EGYPTIAN ACADEMIC JOURNAL OF
BIOLOGICAL SCIENCES
ENTOMOLOGY

A

ISSN
1687-8809

WWW.EAJBS.EG.NET

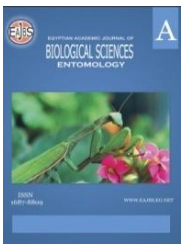
Vol. 16 No. 2 (2023)

Citation: *Egypt. Acad. J. Biolog. Sci. (A. Entomology) Vol. 16(2) pp.143-154 (2023)*
DOI: 10.21608/EAJBSA.2023.306122

Egypt. Acad. J. Biolog. Sci., 16(2):143-154(2023)

Egyptian Academic Journal of Biological Sciences
A. Entomology

ISSN 1687- 8809
http://eajbsa.journals.ekb.eg/



Prediction of the Annual Generations of The Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) at Maize Crop Using Accumulated Heat Units in South Egypt

Moustafa M.S. Bakry; Hassan F. Dahi and Walaa E. Gamil
Plant Protection Research Institute, Agricultural Research Center, Dokki, Giza, Egypt.
***E-mail:** md.md_sabry@yahoo.com - hassandahi@yahoo.com - walaagamil@yahoo.com

ARTICLE INFO
Article History
Received:21/4/2023
Accepted:23/6/2023
Available:27/6/2023

Keywords:
Spodoptera frugiperda, seasonal incidence, generation, heat units, predicting.

ABSTRACT

The fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), is among the dangerous pests infesting maize plants in Egypt. The purpose of this work was to estimate the approximate numbers, appearance date, size of the generations, and peaks of *S. frugiperda* on maize plants in Esna district, Luxor Governorate, South Egypt, throughout two corn seasons (2021 and 2022). As well as the prediction of their forecasted peaks using thermal units accumulation. This was done by examining the relationship between the population seasonality of *S. frugiperda* and the accumulated heat units expounded as degree-days (DD's). The acquired results detected that *S. frugiperda* had three generations per season in the field conditions at Luxor region. These generations were achieved on July, 7th, August, 4th and September, 1st, during every season. These generations lasted 4, 6, and 4 weeks, respectively. The densities of these generations were 45.00, 82.88, and 55.88 larvae per 10 plants during the first season, respectively. But, during the second season, it was 43.88, 77.99, and 58.80 larvae per 10 plants, respectively. In general, the second generation was the longest and bigger in size than the other generations throughout the two seasons.

There was a positive association between the cumulative number of *S. frugiperda* larvae per 10 plants and the accumulated heat units over the two seasons. As well, the results mentioned the occurrence of three actual peaks that took place on (June, 7th, July, 4th, and September, 1st) and four prospective peaks that took place on (July, 4th, July, 23rd, August, 10th, and August, 27th) during the first season. However, across the second season, there were four expected peaks that occurred on (July, 5th, July, 24th, August, 11th, and August, 31st), respectively. Additionally, by using obtainable weather data in the Luxor region, the expected peaks of larvae generations could be revealed when the accumulated thermal units attained 364.83 ± 9.36 DD's degree days.

INTRODUCTION

The fall armyworm (FAW) *Spodoptera frugiperda (*Lepidoptera: Noctuidae), has been seen to attack 186 plant species from 42 families, is polyphagous, and is a significant pest of cereal crops and pasture grasses (Casmuz Augusto *et al.,* 2010). It affects a number of nations, including Brazil, Argentina, and the USA (Prowell *et al*., 2004 and Clark *et al.,*

*2*007), resulting in financial losses in a variety of crops, including maize (Pogue, 2002; Nagoshi, 2007 and Bueno *et al.,* 2010 and Nabity *et al.,* 2011). Its larvae consume maize at various stages of development, including leaves, stalks, cobs, and tassels, and result in a decrease in the resulting yield (Bakry and Abdel-Baky, 2023). The first appearance of *S. frugiperda* in Egypt was 2019 on corn crop (Dahi *et al*., 2020 and Hend *et al*., 2022).

