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Comparison of Trapping Effects of Different Traps and Monitoring the Occurrence Dynamics of *Spodoptera litura* in Soybean Fields of Dangtu, Anhui Province, China

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Abstract: In order to clarify the trapping efficiency of different types of sex pheromone traps on populations of *Spodoptera litura* in soybean fields, three kinds of conventional traps, called YL-VT, YL-HEMT and YL-NMT, and types of traps equipped with a automatic catch monitoring mechanism, called AIM and AIM-lite-A, have been tested. These last two allow monitoring the diurnal and seasonal rhythms of the catches. From 5 August to 5 October 2020, each YL-VT trap caught an average of 84.4 heads of *S. litura* moths per day, which was significantly higher than the YL-HEMT (11.8 heads), YL-NMT (16.5 heads) and AIM (9.7 heads), which did not show significant differences between them. The half-life of pheromone attraction effect in YL-VT trap is about 17–20 days. Considering the number of trapping and the duration of pheromone attraction effect, YL-VT trap is the best. For efficient monitoring, the validity period is approximately 15 days. Among the causes that could explain its higher capture rate and efficiency, the YL-VT trap has the smallest and largest number of inlet devices, and in it, the lure core is located inside of the insect inlet device. Under different occurrence numbers of *S. litura*, the accuracy of the automatic count of AIM-lite-A is 90% greater than in the AIM trap. The diurnal rhythms of *S. litura* observed by AIM-lite-A show that *S. litura* have two active periods that are from 18:00 to 21:00 and from 23:00 to 4:00 at night and that the first active period may be affected by sunshine and temperature. The annual activity rhythm of *S. litura* monitored by AIM showed that the activity of *S. litura* was related to temperature, there were approximately 6 generations of *S. litura* in a year and that the activity peak was from August to September in Dangtu, China. AIM and AIM-lite-A can be used for the annual monitoring of *S. litura* population in soybean fields because of their automatic counting function. AIM can simultaneously record a variety of meteorological data, AIM-lite-A has higher accuracy and a lower cost, which can be selected according to different situations. In conventional traps, the trap YL-VT can be used for the population monitoring of *S. litura* in soybean fields and pest control in the field, especially in greenhouses and net rooms where organic soybeans are grown, due to its low cost and efficient trapping ability.

Keywords: monitoring application; pheromone lure; soybean; *Spodoptera litura*; traps

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Citation: Xu, Y.; Ye, Z.; Xie, Z.; Zhang, D.; Liu, X.; Yan, Y.; Sun, L.; Chen, F.; Gai, J.; Xing, G. Comparison of Trapping Effects of Different Traps and Monitoring the Occurrence Dynamics of *Spodoptera litura* in Soybean Fields of Dangtu, Anhui Province, China. *Agronomy* **2023**, *13*, 47. https://doi.org/10.3390/agronomy13010047

Academic Editor: Stanislav Trdan

Received: 21 November 2022
Revised: 12 December 2022
Accepted: 19 December 2022
Published: 23 December 2022

1. Introduction

The common cutworm, *Spodoptera litura*, is a pest with chewing mouthparts that cause serious damage to soybeans in tropical Asia, as well as other economically important crops, such as tobacco, sugar beets and cotton [1,2]. It is widely distributed, causing intermittent disasters to crops and great losses to local agricultural production. Traditional pest control methods are prone to environmental pollution, pesticide residues and insecticide resistance of pests [3], therefore, it is necessary to establish an environment-friendly pest monitoring and control system.

Insect pheromones are chemicals released by insects that cause changes in their behavior. They are a general term for compounds that play a role in communication between insects and can be used as a chemical molecular language for communication between them [4]. When they affect individuals of the same species, the effects can be roughly divided into dispersal, aggregation, alarm, trail, sexual ... However, they can also affect the behavior of species other than the producers, including synomones, kairomones and allomones [5]. Among them, sex pheromones are trace chemical substances normally synthesized and released by females into the external environment, in order to attract males and to complete mating. In 1974, Tamaki et al. first separated and purified the crude extract of the female end of *S. litura* from the Japanese population, and identified two components: (Z, E)-9,11-tetradecadiene acetate and (Z, E)-9,12-tetradecadiene acetate [6,7]. In 1985, Kawasaki used electroantennogram (EAG) technology in research and found that component A in the sex pheromone is the main substance that attracts male *S. litura*, that component B can enhance the attraction, that components C and D exhibit inhibition and that component C has the strongest inhibition. The best proportion of various components of sex pheromones is an important factor in the sex-pheromone-inducing ability [8]. According to previous studies, the analogues of sex pheromones artificially extracted and synthesized are called sex attractants, which have the characteristics of high sensitivity, strong specificity, no pollution and no harm to natural enemies. Therefore, it has good application prospects in pest monitoring and control [9]. Le et al. completed a three-year dynamic monitoring of *S. litura* in Guiyang using insect sex pheromone trap with *S. litura* sex pheromone lure [10]. Yi et al. showed that pheromones can effectively control the number of *S. litura* on tobacco and reduce the use of pesticides which suggested that sex pheromone trapping technology be incorporated into environment-friendly control technology system of *S. litura* [11].

Sex pheromone lures are often combined with various traps, such as container, sticky board and basin traps, to monitor and control pests [12]. Traps combined with containers and plastic bags can usually trap living insects, while sticky board and basin traps usually kill insects. Appropriate traps can be selected according to needs [13]. The trapping effects of a dry trap, bucket trap, cylindrical trap, ship trap and triangular delta trap on male *S. litura* were compared, and it was found that the trapping effect of dry traps was significantly better than the other four traps [12].

For the conventional traps currently used, there are disadvantages regarding manpower needs and time-consuming and laborious statistical identification, and they are easy for captured living insects to escape, and they fall and get damaged in strong wind [14,15]. In view of these defects, automatic insect monitoring (AIM) and lite automatic insect monitoring (AIM-lite-A) has been developed by Pherobio Techonology Co., Ltd. In order to further promote the establishment and improvement of an environment-friendly pest monitoring and control system, Nanjing Agricultural University and Pherobio Techonology Co., Ltd. cooperated to carry out trapping experiments on *S. litura* with different traps. Based on three conventional traps [16,17] and two kinds of automatic insect monitor developed by Pherobio Techonology Co., Ltd., the present study aims to compare the trapping effect of different traps on *S. litura* and to evaluate the trapping effect and the counting accuracy of AIM, as well as to monitor the diurnal and seasonal rhythm of *S. litura*, which will provide a theoretical basis for the accurate monitoring and control of *S. litura*, the main insect in soybean fields.

2. Materials and Methods

2.1. Trap Types and Pheromone Lure

Trap were all provided by Pherobio Techonology Co., Ltd. (Yangling, China), including three conventional traps YL-HEMT (Figure 1a), YL-NMT (Figure 1b) and YL-VT (Figure 1c), and two kinds of automatic insect monitor (AIM (Figure 2a) and AIM-lite-A (Figure 2b)). The red PVC pheromone lure cores of *S. litura* were also provided by Pherobio Techonology Co., Ltd. (Yangling, China).

