33	0.39
	indifferent species	
Idaea ochrata, Scopoli	92.0	1.86
Timandra comae, Schmidt	74.67	1.51
Lythria purpuraria, L.	25.83	0.52
Mythimna vitellina, Hübner	15.17	0.31

Table 1 shows the attraction of indifferent species and representatives of useful entomofauna in addition to economically significant phytophages.

Twenty five species not included in Table, mainly of the order Lepidoptera, were caught singly (less than 10 individuals during the entire research period) and were representatives of harmful, beneficial, and indifferent entomofauna: order Lepidoptera—*Nomophila noctuella* Denis & Schiffermüller, *Lymantria dispar* L., *Malacosoma neustria* L., *Euthrix potatoria* L., *Idaea ochrata* Scopoli, *Timandra comae* Schmidt, *Lythria purpuraria* L., *Paracolax tristalis* Fabricius, *Sphinx ligustri* L., *Mythimna vitellina* Hübner, *Emmelia trabealis* Scopoli, *Laothoe populi* L., *Macroglossum stellatarum* L., *Eilema sororcula* Hufnagel, *Hyles euphorbiae* L., *Lacanobia oleracea* L., *Phragmatobia fuliginosa* L., *Eilema caniola* Hübner, *Hyles lineata* Fabricius (*Hyles livornica* Esper), *Aedia funesta* Esp., *Acontia candefacta* Hübner, and *Agrius convolvuli* L.; order Coleoptera—*Harmonia axyridis* Pallas, *Thanatophilus rugosus* L., and *Coccinella septempunctata* L.; order Hymenoptera—*Apis mellifera* L. and *Ophion* sp.; order Neuroptera—*Chrysopa perla* L.; order Hemiptera—*Dolycoris baccarum* L. and *Metcalfa pruinosa* Say.

The figure below shows data on the summer dynamics of the cotton bollworm according to three light traps on average with the upper values of the confidence interval (±SEM) (Figure 2).

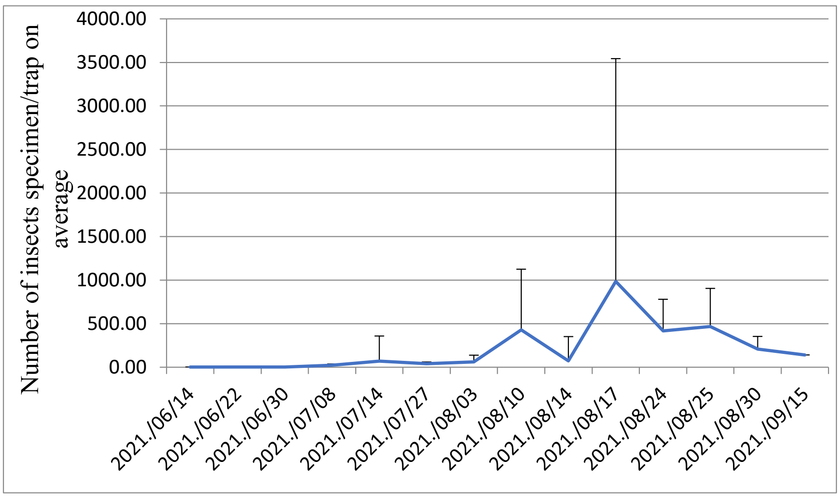

Figure 2. Summer dynamics of the cotton bollworm. Central zone of Krasnodar Krai. 2021.

The correlation analysis showed no mathematical dependence of the summer dynamics on the complex of abiotic factors (temperature and precipitation) (Figure 3).