The link between temperature and development rate has a significant influence on biology, spread, and pest abundance (Tobin *et al.*, 2003). Because insects develop within a narrow temperature range, a change in temperature will affect how quickly they develop, how long their life cycles last, and whether they survive (Howe, 1967). As a result, Porter (1991) found that climatic and weather variations had an impact on the status of pest species. Since this will help with risk analyses, forecasting, and management strategies to reduce pest infestation rates, it is crucial to understand how temperature affects the development of target insect species under the present changing environmental circumstances (Calvo and Molina, 2005). In contrast to conditions when insects are exclusively exposed to steady temperatures, oscillations in temperature in natural habitats have an impact on insect population dynamics. When the maximum and minimum temperatures are within their ideal range of growth, insects grow more quickly in environments with temperature fluctuations (Hagstrum and Hagstrum, 1970). However, research investigating disturbance insect species under constant temperatures can be utilized to foretell the phenological and seasonal changes that will occur when temperatures change. The pest reproduction dynamics and timing of management measures were studied by Shanower *et al.* (1993) and Mironidis (2014).

In order to control pest populations, integrated pest management programs (IPM) employ a comprehensive approach that relies on forecasting the seasonal population cycles of insects. As a result, numerous mathematical techniques have been developed (Clement *et al*., 1979 and Richmond *et al*., 1983), some of which explained developmental levels as an indicator of temperature (Wagner *et al*., 1984).

Chemical pesticides frequently have trouble controlling the *S. frugiperda*. In order to create a non-chemical technique for its control (Anita *et al.,* 1984 and Valand and Patel 1993). Although the most effective way to affect all lepidopterous pests remains the use of insecticides, the creation and development of an alternative program to protect people and/or the environment has become more important.

The current work is aimed at estimating *S. frugiperda* annual generation peaks on maize plants under field conditions by using the relationship between the seasonal incidence of *S. frugiperda* and accumulated heat units at Esna district, Luxor region. Many authors have reported predicting the annual generation by using the heat requirements for different insect pests (Emara *et. al*., 1999; Ismail *et al.,* 2005 and Bakry and Dahi 2020).

MATERIALS AND METHODS

1- Population Estimates of *S. frugiperda*:

The population fluctuation of *S. frugiperda* exhibited on maize plants in the field over two successive seasons (2021 and 2022) at Esna district, Luxor region, South Egypt (25º19'31" N, 32º32'08" E). One feddan (4200 m2) was planted with a Single-Hybrid 168 Yellow Corn cultivar of maize plants on the optimum planting date (June, 1st of every season). Usually, regular conventional farming procedures were used, except for pest control. When the age of maize corn plants reached 15 days, the infestation by pests appeared; random samples of forty maize plants (ten plants from each replicate) were inspected weekly and continued until crop harvesting. The samples represented different strata of the field and were randomly picked in a "W" method in the morning at 7 a.m. to

estimate the population size of larvae of *S. frugiperda*. The counts of larvae per 10 plants ± standard error was calculated and worked out on every investigation date, to exhibit the occurrence of pests on maize plants (Vinay *et al*., 2022). The weekly mean numbers of larvae per 10 plants were graphically illustrated.

2- The Estimated Number of Annual Generations of *S. frugiperda* Under the Field Condition:

The annual *S. frugiperda* larvae population data per 10 plants were represented graphically in figures. The number and interval of annual generations below field circumstances were registered by using the natural curve method. Which is based on the relationship between the numbers of larvae on 10 plants with time (dates of examination). We have a curve for the number of larvae (beginning of the appearance of larvae population per 10 plants and its end) estimated by integration of the population densities curves, and each peak of the curve reflects the activity and strength of the generation.

3- Forecasting of Peaks of *S. frugiperda* Generations Using Heat Accumulations:

As regards, the prediction of peaks of *S. frugiperda* generations was done by estimating the connection between the seasonal abundance of *S. frugiperda* larvae and accumulated heat units expounded (as degree-days) under field status throughout the two seasons of (2021 and 2022). Weekly mean numbers of the larvae population densities of *S. frugiperda* were graphically demonstrated to determine the counts' peaks (factual observed peaks). Additionally, actual peaks were compared to the prospected peaks as an instrument to assess accumulated heat units for predicting the *S. frugiperda* generations over each season of maize planting. The observed peaks of *S. frugiperda* generations that were recorded in the field were expounded, based on the population densities of the larvae during the research period. The time when average population densities of maximum larvae per 10 plants are reached can represent a peak for one generation. The sine-Wave Model was used to calculate heat units for *S. frugiperda* with horizontal cut-off technique (Allen, 1976) at 30ºC and a lower threshold of 10.39ºC with a mean (364.7 DD's) for generation evolution for coinciding to Dahi *et al.* (2020). This method was used by applying a Microsoft Excel program evolved at Plant Protection Research Institute, Agricultural Research Center, Giza, Egypt.