Figure 1. Three kinds of conventional traps, installation positions of pheromone lure and their insect collection devices. (**a**) Trap YL-HEMT; (**b**) Trap YL-NMT; (**c**) Trap YL-VT; (**d**–**f**) Pheromone lure installation device and location (indicated by the white box and arrow in the figure) of traps YL-HEMT, YL-NMT and YL-VT, respectively; (**g**–**i**) Insect collection devices of trap YL-HEMT, YL-NMT, YL-VT and captured males of *S. litura*. In (**a**,**c**,**f**), these Chinese characters represent the name of the manufacturer. In (**i**), these large Chinese characters represent insect collection devices of trap and these small Chinese characters represent the name, address, telephone number, email address and official website of the manufacturer.

Figure 2. Two kinds of automatic insect monitors, installation positions of pheromone lure and their male collection devices. (**a**) AIM; (**b**) AIM-lite-A; (**c**,**d**) Installation device and location of pheromone lure (indicated by the white box and arrow in the figure) of AIM and AIM-lite-A, respectively; (**e**,**f**) insect collection device of AIM, AIM-lite-A and captured males of *S. litura*.

Compared with conventional traps, AIM is equipped with solar photovoltaic panels and small weather sensors (Figure 2a). Trapped insects are killed with a high-voltage power grid, then they fall into the collection device, and they will be detected and automatically counted by a dual-channel infrared pulse as they pass through. It is connected to the internet and can upload the number of trapped insects and the weather conditions (light intensity, wind strength, wind direction, temperature, humidity, whether it rains) of the sampling area at every hour. Compared with AIM, AIM-lite-A eliminates the functions to measure temperature, light intensity and wind direction and is smaller in size (Figure 2b). It is still connected to the internet and can upload the number of trapped insects and the weather condition (whether it rains) every hour. In the present study, the males of *S. litura* were trapped by installing a *S. litura* sex pheromone lure in a lure basket (Figure 2c,d).

The trap YL-VT has sixteen insect inlet devices, and the lure core stick is located inside the trap (Table 1, Figure 1c,f). The outer side of the insect inlet device features a square hole with a diagonal length of 2.0 cm, located around the trap, and the inner of the insect inlet device is a star entrance, while the narrowest part is only 1 cm (Figure 3b). There is a swivel at the lower end of the trap, which is connected with the plastic bag as a collector (Figure 1c,i). The outer entrance diameter of the insect inlet device of trap YL-HEMT is 29.5 cm (Table 1, Figure 3c), while that of trap YL-NMT is 19.5 cm (Table 1, Figure 3e). The lure cores of these two traps are located outside of the insect inlet device. The shortest distance between the inner entrance of the insect inlet device of trap YL-VT and the pheromone lure core is only 6 cm; however, that of trap YL-HEMT is 29 cm (Table 1, Figure 1d) and of trap YL-NMT is 15 cm (Table 1, Figure 1e). The insect inlet devices of trap YL-HEMT and trap YL-NMT are inverted cones, with the outer entrance located at the lower part of the two traps and the inner entrance being a smaller circular hole located inside the trap. The space formed by the insect inlet device and the outer wall of the two traps is used as the collector. The pheromone lure core of the AIM is located inside the insect inlet device (Table 1, Figure 2c), and the pheromone lure core of the AIM-lite-A is located outside the insect inlet device (Table 1, Figure 2d). Both of them shock the attracted males to make them fall into the collector after passing through the counting device.

Table 1. Morphological parameters of insect inlet devices of five types of traps.

Type	Outer Entrance Diameter (cm)	Inner Entrance Diameter (cm)	Length (cm)	Distance (cm) *	Number of Entrances
YL-HEMT	29.5	4.0	29.00	29.0	1
YL-NMT	19.5	2.0	15.00	15.0	1
YL-VT	2.0	1.0	2.00	−6.0	16
AIM	2.5*8.0	2.5*8.0	0.15	−5.0	6
AIM-lite-A	12.0	6.0	10.00	10.0	1

* The pheromone lure cores of the traps YL-VT and AIM are located inside the insect inlet device, and the distance between the pheromone lure core and the inner entrance of insect inlet device is expressed by a negative number; The pheromone lure cores of traps YL-HEMT, YL-NMT and AIM-lite-A are located outside the insect inlet device, and the distance between the pheromone lure core and the inner entrance of the insect inlet device is expressed by a positive number. The insect inlet device of trap YL-VT is square and gradually narrows inward, while the insect inlet device of AIM has a rectangular hole with an external light shield, and the insect inlet devices of trap YL-HEMT, trap YL-NMT and AIM-lite-A are conical and gradually smaller from outside to inside.

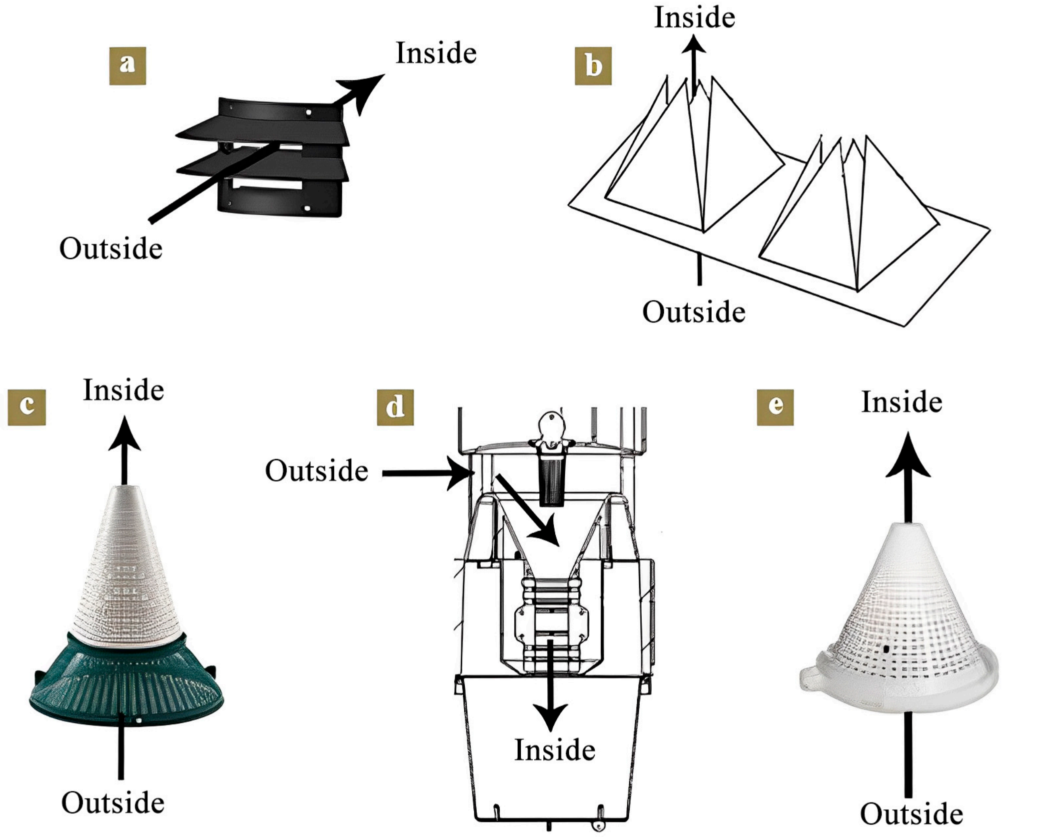

Figure 3. Insect inlet device and the entry route from the outside to the inside of five kinds of traps. (**a**) AIM; (**b**) Trap YL-VT; (**c**) Trap YL-HEMT; (**d**) AIM-lite-A; (**e**) Trap YL-NMT.