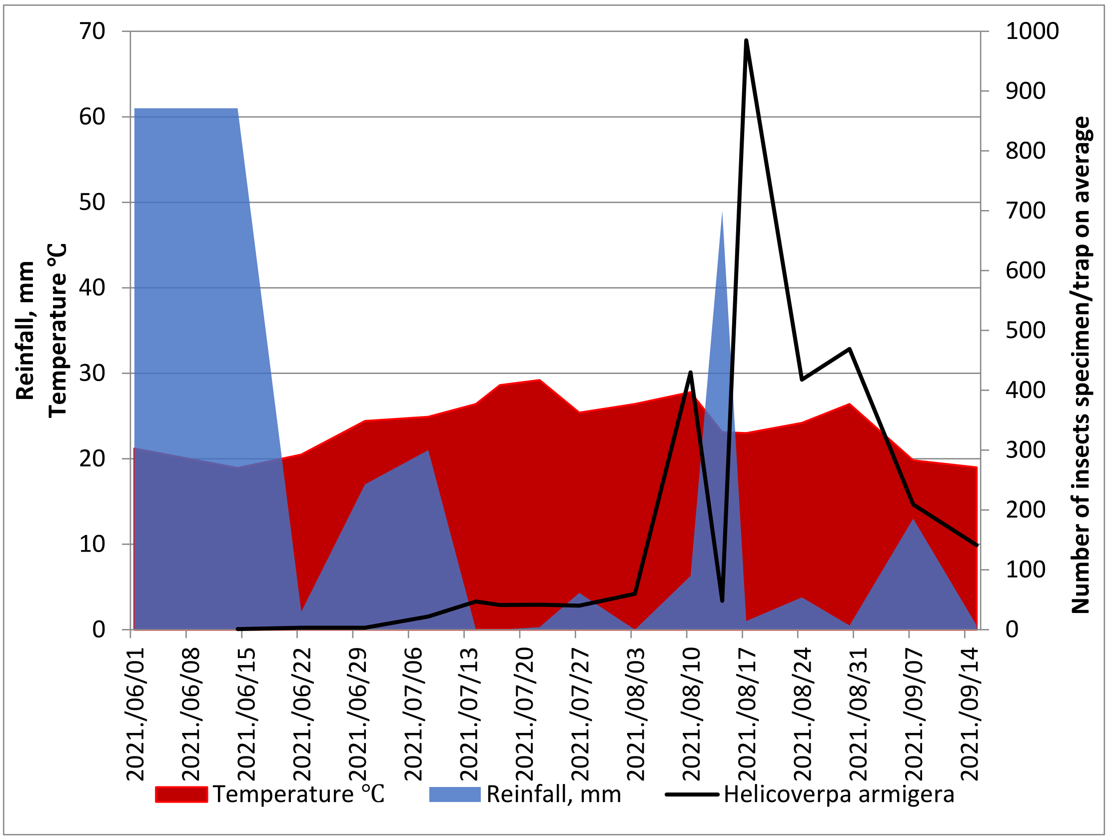

Figure 3. Dependence of the dynamics of the summer of the cotton bollworm on climatic factors. Central zone of Krasnodar Krai. 2021.

Figure 4 presents data on both the summer dynamics of all attracted of the insects and the nutmeg moth according to three light traps on average with the values of the confidence interval.

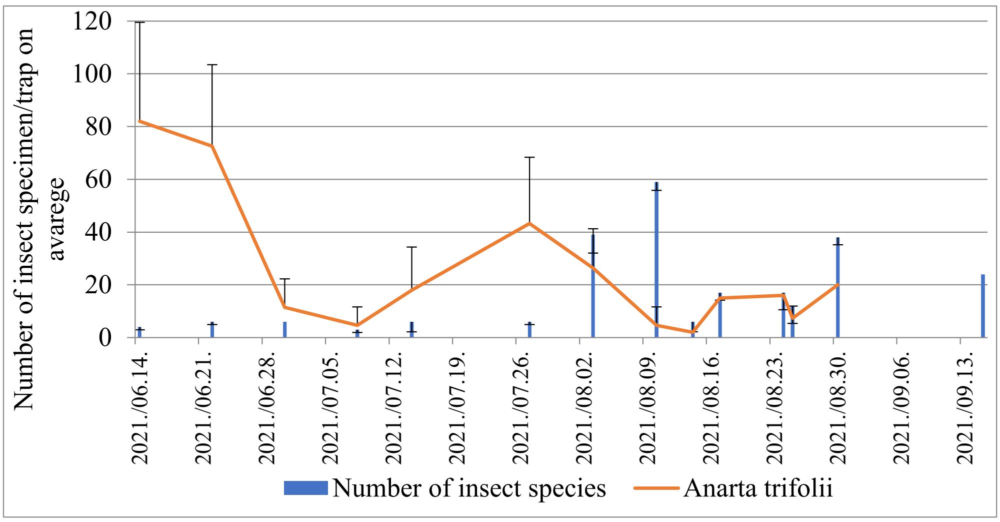

Figure 4. Dynamics of insect attraction to light traps and summer dynamics of the nutmeg moth. Central zone of Krasnodar Krai. 2021.