The methodology was utilizing the daily mean of maximum and minimum temperatures to compute degree-days and accumulated heat units across an interval of time by applying the above-aforementioned technique. The heat units were computed from 14th June to 8th September per season. The daily means of maximum and minimum temperatures, under conditions of Luxor region, were procured by www.wunderground. com .Counting on the averages of heat units needed for completion of the generation (364.7 DD's), evaluated by Dahi *et al*. (2020), and by comparison between actual peaks (exhibited on the field) and expected peaks (estimated by the technique of Allen, 1976).

4-Association between the Cumulative Larvae Counts of *S. frugiperda* Per 10 Plants and the Accumulated Heat Units:

The current work objective is to estimate the relationship between the dependent variable represented as (cumulative larvae counts of *S. frugiperda* per 10 plants and the independent variable (as the accumulated heat units) on maize plants over the two seasons (2021 and 2022).

The data were statistically evaluated using models of simple correlation, regression values, and the explained variance percentage when the counts of mean daily degree days were plotted versus the *S. frugiperda* larvae counts per 10 plants, and the accumulated degree days, were charted versus the cumulative larvae during the two seasons (2021 and 2022) was corresponding by Fisher method (1950) and Hosny *et al*. (1972):

$$\hat{y} = a + bx$$

Where:

$\hat{y}$ =Prediction value **x** = Independent variable

a =Constant **b** =Simple Regression coefficient

The all-statistical studies of the data were executed by SPSS (1999).

RESULTS AND DISCUSSION

This study is considered the first study in Egypt to predict the peaks of the expected *S. frugiperda* generations using accumulated thermal units.

1- Population Fluctuation of *S. frugiperda*:

The results offered in Figure (1) revealed that the seasonal activity of *S. frugiperda* larvae had three peaks of abundance per season was exhibited in the first week of July, the first week of August, and the first week of September throughout the two seasons (2021 and 2022). Moreover, the larvae of *S. frugiperda* appeared on maize plants from the third week of June and continued until the maize harvest time each season. These findings are in harmony with those acquired by Kumar *et al.* (2020) stated the occurrence of *S. frugiperda* was higher in the second week of July month. Reddy *et al*. (2020) recorded that the heaviest infestation appeared at the plant age (45 days) of maize cultivation. Supartha *et al*. (2021) mentioned that FAW counts were detected to be vigorous after 15 days of cultivation of maize.

2 - Generations Estimation of *S. frugiperda*:

Data presented in Table (1) showed the approximated number, duration and size of *S. frugiperda* larvae generations monitored on maize plants under field circumstances in Esna district, Luxor region during the two seasons (2021 and 2022). The data indicated that there are three generations over each season.

First generation: The first generation was observed between the period from the June 23rd and continued until July 14th in the two seasons (2021 and 2022) and covered a period of 4 weeks below field conditions at (39.86°C, 28.73°C and 22.82%) in 2021 and (40.67°C, 26.52°C and 27.70%) in 2022 for a daily mean of max. temp., min. temp., and relative humidity, respectively. The generation peaked on July 7th per season. The generation density was 45.00 and 43.88 larvae per 10 plants throughout the two seasons, respectively, Table (1).

Second Generation: The second generation was found between the interval from July 14th and continued until August 18th and elapsed approximately 6 weeks over each season below field conditions at (40.02°C, 29.95°C and 24.37%) in 2021 and (41.34°C, 27.50°C and 29.58%) in 2022 for a daily mean of max. temp., min. temp., and relative humidity, respectively. The generation peaked on August 4th across each season. The generation density was 82.88 and 77.99 larvae per 10 plants over the two seasons, respectively, Table (1).