2.2. Experimental Design and Investigation Method

2.2.1. Trapping Efficiency Comparison of *S. litura* with Different Traps

The trapping experiment was conducted in the Wanjiang base of Nanjing Agricultural University in Dangtu county, Ma'anshan city, Anhui province (E 118°37′22″ and

N 31°33′4″). Each trap, YL-HEMT, YL-NMT and YL-VT (Figure 1a–c), was equipped with a pheromone lure core (Figure 1d–f). A randomized block design was used with five blocks. In the center of the block, each type of trap was arranged in a straight line with a distance of 20 m. All blocks were set in summer soybean fields with similar growth statuses. From 5 August to 10 September 2020, the number of *S. litura* trapped by each trap was counted at 16:00 every day, at the same time the collection device (Figure 1g–i) was emptied.

2.2.2. Effect of the Reuse of Trap YL-VT on Subsequent Traps of *S. litura*

In order to compare the influence of subsequent reusing on the trapping, a new trap YL-VT that had never been used and the trap YL-VT that was used from 5 August to 10 September 2020 were selected as traps. Each trap was equipped with a new pheromone lure core. A randomized block design was used with 5 repetitions. Traps were evenly installed in summer-sown soybean fields. From 11 September to 5 October 2020, the number of *S. litura* trapped by each trap was counted at 16:00 every day, at the same time the collection device was emptied.

2.2.3. Trapping of *S. litura* by AIM

Three AIMs were installed in the summer-sown soybean fields. From 20 August 2020, the number of *S. litura* trapped, field temperature and humidity, wind direction, light intensity and the presence of rainfall were automatically recorded by the monitor and uploaded to the internet once an hour (http://www.lpsaim.com/device/deviceList accessed on 30 November 2022). From 20 August to 5 October 2020, the number of *S. litura* trapped by each AIM was counted manually at 16:00 every day, then the collection device was emptied (Figure 2e), using manual counts as true values to verify the accuracy of the automatic counting by the AIM. No more capture data was recorded after 5 October 2020 by counting manually. The annual variation and seasonal rhythm of the *S. litura* trapping amount was observed through the data automaticlly recorded by AIM.

2.2.4. Trapping of *S. litura* by AIM-Lite-A

Three AIM-lite-As were evenly installed in the summer-sown soybean field on 22 July 2021. From 23 July 2021, the number of *S. litura* trapped per hour and the weather condition (whether it rains) were automatically recorded by the monitor and uploaded to the internet (http://www.lpsaim.com/device/deviceList accessed on 31 July 2022). From 23 July to 29 July 2021, the number of *S. litura* trapped by each AIM-lite-A was counted manually at 16:00 every day, then the collection device (Figure 2f) was emptied, using manual counts as true values to verify the accuracy of the automatic counting by AIM-lite-A. No manual counting was carried out after 29 July 2021. The diurnal rhythm change of *S. litura* was observed in combination with the data automatically recorded by AIM-lite-A and the data from the local meteorological station (Table 2).

Table 2. Variation of sunrise and sunset time in Dangtu county from July to October in 2021.

Light Dark Change Time	July	August	September	October
Sunrise Time	4:36→4:55	4:55→5:16	5:17→5:35	5:35→5:56
Sunset Time	19:43→19:29	19:28→18:56	18:54→18:16	18:15→17:43

Note: The direction of the arrow shows the change in time from the beginning of the month to the end of the month.

2.3. Data Analysis

The curve of the average trapped number of *S. litura* in different types of traps was drawn with Excel 2018, and then statistical analysis was performed with SAS 9.4. The analysis of variance is carried out by the PROC GLM program with estimates of the missing plots, and the Duncan method is used for multiple comparisons to analyze the difference significance among different traps. Referring to the research method of Chen et al. [18], the half-life fitting curves of a pheromone lure core in different traps were calculated. The manual counting number of *S. litura* trapped in AIM and AIM-lite-A is taken as the true value, and the percentage of the difference between the true value and the number of automatic statistics is taken as the error.

3. Results

3.1. Comparison of Catches of Different Traps

3.1.1. Trapping of *S. litura* with Different Traps

Sex pheromones have strong species specificity and can barely attract insects of other species. There are statistically significant differences among traps, blocks and dates, and the difference among traps is most obvious (Table 3). From 5 August to 8 September, the largest number of *S. litura* trapped came from trap YL-VT with an average of 139.1 per day, followed by trap YL-NMT with an average of 19.0 per day, and the trap YL-HEMT showed the least, at an average of 10.8 per day (Table 4). There was no significant difference between trap YL-HEMT and trap YL-NMT (Table 4). After the pheromone lure core was replaced, from 11 September to 5 October, the trapping effect of each trap was consistent with that of the previous month. The maximum trapped number per day came from trap YL-VT^{used}, which caught an average of 84.4 per day, followed by trap YL-NMT, which caught an average of 16.5 per day, and then trap YL-HEMT, which caught an average of 11.8 per day. There was no significant difference between traps YL-HEMT and YL-NMT (Table 4). In YL-VT traps, the peak of the occurrence of *S. litura* was around 19 August (Figure 4). According to the number of insects trapped every day, trap YL-VT can better reflect the change trend of *S. litura*, but in YL-NMT and YL-HEMT traps, the peak on 19 August was not observed.

Table 3. Analysis of variance of trapped moths for different traps in 2020.

Source of Variation	Date Range 1				Date Range 2				Date Range 3			
	DF	*MS*	*F*	*P*	*DF*	*MS*	*F*	*P*	*DF*	*MS*	*F*	*P*
Trap	2	896,807.6	281.6 **	<0.0001	3	261,098.2	91.2 **	<0.0001	4	125,582.6	103.9 **	<0.0001
Block	4	18,227.2	5.7 **	0.0002	4	9465.9	3.3 *	0.01	4	20,735.0	17.2 **	<0.0001
Date	34	24,929.0	7.8 **	<0.0001	20	9734.5	3.4 **	<0.0001	25	8496.2	7.0 **	<0.0001
Error	411	3184.9			287	2862.6			428	1209.3		

DF: degree of freedom; *MS*: mean squares; *F*: *F* value; *P*: *p* value; *, ** represent significant difference at level of 0.05 and 0.01, respectively. Date Range 1: Comparison among three conventional traps from 5 August to 8 September; Date Range 2: Comparison among four traps (three conventional traps and AIM) from August 20 to 8 September; Date Range 3: Comparison among five traps from 11 September to 5 October.

