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# Predicting the annual generations of *Spodoptera frugiperda* (Lepidoptera:Noctuidae) under climate change in Egypt

**Ouda, M. I.**

***Plant Protection Research Institute, Agricultural Research Center, Dokki, Giza, Egypt.***

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**Abstract**

The fall armyworm (FAW) *Spodoptera frugiperda* (J.E.Smith) (Lepidoptera:Noctuidae) has undergone a significant range expansion from its native range in the Americas, to continental Africa, Asia and mainland Australia. Moreover, the large dispersal potential of FAW adults at wide hosts ranges with optimal environmental conditions. In Egypt, this study was conducted during 2021 and 2022 to predict annual generations expected and observed of FAW on maize in Sheben El-Qanater, Qalyoubia Governorate. The results showed that the calculated number of expected and observed were ten generations in the field by applying the formula of Richmond *et al.* (1983): one generation in the winter: The generation the expected from were 5th and 7th Jan. (Observed 7th and 9th Jan.) during 2021 and 2022, respectively. Two generations in the spring: The generation the expected from 3rd and 14th and 5th and 14th Apr. and May during 2021 and 2022, respectively. The observed generations were 7th and 20th and 7th and 20th Apr. and May during 2021 and 2022, respectively. Four generations in the summer: The generations the expected from 21st Jun**.** 13th Jul., 3rd Aug. and 27th Aug. during 2021 and 21st Jun, 13th Jul., 3rd Aug.m and 27th Aug. in 2022. The generations observed were 25th Jun., 18th Jul., 7th Aug. and 1st Sep. during 2021 and 26th Jun., 18th Jul., 8th Aug. and 3rd Sep. during 2022. Three generations in the autumn: The generations expected from 22nd Sep., 20th Oct. and 25th Nov. during 2021 and the generations were 22nd Sep., 20th Oct. and 25th Nov. during 2022. The generations observed were 26th Sep., 25th Oct., and 1st Dec. during 2021 and the generations were 30th Sep, 31st Oct., and 1st Dec. during 2022. Whereas the results indicated that there was a correlation significant between the numbers of FAW with plant age and maximum and minimum temperature.

## Introduction

The fall armyworm (FAW) *Spodoptera frugiperda* (J.E.Smith) (Lepidoptera:Noctuidae) became an invasive pest in west and central Africa where the outbreak occurred for the first time in 2016. Moreover, FAW first appeared in Nigeria during 2016 and was intercepted in Europe, in specimens incoming to Germany and the Netherlands (Goergen *et al.,* 2016 and CABI, 2017). More recently, this pest was found invasive in Africa during 2017 and in 2019 recorded in southern Egypt on maize crop (Al-Jubouri *et al*., 2021 and FAO, 2018).

The pest causes yield loss in maize in the USA due to falling armyworm, showing that the pest attacks many crops, maize, cotton, rice, sorghum, and others. In Brazil and the United States, *S. frugiperda* is a major pest (Blanco *et al*, 2016). Fall armyworm larvae can cause a 34 to 38% yield loss. If an attack occurs and a late start in the early phase the attack can reach 100% (Fotso Kuate *et al.*, 2019), has also conducted a case study in Cameroon Africa on damage and distribution as well as farmers' responses to this pest. Efforts to control the fall armyworm attack must always be followed. In the United States, fall armyworm is a major pest of maize. Many technologies have been studied to control these pests. In the USA, the researcher has studied the control of *S. frugiperda* using sterile insect techniques (Carpenter *et al.*, 1997). The results contribute to knowledge of fall armyworm population ecology on a continental scale and will aid in the prediction and interpretation of inter-annual variability of insect migration patterns including those in response to climatic change and adoption rates of transgenic cultivars (Westbrook *et al*., 2016). Moreover, the result is temperature is the main factor affecting the growth, development, and reproduction of insects. Related to the fact that *S. frugiperda* is native to tropical and subtropical America and its distribution is limited by low temperatures. And studies have shown that humidity levels that are too low or too high will affect the hatching rate, larval survival rate, pupation rate and other factors (Wang *et al.,* 2020 and Li *et al*., 2020). More recently, the armyworm appeared in 2016 on maize crops in Americas, causing significant damage. In the USA, one of the important phytosanitary problems faced with the maize crop is FAW, a widely spread polyphagous noctuid. In addition, armyworm is well-established in the United States, Mexico, Brazil, and Argentina (Clark *et al.*, 2007 and Gutierrez *et al.*, 2020). FAW became an invasive pest in west and central Africa where the outbreak occurred for the first time in 2016. Moreover, FAW first appeared in Nigeria during 2016 and was intercepted in Europe, in specimens incoming to Germany and the Netherlands (Goergen *et al.*, 2016 and CABI, 2017). More recently, this pest was found invasive in Africa during 2017 and in 2019 recorded in southern Egypt on maize crops (Al-Jubouri *et al*., 2021 and FAO, 2018).