Third Generation: The third generation appeared in the interval from August 18thand extended till Sept., 8thwith a duration of 4 weeks through every season under field circumstances at (40.86°C, 29.77°C and 25.90%) in 2021 and (41.48°C, 27.54°C and 31.43%) in 2022 for daily mean of max. temp., min. temp., and relative humidity, respectively. The generation peaked in September, 1st per each season. The generation density was 55.88 and 58.50 larvae per 10 plants over the two seasons, respectively, Table (1).

The results mentioned that the population densities of larvae differed from one generation to another. The second generation per season, which started in both of them on July 14th and continued to August 18th, was the longest one and biggest in size compared to the other generations over the two seasons. This may be due to the various oscillations of

climatic variables.

The conclusions are in coincide with those obtained by Dent (1991) elucidated that the seasonal activity of pests in any region is defined by the climatic variables at that place. Murúa *et al.* (2009) reported that the counts of *S. frugiperda* larvae be influenced by the plant's age and its growth. Valdez-Torres *et al*. (2012) mentioned that through maize planting, *S. frugiperda* had two field generations per season. Sisay *et al*. (2019) concluded that the generation interval of *S. frugiperda* was little, around 20 to 30 days.

3- Heat Units and Seasonal Abundance of *S. frugiperda* larvae related:

The acquired results in Figure (2), exhibit the accumulated heat units and the weekly numbers of the cumulative larvae of *S. frugiperda* per 10 plants over the two seasons. It was noticed that both of them started to increment gradually to the finish of every season, (Fig. 2).

By calculation of the cumulative larvae of *S. frugiperda* (as dependent variable) versus the accumulated heat units (as independent variable), the simple regression method pointed out that the numbers of cumulative larvae per 10 plants were more related to the accumulated heat units for the two seasons, demonstrated in Figure (3).

The regression method mentioned that the association offered a logical fit and the coefficient of determination (R^2) appeared that the increment in the cumulative larvae numbers happened due to the rise in the accumulated heat units.

The associations between them could be defined by the succeeding equations acquired in Figure (3):

$Y = -10.58 + 010\ x$ $R^2 = 99.81\%$ for the first season

$Y = -10.35 + 0.10\ x$ $R^2 = 99.82\ \%$ for the second season

4- Predicting of *S. frugiperda* Generation Peaks Using Accumulated Heat Units:

By using the lower threshold (10.39ºC) and the degree- days average needed to complete the generation of *S. frugiperda* larvae (364.7 DD's), that evaluated (Dahi *et al*., 2020), and by differentiation between actual peaks (that passed in the field) and prospective peaks (which estimated by applying the Sine-Wave method (Allen, 1976) by horizontal cut off technique at 30ºC and lower threshold of 10.39ºC over the two seasons of (2021 and 2022) are depicted in Table (2).

The succeeding results could be discovered; the first generation happened between the interval from June 23rd and continued until July 14th and the generation peaked (actual field) on July 7th per each season. But the expected peak was discovered earlier on July 4th and July 5th with 362.70 and 362.70 DD's, over the two seasons, respectively, **Table (2).** The second generation elapsed between the period from July 14th and continued until August 18th, the field peak appeared latterly on August 4th as compared to the awaited peak. The probable peak was attained on July 23rd and 24th with 370.87 and 366.06 DD's, for the two seasons, respectively, Table (2).

The third generation per season was observed in the interval from August 18th and extended to Sept., 8th, the field peak exhibited on September, 1st, was dotted delayed as compared to the prospective peak recorded on August 10th and August 11th when the Accumulated heat units were 352.92- and 347.66-degree days, during the two seasons, respectively, Table (2).

Moreover, there was a potential predicted fourth peak was achieved on August 27th and August 31st, when the accumulated heat units needed 367.74 and 377.33 DD's through the two seasons, respectively. Contrarily, no actual peak was observed in the maize field in this period, Table (2).

Data exposed that the prospected peaks of generations could be discovered when the accumulated thermal units reached (364.7 DD's), which agrees with (Dahi *et al*., 2020).

Applying obtainable meteorological data handed for the Luxor region, the mean ± STD accumulated heat units per generation for *S. frugiperda* larvae over the two seasons were estimated to be 364.83 ± 9.36 DD's.

Eventually, it could be mentioned that the accumulated heat units needed under the climatic circumstances in the Luxor region are important for forecasting the appearance of *S. frugiperda* larvae, and can assist determine the suitable procedures to control *S. frugiperda* larvae.