Table 4. Multiple comparisons of moths trapped by different traps (head per day) in 2020.

Trap	Date Range 1	Date Range 2	Date Range 3
YL-HEMT	10.8 b	1.4 c	11.8 c
YL-NMT	19.0 b	3.0 c	16.5 c
YL-VT^{used}			84.4 a
YL-VT^{new}	139.1 a	107.8 a	52.0 b
AIM		25.6 b	9.7 c

The different lowercase letters after numbers in the same column indicate a significance difference. Date Range 1: Comparison among three conventional traps from 5 August to 8 September; Date Range 2: Comparison among four traps (three conventional traps and AIM) from 20 August to 8 September; Date Range 3: Comparison among five noctuid traps from 11 September to 5 October. Traps YL-VT^{used} are the YL-VT traps that had been used from 5 August to 8 September, and a new lure core was replaced, with subsequent reuse in the Date Range 3 experiment. Traps YL-VT^{new} are new YL-VT traps equipped with new pheromone lure cores. Traps YL-VT^{used} and traps YL-VT^{new} are only used as distinctions in Date Range 3.

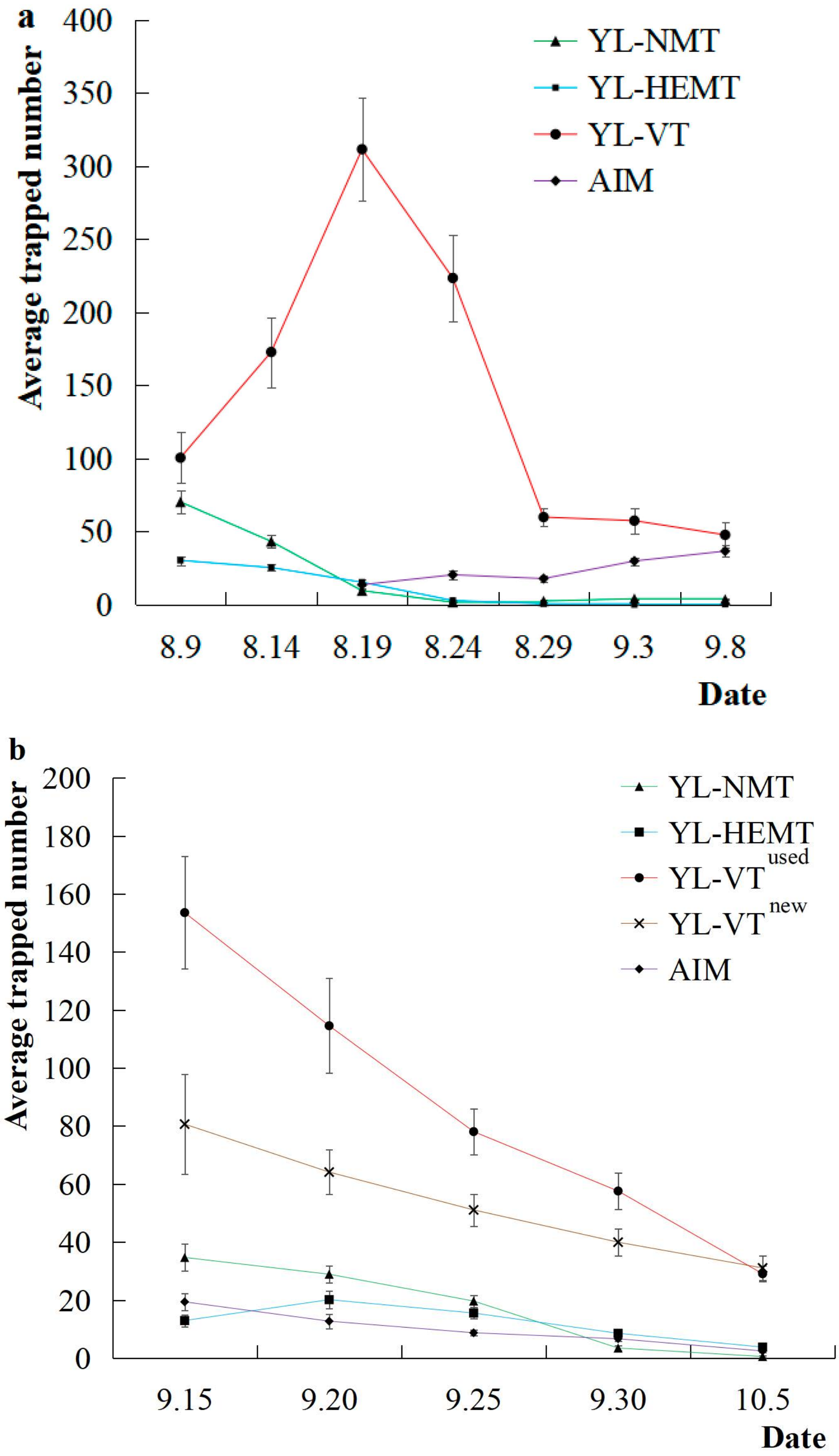

Figure 4. Trapping dynamics of *S. litura* with three conventional traps and AIM in 2020. (**a**) Average trapping dynamics of *S. litura* for each trap every 5 days, from 5 August to 8 September; (**b**) Average trapping dynamics of *S. litura* for each trap every 5 days, from 11 September to 5 October. Traps YL-VT^{used} are YL-VT traps that had been used from 5 August to 8 September, and a new lure core was replaced, with subsequent reuse in the trapping experiment from 11 September to 5 October. Traps YL-VT^{new} are new YL-VT traps equipped with new pheromone lure cores. All data are mean ± SE.

3.1.2. Effect on Trapping from Subsequently Reused YL-VT Traps

From 11 September to 5 October, 84.4 moths of *S. litura* were trapped per day by the YL-VT^{used} trap with subsequent reuse, while only 52.0 moths were trapped per day by the YL-VT^{new} trap used for the first time. The subsequent reuse of the YL-VT trap after replacing the pheromone lure core trapped significantly more moths of *S. litura* than the YL-VT trap used for the first time (Table 4), and the trapping number of the two were quite different within 15 days after installing the new pheromone lure core, while the difference between them gradually decreased until the end of the experiment (Figure 4b).