## Materials and methods

The experiments were carried out in the open field at Sheben El-Qanater City, Qalyoubia Governorate, during 2021 and 2022 years. Weather factors daily mean maximum, daily mean temperature and relative humidity were obtained for Qalyoubia area from www.wunderground.com (Ata, 2013). An area of 1/2 (2100 $m^2$)/feddan was sown of maize plants *Zea mays* L. (Fam.: Poaceae) variety "Single hybrid white ten" the plantation on March $15^{th}$ and Jun $15^{th}$ and variety "Corn for fodder green" the plantation on Sep. $15^{th}$ during 2021 and 2022 years. Seeds were sown in rows at the rate of 12 rows/2 poles with agricultural practices done as recommended and the absence of any insecticidal application. The inspection taken randomly population was recorded weekly during the two years 2021 and 2022. Used Direct count technique (Four replicates contain 25 plants per replicate, larval population /100 plants) until the end of the season.

Predicting of annual (FAW) *S. frugiperda* generations was carried out by studying the relationship between thermal heat units expressed as degree-days (D.D's), and the population of the FAW during 2021 and 2022 years. Field maximum and minimum temperatures were used and the developmental temperature threshold for generation ($t_0$) was estimated to be 10.93 ˚C, the average required thermal units was 472.21 D.D'S for completion the FAW generation. The lower threshold temperature ($t_0$) for *S. frugiperda* generation that had been calculated by Ouda *et al.* (2022) by applying the formula Richmond *et al*. (1983):

H = Σ HJ

H = Number of accumulated heat units to emergence.

HJ = (Max. + Min.)/ 2-C, if max.>C & min.>C

= $(\text{max.- C})^2$ /2(max.- min.) if max >C & min.<C

= 0 if max. <C & min.<C

C = Threshold temperature.

This formula was used to determine the required heat units of FAW under daily field fluctuation temperatures. The weekly total of FAW counts were graphically illustrated to determine the observed population and was compared with the expected population as a tool to estimate heat units requirements for predicting the FAW annual generations.

The statistical analysis (Simple correlation and partial regression) of the obtained data was performed by using SAS Institute (1997) program.

## Results and discussion

Results obtained in Table (1) and Figure (1), showed that the generations FAW *S. frugiperda* as follows:

### 1. The first generation:

The ($1^{st}$) winter generation lasted for about 88 and 89 days during 2021 and 2022 years. The expected generation date from $5^{th}$ Jan. and $7^{th}$ Jan. and the required thermal units recorded for completion this generation 575.6 and 570.8 D.D'S for completion this generation during 2021 and 2022 years. While the observed generation date in field from $7^{th}$ Jan. and $9^{th}$ Jan. during 2021 and 2022 years, on host plant green fodder corn. Additionally, the peak population (48 and 46 larvae/100 plant) of *S. frugiperda* larvae recorded for this generation on $1^{st}$ week of Mar. and $4^{th}$ week of Feb. during years 2021 and 2022.