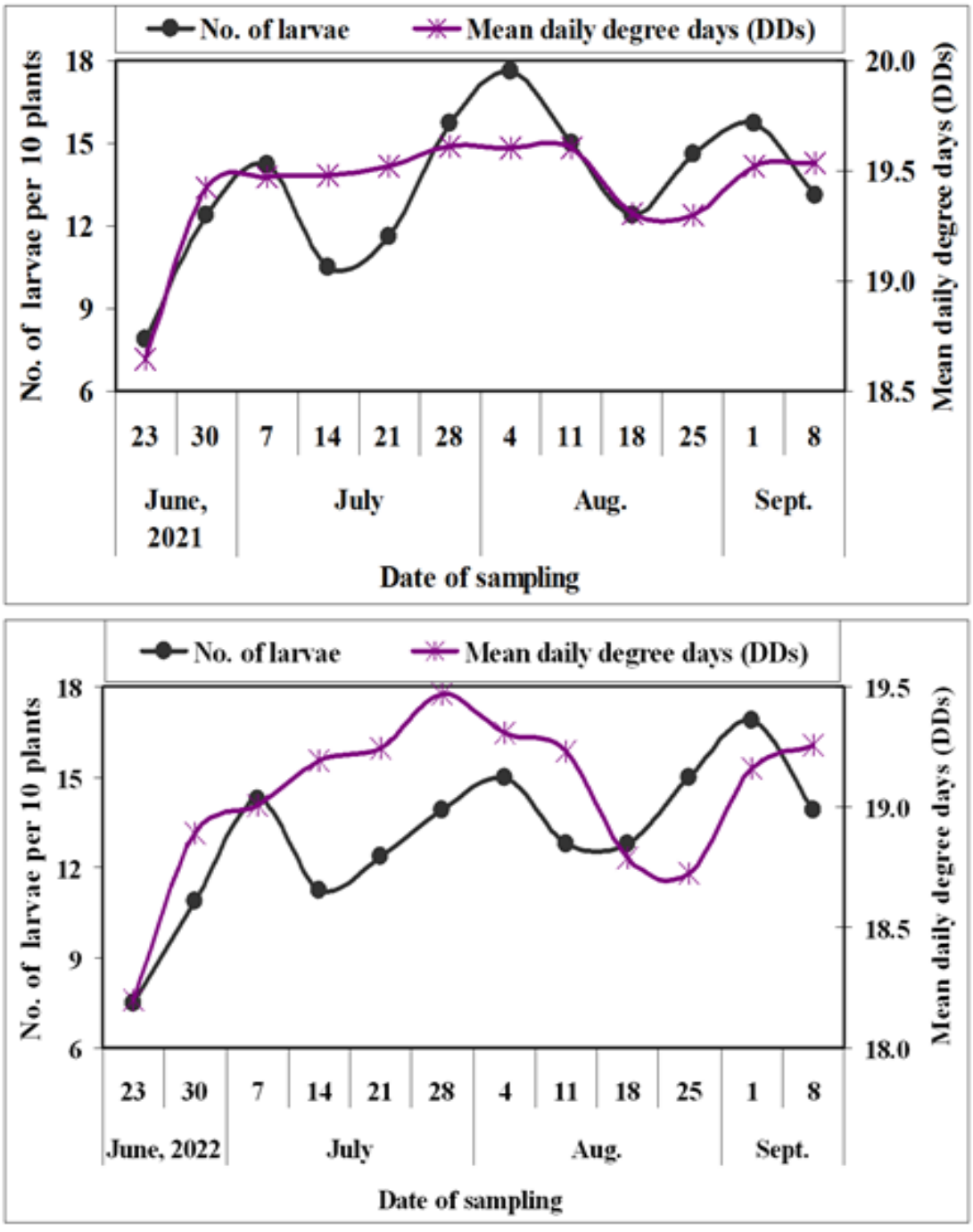


Fig. 1: Means of weekly counts of daily degree days, and the seasonal incidence of *S. frugiperda* larvae per 10 maize plants, during the two seasons (2021 and 2022).

Table 1: An estimate of the number, length, and size of *S. frugiperda* larvae generations that occurred on maize plants in the field throughout the two seasons (2021 and 2022).