The insect species in Figures 2 and 4 were lured regularly. As a result, we assessed seasonal summer dynamics. The reasons for this may be the constant presence of the cotton bollworm and the nutmeg moth in soybean agrobiocenosis. The remaining economically significant phytophages were present in 4–6 counts out of 14 during different periods of the study. An analysis of the obtained data provides a clear picture of certain species present in soybean agrocenosis. Insect counts on 3 August, 10 August, and 30 August (Figure 4) were the highest in terms of species diversity.

Then, we calculated the values of the indices of biodiversity and the dominance of insect species in soybean agrocenosis (Table 2).

Table 2. Biodiversity analysis of soybean agrocenosis. Central zone of Krasnodar Krai. 2021.

Index	Count Date			
	3 August	**10 August**	**30 August**	**15 September**
Shannon and Wiener	2.90	2.46	2.05	1.94
Margalef	5.89	5.21	6.26	3.74
Simpson Diversity	0.07	0.20	0.33	0.29
Berger–Parker	7.73	2.33	1.77	1.94
Pielou's evenness	0.79	0.68	0.56	0.63
Number of insects per specimen	39	37	38	22
Number of insects specimen per trap on average	631.67	1004.00	369.50	273.00

4. Discussion

According to our research, the separating insect receptacle helped to significantly reduce and prevent the trapping of small Carabides, Hymenoptera, Heterocerids, Hydrophilids, and other representatives of beneficial and indifferent entomofauna in large numbers [29].

The light traps revealed the summer dynamics of the cotton bollworm. During the summer peaks of the second summer generation, the number of attracted cotton bollworm individuals reached more than 2500 specimens per trap a week.

The correlation of summer dynamics with temperature had a low positive value: $r^2 = 0.02$, and a negative value for precipitation: $r^2 = -0.29$. However, the graph shows that the summer peaks were observed within 3–10 days after heavy precipitation. On August 14, 49 mm of precipitation was noted; on 17 August, the summer peak of the pest was noted. After slight rainfall on 24 August (3.8 mm), we registered an increase in the cotton bollworm on 30 August (Figure 3). Additionally, this is despite the fact that the summer peak had already passed, and we registered pest reduction.

The index values indicate a fairly balanced entomocomplex at the research site despite the active use of chemical plant protection products. As proven by the Shannon and Wiener, Margalef, and Pielou values.

The number of species in the counts is of great importance for the Shannon and Wiener index. If the species diversity is small ($S < 30$), then the value of the index value is mainly influenced by the number of species rather than a stable numerical ratio between individuals of different species during biocenosis. With an increase in the number of species to over 60, the influence of the species richness on the index value significantly weakens [33,35,36]. Thus, taking into account the number of species (from 22 to 39 in different counts), the obtained values of the Shannon and Wiener index can be considered a measure of diversity that adequately reflects biodiversity in the counts where the number of species slightly exceeded "30". In such counts, despite the "complexity" of the index, we can assume that the factor of influence of the number of species on the H value (the value of the Shannon and Wiener index) prevails.

Simpson's diversity index is more sensitive to changes in the abundance of the most common species [37]. The Shannon and Wiener index is the opposite and is sensitive to changes in the abundance of rare species. The first shows the characteristics of the community according to the dominant group of species. The second is more preferable for a complete analysis of the species c-diversity, including the abundance of rare species.

Previous studies revealed the effective spectra for attracting insects. LEDs featuring a relatively narrow spectral emission profile is one of them [21]. White [21], blue [22], and ultraviolet [23] radiation spectra turned out to be the most effective. The efficiency of the UV LED traps is comparable to those based on more energy-intensive and environmentally hazardous mercury lamps [24]. The use of low-energy, super bright LEDs creates mobile, self-contained devices that are convenient for entomological studies in places with an unstable or completely absent power supply [25].