3.1.3. Half-Life of Pheromone Lure Core in Different Traps

According to the half-life fitting curve calculation of lure core, YL-VT^{used} and YL-VT^{new} have the best degree of fit, with R^2 values of 0.9967 and 0.9996, and their predictions of the half-life of the pheromone lure core, are the most accurate. The R^2 of YL-HEMT is the smallest, but it also reaches 0.8996, indicating that the regression prediction is still accurate. The half-lives of the pheromone lure core in the traps of type YL-HEMT, YL-NMT, YL-VT^{used}, YL-VT^{new} and AIM are 23.1 d, 17.5 d, 17.2 d, 19.9 d and 15.0 d, respectively (Figure 5). In short, the PVC pheromone lure core of *S. litura* produced by Pherobio Techonology Co., Ltd. (Yangling, China) can be used for accurate monitoring, and the validity period should be about 15 days.

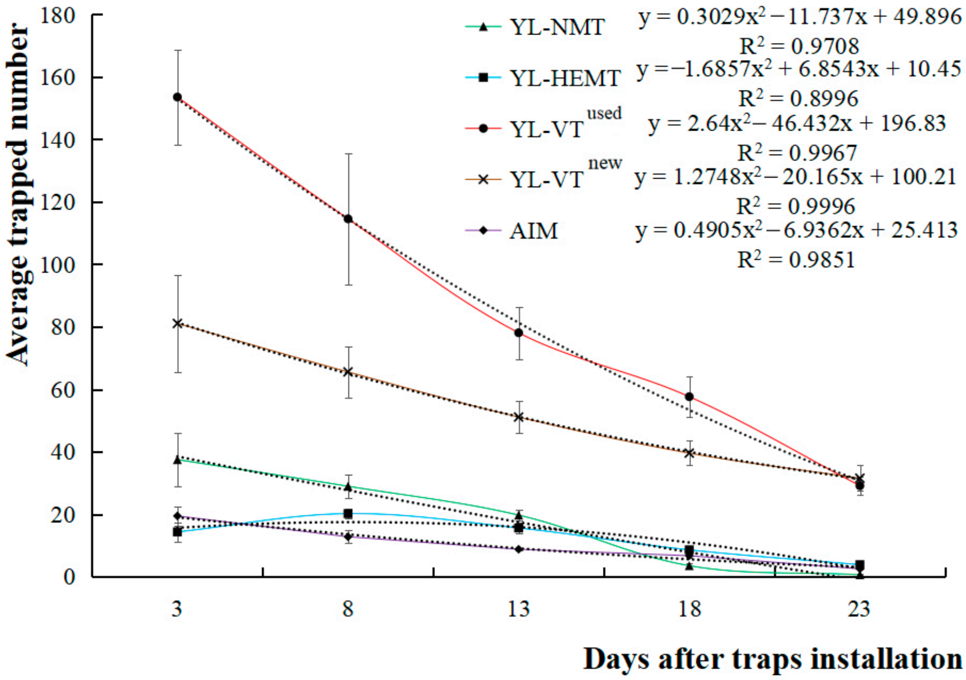

Figure 5. Curve of the number of *S. litura* trapped by pheromone core in five kinds of traps with time. Average trapped number of *S. litura* by each trap every 5 days, from 11 September to 5 October in 2020, were used for half-life fitting curve calculation. YL-VT^{used} traps are YL-VT traps that had been used from 5 August to 8 September, and the lure core was replaced for subsequent reuse in the experiment of Date Range 3. YL-VT^{new} traps are new YL-VT traps equipped with new pheromone lure cores. All data are mean ± SE.

3.2. *Accuracy of AIM and AIM-Lite-A in Monitoring S. litura*

The accuracy of the automatic counting of *S. litura* under different occurrence amounts was investigated. In most cases, the counting error of AIM could be maintained at a relatively low level (<12.5%), when the daily manual counting trapped amount was less than 40 (Figure 6a). When the average daily manual counting trapped amount constituted 40 to 60, the error was less than 30%. When the average daily manual counting trapped amount exceeded 60, the error was the highest (30–65%). Overall, manual counts were larger than AIM automatic counts in most cases (Figure 6a); on the contrary, the manual counting of AIM-lite-A was almost consistent with the automatic counting of the monitor.

The maximum error after the daily trapped amount exceeded 50 was only 10% (Figure 6b). The automatic counting of AIM-lite-A is more accurate.

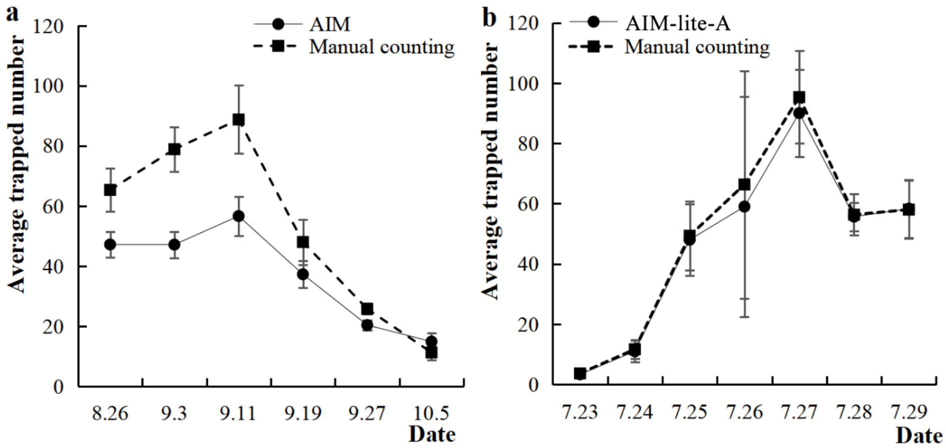

Figure 6. Automatic counting accuracy of two automatic insect monitors under different occurrence of *S. litura*. All data are mean ± SE. (**a**) Automatic counting accuracy of AIM in monitoring *S. litura*; (**b**) Automatic counting accuracy of AIM-lite-A in monitoring *S. litura*.

3.3. Application of AIM and AIM-Lite-A in Monitoring *S. litura*

3.3.1. Diurnal Rhythm of Moth Activity among Main Months of *S. litura* Occurrence

The changes in the diurnal rhythm of *S. litura* with the changes in sunshine and temperature from July to October were recorded by AIM-lite-A in 2021. It shows that there were two main activity periods of *S. litura* every day. The first peak had a lower number of *S. litura*, and its duration changed with the sunset time. The sunset time migration was from 19:43 of July to 17:43 of October (Table 2), which makes the first peak of *S. litura* activity migration from about 20:00 to about 18:00 (Figure 7). However, the second activity peak halfway through night (0:00~4:00) was not affected by the sunset time and the sunrise time, and it did not change with sunset time migration from 19:43 of July to 17:43 of October and sunrise time delay from 4:36 of July to 5:56 of October (Table 2). To sum up, with the extension of the night hour, the moth activity time increased.