Season	Generation	Date	Peak of generation	Duration in weeks	Larvae generation size per 10 plants	Means climatic factors					Mean daily degree days (DD's) per generation
						Max. temp.	Min. temp.	Range temp.	Mean temp.	% R.H.	
2021	1st	June 23rd to July 14th	July 7th	4	45.00	39.86	28.73	11.13	34.29	22.82	19.26
	2nd	July 14th to August 18th	August 4th	6	82.88	40.02	29.95	10.07	34.98	24.37	19.52
	3rd	August 18th to Sept., 8th	Sept., 1st	4	55.88	40.86	29.77	11.09	35.32	25.90	19.42
2022	1st	June 23rd to July 14th	July 7th	4	43.88	40.67	26.52	14.15	33.59	27.70	18.82
	2nd	July 14th to August 18th	August 4th	6	77.99	41.34	27.50	13.84	34.42	29.58	19.20
	3rd	August 18th to Sept., 8th	Sept., 1st	4	58.50	41.48	27.54	13.94	34.51	31.43	18.98

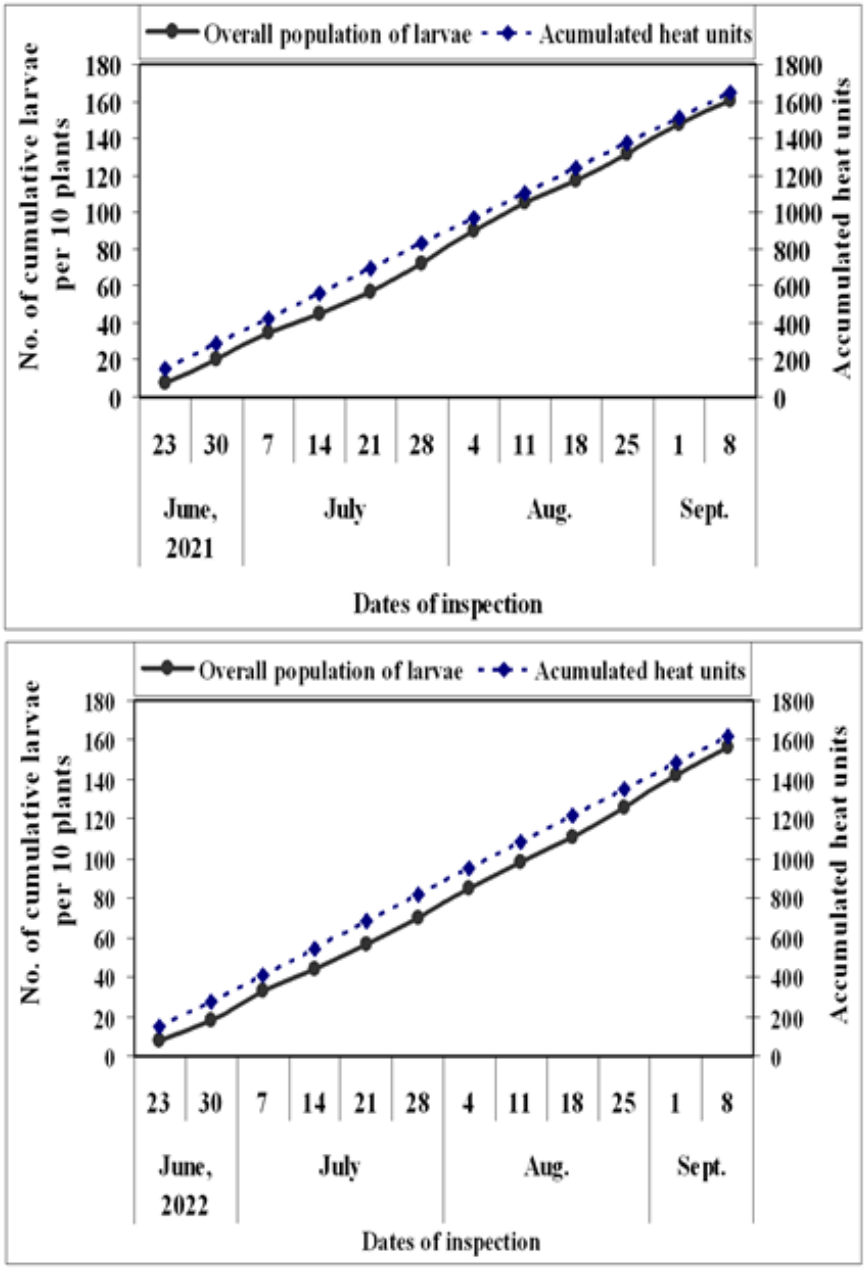


Fig. 2: Means of weekly counts of accumulated heat units and the cumulative larvae of *S. frugiperda* per 10 maize plants, during the two seasons (2021 and 2022).