The results of simple correlation and the Partial regression analysis showed the relations between the total number of *S. frugiperda* for winter season and all plant ages and daily mean maximum temperatures revealed positive and significant (Pro.=0.05) during 2021 and 2022 seasons. However, the daily mean minimum temperature and daily mean RH. % were negative and not significant on the total population of FAW during the winter seasons of 2021 and 2022. Additionally, the results revealed that the combined effect of weather factors and all plant ages was highly significant on total numbers of FAW during 2021 and 2022 seasons. The calculated "F" value was recorded 4.16 and 4.89 with "P" value recorded 0.004 and 0.001 and the E.V. % reached 78.10 and 85.62 % during seasons 2021 and 2022. It’s clearly attributed this percentage to the combined effect of studied factors on FAW population, while the remainder percent is due to other factors.

### 2. The second generation:

The (1st) spring generation lasted for about 41 and 39 days during 2021 and 2022 years. The expected generation date from 3rd Apr. and 5th Apr. and the required thermal units recorded for completion this generation 478.6 and 476.6 D.D'S for completion this generation during 2021 and 2022 years. Whereas the observed generation date in field from 7th Apr. and 6th Apr. during years 2021 and 2022, on host plant maize crop. Hence, the peak population (57&63 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation on 4th week of Apr. during the years 2021 and 2022.

**3. The third generation:**

The (2nd) spring generation lasted for about 38 days during 2021 and 2022 years. The expected generation date from 14th May and the required thermal units recorded for completion of this generation are 472.2 and 473.8 D.D'S for completion of this generation during 2021 and 2022 years. Whereas the observed generation date in field from 18th May during years 2021 and 2022, on host plant maize crop. Hence, the peak population (57 and 63 larvae/100 plant) of *S. frugiperda* larvae recorded for this generation on 4th week of Jul. during years 2021 and 2022.

The results of simple correlation and the partial regression analysis showed the relations between the total number of *S. frugiperda* for the spring season and all plant ages, daily mean minimum, maximum temperatures, and daily mean RH. % revealed positive and not significant (Pro.=0.05) on the total population of FAW during the spring seasons 2021 and 2022. Additionally, the results revealed that the combined effect of weather factors and all plant ages were insignificant on total numbers of FAW during 2021 and 2022 seasons. Moreover, the calculated "F" value recorded at 1.44 and 1.07 with "P" values recorded 0.3203 and 0.4600 and the E.V.% reached 65.23 and 77.78% during seasons 2021 and 2022. It's clearly attributed this percentage to the combined effect of studied factors on FAW population, while the remainder percent is due to other factors.

**4. The Fourth generation:**

The (1st) summer generation lasted for about 20 and 22 days during 2021 and 2022 years. The expected generation date is from 21st Jun. and the required thermal units recorded for completion of this generation 470.7 and 473.0 D.D'S during 2021 and 2022 years. Subsequently, the observed generation date in field from 25th and 26th Jun. during the years 2021 and 2022, on the host plant maize crop. Hence, the peak population (60 and 66 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation in week during 1st week of Jul. of the years 2021 and 2022.

**5. The Fifth generation:**

The (2nd) summer generation lasted for about 22 and 21 days during 2021 and 2022 years. The expected generation date from 13th Jul. and the required thermal units recorded for completion of this generation 477.9 and 476.0 D.D'S during 2021 and 2022 years. Whereas the observed generation date in the field from 18th Jul. during years 2021 and 2022, on host plant maize crop. Additionally, the peak population (57 and 63 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation on 4th week of Jul. during years 2021 and 2022.

**6. The Sixth generation:**

The (3rd) summer generation lasted for about 24 days during 2021 and 2022 years. The expected generation date from 3rd Aug. and the required thermal units recorded for completion of this generation 473.2 and 473.0 D.D'S during 2021 and 2022 years. Whereas the observed generation date in the field from 7th Aug. and 8th Aug. during the years 2021 and 2022, on the host plant maize crop. Whereas the peak population (80 and 86 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation in week during 3rd week of Aug. during the years 2021 and 2022.