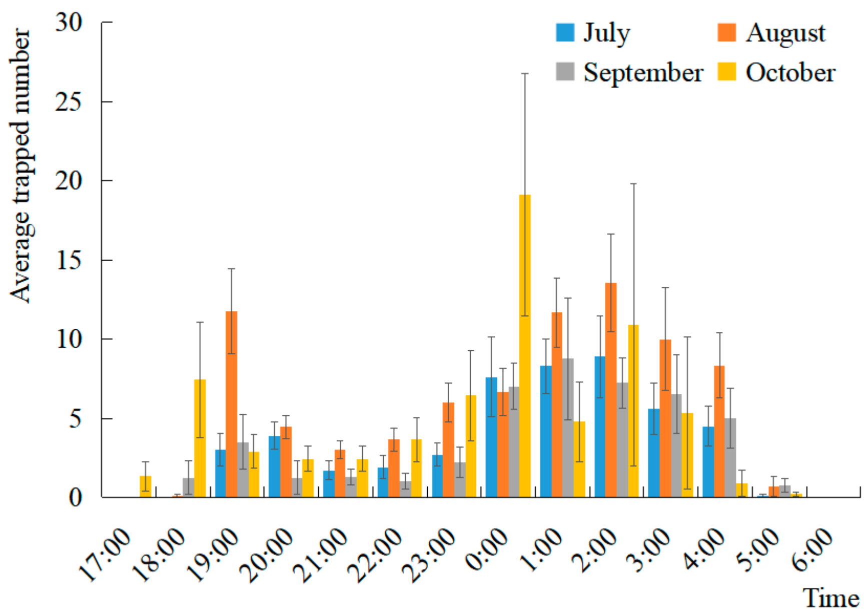

Figure 7. Diurnal rhythm of *S. litura* male moths trapped by AIM-lite-A from July to October in 2021. Diurnal rhythm of *S. litura* male moths trapped by AIM-lite-A from July to October in 2021. Time points 7:00–16:00 are not shown in the figure; *S. litura* were almost not trapped at these time points.

3.3.2. Seasonal Rhythm of *S. litura* Moth Occurrence and Its Relationship with Meteorological Factors

According to the annual trapping data of AIM, *S. litura* moths began to appear with the temperature increase in May, reached a peak in August and almost disappeared after November 2021 (Figure 8 and Figure S1). The number of rainy days from August to October in 2020 to 2022 were 29, 36 and 8, respectively. The trapped number of *S. litura* and number of rainy days in the same period were higher in 2021 and 2020 than in 2022. Thus, fewer rainy days may be one of the reasons for the decrease in the occurrence of *S. litura* in 2022 (Figure S1).