Light traps of various designs show good results in open and closed ground for the monitoring and mass capture of both nocturnal [21–25] and diurnal insects [26]. Various researchers point out that depending on the research site, devices based on super bright LEDs are effective in attracting representatives of the orders Diptera (Diptera) [21] and Lepidoptera (Families Noctuidae, Pyraustidae, and Pyralidae) [22]. It is important to note the high efficiency of attracting the diurnal phytophage known as the glasshouse whitefly (*Trialeurodes vaporariorum* (Westwood)) with the help of light traps compared to sticky traps. This promotes research on the effectiveness of attracting a number of sucking pests with light traps [26].

Electrophysiological studies describe the reaction of Lepidoptera to light with wavelengths of 360–400, 420–460, and 520–550 nm [38]. Various taxonomic groups do not respond identically to different light spectra. Laboratory and field experiments by various researchers confirm this [39,40]. Similar studies are important to prevent damage to beneficial and indifferent entomofauna. The separation effect attempts to mass capture large phytophages (for example, cotton bollworm) and is one of the techniques to reduce harm to beneficial insects [29].

At the same time, the negative effect of UV light on the retinas of warm-blooded animals is known. Ultraviolet light is broken into several wavelengths. The literature mentions UVA (315–400 nm), UVB (280–315 nm), and UVC (100–280 nm) [41]. Each of the UV subtypes has a different effect on warm-blooded animals. According to medical studies, UVA is considered the safest for the retinas of warm-blooded eyes [42–44]. In addition, according to medical studies, a UVA radiation power of 0.35–0.45 mW does not harm the retina and is considered the threshold value [45].

5. Conclusions

We have assessed the effectiveness of the light traps designed by the FRCBPP for studying the biodiversity of soybean entomofauna. We analyzed the biodiversity of the soybean agro-ecosystem using indices of biodiversity, species dominance, and the population evenness.

The traps lured 44 species of insects from eight orders and 27 families. Captures of 15 species of economically important phytophages were recorded—representatives of various orders and families: order Lepidoptera—Noctuidae, Crambidae, Erebidae, and Geometridae; order Hemiptera—Flatidae; order Coleoptera—Elaterida, etc. As a result, 4955.41 insect specimens were caught with one trap on average per one trap. Most of the attracted insects belong to harmful entomofauna: namely the cotton bollworm (*Helicoverpa armigera*, Hübner)—58.9%, the beet webworm (*Loxostege sticticalis*, L.)—12.74%, the nutmeg moth (*Anarta trifolii*, Hufnagel)—6.5%, the European corn borer (*Ostrinia nubialis*, Hübner)—2.68%, and some other species—19.2%. In addition to economically significant phytophages, we registered some indifferent and beneficial species.

The separating insect receptacle significantly reduced the capture of small representatives of beneficial and indifferent entomofauna. The summer dynamics of the cotton bollworm and the nutmeg moth were obtained for the entire research period. Then, we calculated the values of the indices of biodiversity and the dominance of insect species. An analysis of the index values allowed us to conclude the presence of a balanced entomocomplex at the research site.

The designs used for the attracting element of the light trap are safe for the retinas of warm-blooded eyes.

6. Patents

Sadkovsky V.T., Sokolov Yu.G., Ermolenko S.A., Mkrtychan A.G., Kremneva O.Yu. "Insect trap"/Utility model patent RUS 186343 16 January 2019.

Author Contributions: Conceptualization, O.K. and A.P. (Alexey Pachkin); methodology, A.P. (Alexey Pachkin) and A.P. (Artem Ponomarev); validation, O.K. and R.D.; formal analysis, A.P. (Alexey Pachkin), R.D. and D.L.; data curation, A.P. (Alexey Pachkin), D.L., R.D. and A.P. (Artem Ponomarev); writing—original draft preparation, A.P. (Alexey Pachkin) and D.L.; writing—review and editing, A.P. (Alexey Pachkin), D.L. and O.K.; visualization, A.P. (Alexey Pachkin) and O.K.; project administration, O.K.; funding acquisition, O.K. All authors have read and agreed to the published version of the manuscript.

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