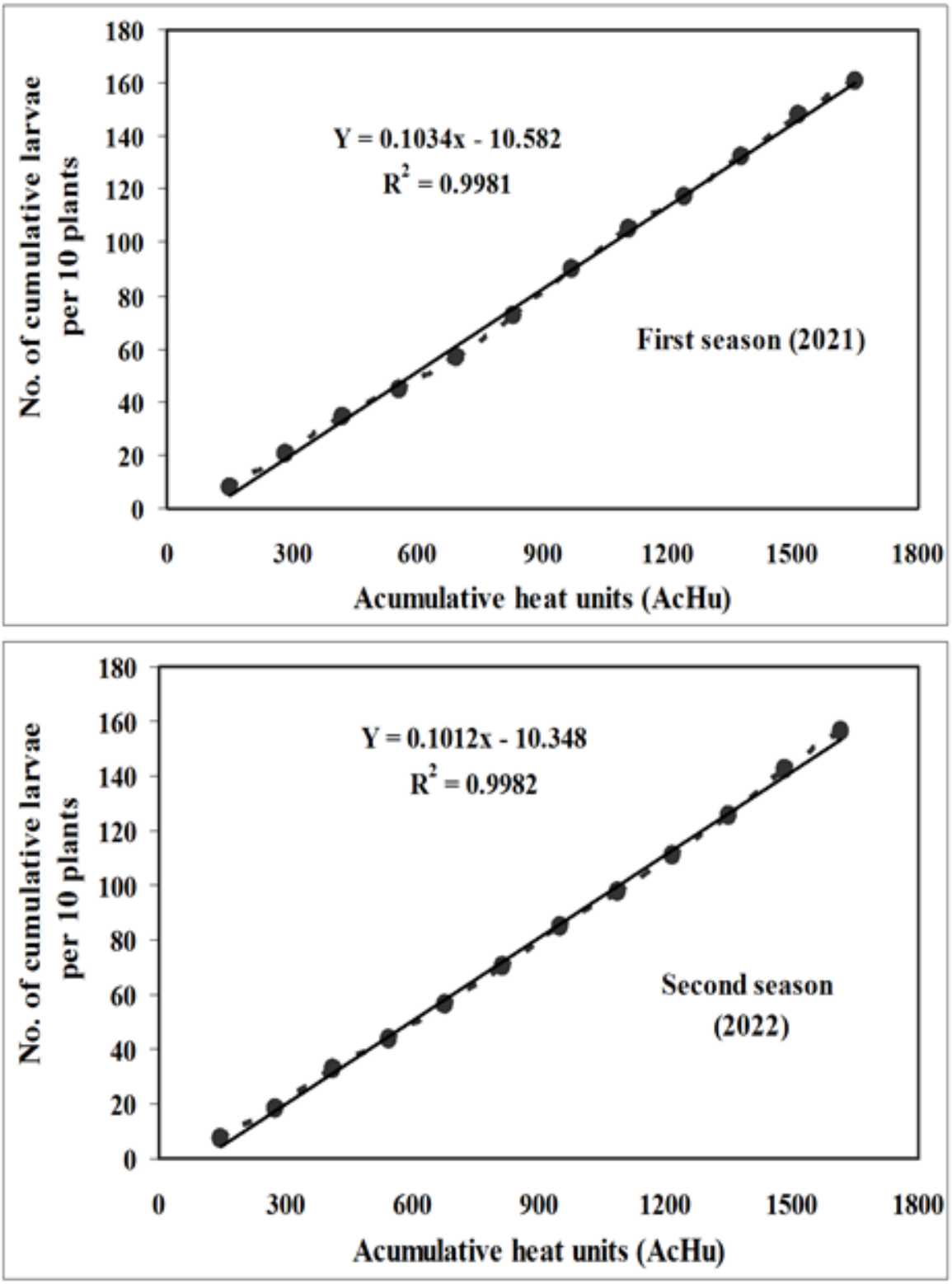


Fig. 3: Relationship between the accumulated heat units (AcHu) and the cumulative *S. frugiperda* larvae of 10 maize plants, during the two seasons (2021 and 2022).