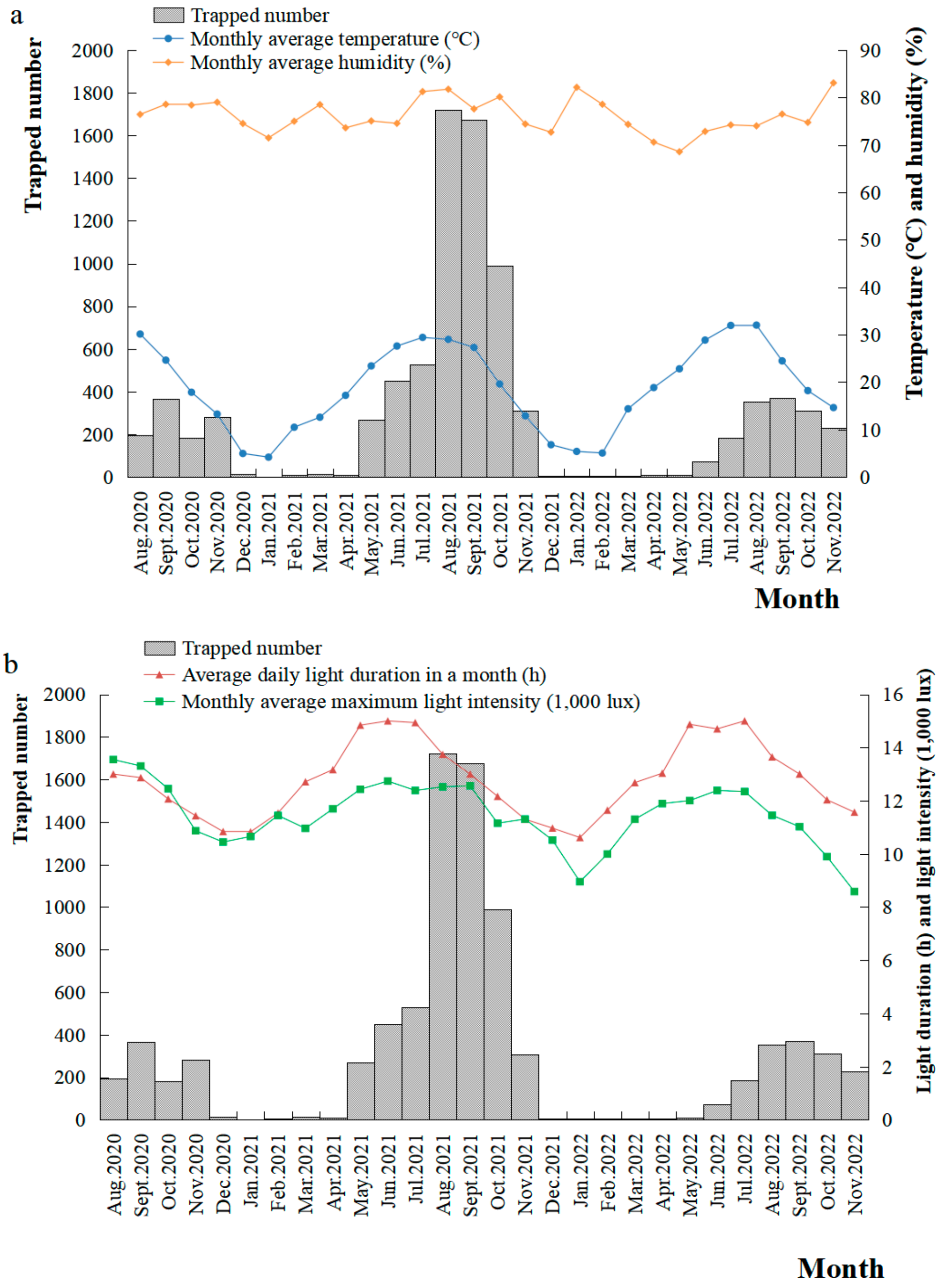

Figure 8. *Cont.*

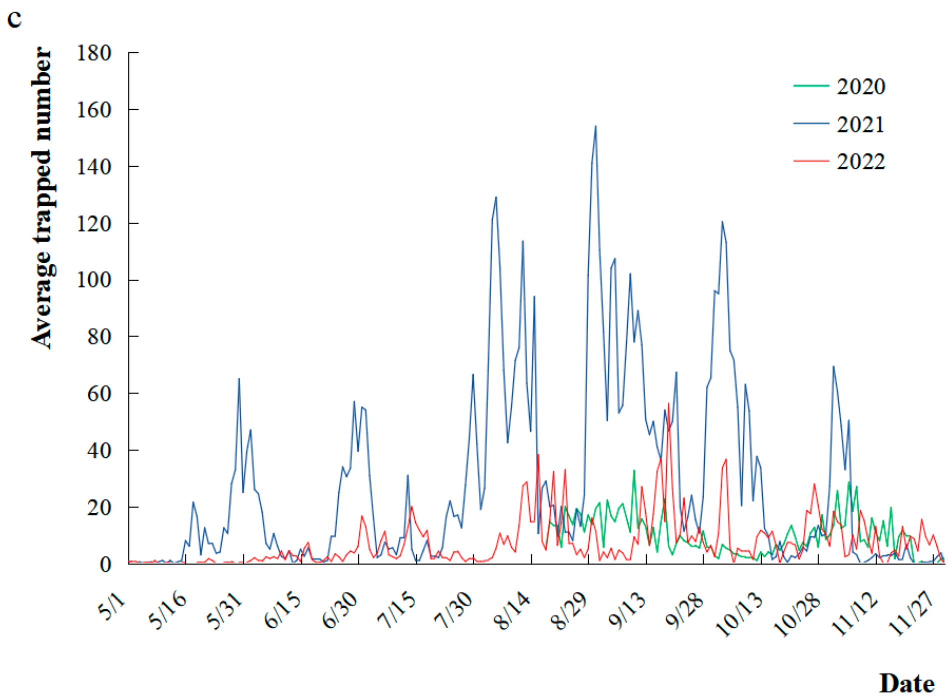

Figure 8. Trapping dynamics of *S. litura* male moths in different months. (**a**) The total number of *S. litura* male moths and monthly average temperature and humidity monitored by AIM; (**b**) the total number of *S. litura* male moths and the averages of daily light duration and maximum light intensity in a month monitored by AIM; (**c**) the daily trapped number of male moths during the occurrence period of *S. litura* after AIM installation.

From 2020 to 2022, AIM also recorded a lot of meteorological data, which can be analyzed together with the trapped numbers of *S. litura* to study the relationship between them. Among these meteorological factors, temperature, light duration and light intensity have a significant positive linear correlation. The annual change of light intensity is relatively large. The correlation coefficient of the trapped numbers of *S. litura* male moths and the monthly average temperature was 0.47, and the correlation coefficient with the monthly average humidity was 0.48, both of which are moderately positive correlation. In 2021, the positive correlation coefficients between the trapped amount of *S. litura* male moths and the monthly average temperature and humidity were 0.70 and 0.67, respectively, both of which reached a significant level, and the correlation was more obvious when the number of *S. litura* male moths was high. The trapping peak from August to September was later than the temperature peak from June to September in 2021 (Figure 8a). Although there was no significant correlation between light duration and light intensity and the occurrence of *S. litura* (Figure 8b), the occurrence peak of *S. litura* was often behind the peak of these two factors. It is also noteworthy that these two factors play an important role in the growth of soybean.

The survival time of adult *S. litura* is generally 15 days, so when the trapped number of one day is the highest of about 15 days before and after that day, it is called a peak. The trapped number of *S. litura* male moths in 2021 shows that there were six obvious peaks (Figure 8c); this confirms previous research results that the annual occurrence of *S. litura* in the Yangtze River basin constitutes five to six generations [19]. The durations of two peaks from the end of July to the end of September were about 24 days and these two peaks showed higher male moth occurrence compared to others. The duration of the other peaks was about 12–15 days. The duration and the occurrence of *S. litura* moths increased, maybe due to overlapping generations. However, the number of peaks over the same time period in 2020 and 2022 decreased compared to 2021, due to the decline in the total number of *S. litura* (Figure 8c).

4. Discussion

4.1. Factors Affecting Trapping Efficiency of S. litura Traps

From 20 August to 5 October in 2020, YL-VT traps trapped a total of 44,227 *S. litura* male moths, while the AIM trapped number in the same period was only a total of 2467. In 2021, only AIM and AIM-lite-A were used to monitor *S. litura*. In the occurrence period of *S. litura* from July to October 2021, the trapped *S. litura* male moth numbers of AIM and AIM-lite-A were a total of 12,496 and 12,245, respectively. The poor trapping effect of the AIM in 2020 might be caused by YL-VT traps that had strong trapping ability and a large total number in the soybean fields. If AIM or AIM-lite-A were used alone in the fields, they could correctly reflect the occurrence rhythm of *S. litura*. The reason why YL-VT^{used} is more attractive than YL-VT^{new} may be that the trapped male moths leave pheromones that can make moths gather. This needs further study in the future.

4.1.1. Configuration Parameters of Inlet Devices and Collecting Devices

In view of the results, the trapping efficiency is related to the distance between the pheromone lure and the inlet device entrance and the size of the inlet device (Table 1). Among the factors influencing the efficiency of trapping, the short distance between the pheromone lure and the internal entrance of the input device, as well as the small size of the internal entrance of the input device, most likely stand out; these effects together facilitate a greater capacity for attraction and in turn make it difficult for the trapped moths to escape. Previous studies also show that insect-trapping efficiency is affected by the designs of traps in the same install density; the traps with a big inlet device do not mean high attracting efficiency [15]. The color of the traps can also affect the efficiency; Karakasis et al. compared the trapping effects of traps with different colors (green, striped (with black and white stripes) and white) on male *Helicoverpa armigera* moths, finding that the white traps performed the best [20]. The YL-HEMT and YL-NMT traps have bigger collecting space, so the moths inside are easier to move, survive and escape, but the YL-VT traps are equipped with plastic bags that have less mobile space, and males' wings may rub and crash against the plastic bag, which makes scales on the wings fall off and die easily [14]. The small and numerous inlet devices and the plastic collecting bags may be the key factors for the high trapping efficiency of YL-VT.

4.1.2. Influence of Pheromone Lure and Its Installed Position on Trapping Effect

The installed position of a pheromone lure will affect the trapping effect. The trapping capability of YL-NMT and YL-HEMT was significantly reduced after 5 days of the lures being installed, but YL-VT was still functional, and to some extent, YL-VT reflected the fluctuations in the number of *S. litura* moths among the dates (Figure 4a). The lure was installed in the inner side of the YL-VT inlet device (Figure 1f), which makes the pheromone emits slower and more strongly attracts males of *S. litura* to enter the trap. On the other hand, the lures are installed on the outer side of YL-HEMT and YL-NMT inlet devices with larger outer entrance (Figure 1d,e), which makes the pheromone emits faster, and the males tend to stay outside and are less likely to enter these traps.

In order to maintain the good trapping efficiency of the trap, the frequency of changing the pheromone lure should be increased when the number of *S. litura* is large. In trap YL-VT, the longevity of the sex pheromone lure also decreased faster when the trap caught more *S. litura*. It is speculated that a large number of male moths can directly touch the lure, resulting in faster pheromone loss.

Proper lure choice may be helpful for *S. litura* trapping according to different conditions. The pheromone trapping capability of the same insect species are different among different populations [21,22]. There are differences in longevity among different pheromone lures in the trapping process of *S. litura* moths [18]. Pherobio Techonology Co., Ltd.'s lures were found to be more effective than Ningbo newkang's lures when trapping *S. litura* in the tea plantations in Sichuan [23]. Meanwhile, Ningbo newkang's lures were found to be more effective than Pherobio Techonology Co., Ltd.'s lures when trapping *S. litura* on vegetables in Shanghai [24].

4.2. Future Application and Improvement of AIM-Lite-A and AIM

Compared with conventional traps, automatic insect monitors have many advantages [25]. (1) They can save daily investigation time by collecting and recording data automatically on the internet; (2) they can record the number of trapped *S. litura* by different time periods to make it possible to observe *S. litura*'s life rhythm and alert activity peaks; (3) the solar panels also ensure the systems work without interruption all year round; (4) they can monitor and reduce the population density in economically developed areas. AIM and AIM-lite-A have to face counting errors caused by not being able to kill *S. litura* completely. When we looked at the collection device of AIM and AIM-lite-A for manual counting, we often found living moths. It is speculated that the living moths ran away from the count of the infrared sensor, resulting in number decreasing in automatic counting.

Compared with the conventional YL-VT trap in the present study, AIM and AIM-lite-A have some drawbacks. Compared to trap YL-VT, AIM is still less efficient, but we can improve AIM by modifying the inlet device configuration with reference to trap YL-VL. AIM-lite-A has a more accurate automatic counting function compared to AIM, and it can also collect and count by period automatically. Moreover, AIM-lite-A is cheaper and easier to install, but it cannot record meteorological data like AIM. Temperature and rainfall are highly associated with *S. litura* occurrences [26]. The meteorological factors can significantly affect insects' richness. In the future, it is expected to cooperate with a local meteorological station to obtain detailed meteorological data so that we can analyze the relationship between weather and insect trapping [27].

AIM and AIM-lite-A are helpful for clarifying *S. litura* activity rhythm. Applying pheromones to finding an activity peak is effective for *S. litura* control [28]. Hence, it is important to know *S. litura*'s activity rhythm and analyze the correlation between rhythm and local climate for predicting the occurrence peak of *S. litura*, reducing the use of pesticides and controlling cost.

4.3. Application of Pheromone Traps in Pest Control

To avoid a poor living environment, migration is insects' special strategy. It is also an important reason for pest outbreaks [29,30]. The number of migratory insects can affect the population density of local insects [27]. The migration of *S. litura* makes it considered as a kind of migratory pest [31], the distribution of them has been studied in China, but detailed knowledge of migration routes still needs further investigation [32]. From this, it is deduced that future research based on molecule marking technology, meteorology, bioinformatics and other related fields is required, which can provide relevant information on the knowledge of the distribution of *S. litura* and the occurrence of epidemic outbreaks [33]. Therefore, it is necessary to collect data on *S. litura* and meteorological data from different locations. Pheromone traps with multiple functions have good prospects.

It has been demonstrated that the pest-trapping technology of a pheromone trap is reaching its maturity [34]. It has been applied to pest monitoring and the control of many crops, which proves its effectiveness. Hopefully, it will be one of the main methods of eco-friendly biological control [35,36]. The YL-VT trap, with low costs, environment friendly nature and high trapping efficiency, can monitor *S. litura* in economically underdeveloped areas and reduce the insect population density. The number of *S. litura* caught by pheromone trap is positively related to the number of eggs produced in the same period [37]. It is plausible to observe the pest population dynamics with the traps and to find the most appropriate time for pest prevention and control, so that we can reduce the cost of pest control and avoid pollution caused by pesticide to the greatest extent [38]. However, it also indicates that the number of *S. litura* males trapped by pheromones cannot always reflect the population correctly [39]. It may be important to count the number of female moths. Therefore, pheromone traps, food traps, meteorological data and manual observations of the soybean fields should be used in conjunction to establish a more reliable pest monitoring and prevention system [40].

4.4. Insect Resistant Soybean Breeding to *S. litura*

After the installation of three AIMs in August 2020, the average number of male moths trapped by each AIM in 2020, 2021 and 2022 were 1036, 5968 and 1543 by 30 November 2022, respectively. After three AIM-lite-A were installed in July 2021, the average number of male moths trapped by each AIM-lite-A was 6005 by 31 July 2022. The results show that *S. litura* is the main pest of soybean in this area, which is consistent with previous studies [41], indicating the importance of resistance breeding to *S. litura* in soybean. The trapping of a large number of *S. litura* can reflect the prevalence rhythm of local *S. litura* and combine with the resistance evaluation of soybean organs to *S. litura* in different reproductive growth periods [42], it is helpful to select varieties resistant to *S. litura*. Highly efficient trapping with sex pheromone traps and cultivating new soybean varieties resistant to *S. litura* [43] can become the most effective and environmentally friendly methods for pest control.

5. Conclusions

Conventional traps using pheromone lures have the advantages of a low cost and convenient installation. The best trapping effect can be achieved by selecting the appropriate trap type for different pests. For pests such as *S. litura*, the use of traps such as YL-VT, wherein the distance between the pheromone lure and the entrance orifice is the shortest among the compared models, as well as featuring a smaller entrance size and the most inlet devices, has been shown to be more efficient and the one that allows a longer duration of activity of the sex pheromone. YL-VT^{used} has better trapping ability than YL-VT^{new}, which shows the feasibility of recycling traps. The automatic insect monitors can record the diurnal and seasonal rhythm of *S. litura* moth occurrence and meteorological conditions. The monitoring in Dangtu, Anhui Province, China, revealed that the local average temperature from the end of August to the middle of September was 27 °C, which was the optimal temperature for the growth of *S. litura*. The popularization of AIM or AIM-lite-A will help to study the geographical distribution of pests and explore the relationship between wind direction, wind power and pest migration. Breeders everywhere can select traps according to their own conditions and needs in order to define local insect resistant breeding goals.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13010047/s1, Figure S1: Heat map of trapped *S. litura* male moth and whether it rains per day after AIM installation. The * indicates that it rained that day.

Author Contributions: Conceptualization and method G.X., F.C. and J.G.; sex pheromone lure and automatic insect monitor Z.X. and D.Z.; field experiments Y.X. and L.S.; data collection, Y.X., Z.Y. and X.L.; data analysis, Y.X., G.X. and Z.Y.; data presentation, writing, reviewing, and editing, Y.X., G.X., Y.Y., Z.Y., F.C. and J.G.; All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Key R&D Program of China (2021YFD1201604), the Natural Science Foundation of China (31571694), MOE 111 Project (B08025), MOA CARS-04 Program, Jiangsu Higher Education PAPD Program, and Jiangsu JCICMCP Program.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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