Table 2: Comparison between actual and predicted peaks of *S. frugiperda* larvae generations on maize plants and accumulated thermal units under field conditions at Esna district, Luxor region over the two seasons (2021 and 2022).

Season	Generation	Generation period		Peak		Accumulated heat units per generation
		From	To	Observed	Expected	
2021	1st	June 23rd	July 14th	July 7th	July 4th	362.70
	2nd	July 14th	August 18th	August 4th	July 23rd	370.87
	3rd	August 18th	Sept., 8th	Sept., 1st	August 10th	352.92
	4th	-		-	August 27th	367.74
2022	1st	June 23rd	July 14th	July 7th	July 5th	372.32
	2nd	July 14th	August 18th	August 4th	July 24th	366.06
	3rd	August 18th	Sept., 8th	Sept., 1st	August 11th	347.66
	4th	-		-	August 31st	377.33

The mean ± standard deviation of accumulated heat units per generation for *S. frugiperda* larvae over the two seasons was estimated to be 364.83 ± 9.36 DD's.

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ARABIC SUMMARY

التنبؤ بقمم أجيال دودة الحشد الخريفية التي تصيب نباتات الذرة الشامية باستخدام الوحدات الحرارية المتجمعة فى جنوب مصر

مصطفى محمد صبرى بكري– حسن فرج ضاحي -ولاء جميل ابراهيم
معهد بحوث وقاية النباتات - مركز البحوث الزراعية- الجيزة - مصر

تعتبر دودة الحشد الخريفية من بين الآفات الخطيرة التى تصيب نباتات الذرة الشامية فى مصر. فقد تم تحديد عدد الأجيال ومدة وحجم كل جيل وقمم هذه الأجيال وحساب الوحدات الحرارية المتجمعة اللازمة لكل جيل تحت الظروف الحقلية، والتنبؤ بقمم الأجيال السنوية للحشرة من خلال دراسة العلاقة بين الوحدات الحرارية المتجمعة (معبرا عنها DD's) وكثافة تعداد يرقات الحشرة على نباتات الذرة الشامية فى مركز إسنا محافظة الأقصر خلال موسمين متتاليين من (2021 و2022).

أظهرت النتائج، أن لهذه الحشرة ثلاثة أجيال حقلية خلال الموسم. فقد سجلت هذه الأجيال فى يوم 7 يونيو، 4 يوليو، 1 سبتمبر خلال كل موسم، على التوالى. ومدة هذه الأجيال 4 و6و4 أسابيع، على التوالي. وكان حجم الأجيال 45.00 و82.88و55.88 يرقات على 10 نباتات، على التوالي. أما العام الثانى، فكان حجم هذه الأجيال 43.88 و77.99و58.80 يرقات على 10 نباتات، على التوالي. أيضا، كان الجيل الثانى، أكبرهما حجما ونشاطا وأطول مدة من الأجيال الأخرى خلال الموسمين.

وأظهر التحليل الأحصائى، أن عدد اليرقات على 10 نباتات أبدى أستجابة معنوية موجبة بزيادة عدد الوحدات الحرارية المتراكمة خلال الموسمين.

وكشفت نتائج الدراسة، وجود ثلاثة قمم فعلية حقلية والتي حدثت في (يوم 7 يوليو و4 أغسطس و1 سبتمبر)، ولها أربعة قمم متوقعة والتي حدثت في يوم 4 يوليو و23 يوليو و10 أغسطس و27 أغسطس خلال الموسم الأول من الدراسة. وخلال الموسم الثانى، لوحظ أربعة قمم محتملة والتي حدثت في (يوم 5 يوليو و24 يوليو و11 أغسطس و 31 أغسطس) على التوالى.

أيضاً، باستخدام بيانات الأرصاد الجوية المتاحة لمنطقة الأقصر، يمكن الكشف عن القمم المتوقعة لأجيالِ اليرقات عندما بلغت الوحدات الحرارية المتراكمة إلى 364.83 ± 9.36 وحدة حرارية.