**7. The Seventh generation:**

The (4th) summer generation lasted for about 27 and 26 days during 2021 and 2022 years. The expected generation date from 27th Aug. and the required thermal units recorded for completion of this generation 473.7 and 472.7 D.D'S during 2021 and 2022 years. Whereas the observed generation date in the field from 1st and 3rd Sep. during years 2021 and 2022, on host plant maize crop. Whereas the peak population (92 and 91 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation on the week of 7th and 9th Sep. during the years 2021 and 2022.

The results of simple correlation and the partial regression analysis showed the relationship between the total number of *S. frugiperda* for the summer season and all plant ages, daily mean minimum, maximum temperatures, and daily mean RH. % revealed positive and highly significant (Pro=0.05) on the total population of FAW during the summer seasons 2021 and 2022. Additionally, the results revealed that the combined effect of weather factors and all plant ages was highly significant on the total numbers of FAW during the 2021 and 2022 seasons. Likewise, the calculated "F" value recorded at 2.90 and 2.91 with "P" values recorded at 0.004 and 0.005 and the E.V.% reached 73.31 and 71.39% during seasons 2021 and 2022. It's clearly attributed this percentage to the combined effect of studied factors on the FAW population, while the remainder percent is due to other factors.

**8. The Eighth generation:**

The (1st) autumn generation lasted for about 28 days during 2021 and 2022 years. The expected generation date from 22nd Sep. and the required thermal units recorded for completion of this generation 474.2 and 473.9 D.D'S during 2021 and 2022 years. Whereas the observed generation date in the field from 27th and 26th Sep. during years 2021 and 2022, on host plant maize crop. Whereas the peak population (95 and 90 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation on the week of 4th Sep. during years 2021 and 2022.

**9. The Ninth generation:**

The (2nd) autumn generation lasted for about 35 and 36 days during 2021 and 2022 years. The expected generation date from 20th Oct. and the required thermal units recorded for completion of this generation 473.4 and 472.0 D.D'S during 2021 and 2022 years. Whereas the observed generation date in the field from 25th Oct. during years 2021 and 2022, on host plant maize crop. Whereas the peak population (76 and 82 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation on the week of 7th Nov. during the years 2021 and 2022.

**10. The Tenth generation:**

The (3rd) autumn generation lasted for about 42 and 43 days during 2021 and 2022 years. The expected generation date from 25th Nov. and the required thermal units recorded for completion of this generation 472.9 and 472.1 D.D'S during 2021 and 2022 years. While the observed generation date in the field from 1st Dec. during the years 2021 and 2022, on the host plant green fodder corn. Whereas the peak population (73 and 69 larvae/100 plant) of *S. frugiperda* larvae was recorded for this generation on the week of 14th Dec. during the years 2021 and 2022.

The results of simple correlation and the partial regression analysis showed the relations between the total number of *S. frugiperda* for the autumn season and all plant ages, daily mean minimum, maximum temperatures, and daily mean RH. % revealed positive and highest significant (Pro=0.05) on the total population of FAW during the autumn seasons 2021 and 2022. Also, the results revealed that the combined effect of weather factors and all plant ages had the highest significance on total numbers of FAW during the 2021 and 2022 seasons. Wherever the calculated "F" values recorded at 3.13 and 3.21 with "P" value recorded at 0.006 and 0.003 and the E.V.% reached 72.85 and 73.32 % during seasons 2021 and 2022. It's clearly attributed this percentage to the combined effect of studied factors on the FAW population, while the remainder percent is due to other factors.

Previous results showed that the FAW *S. frugiperda* has ten generations per year, distributed in the following seasons: The winter generation appeared on green fodder corn, which is the lower generation due to the impact of climatic factors on its population. FAW feeding affects the quality of green fodder crops during this season. The spring generations appeared in the maize crop, which is the least generation due to the impact of climatic factors on its population. The summer and autumn generations appeared in the maize crop which is high generation due to the Suitability of climatic factors for population. They are among the most infestation seasons for maize plants.

The results of this study showed that the FAW *S. frugiperda* has ten generations per year, distributed over the seasons year 2021 and 2022, and climatic factors had an impact on the population. These results agree with (Chunxian Jiang *et al*., 2022) indicating with global climate change and the emergence of extreme weather, agricultural production and food security may encounter more crises. Climate change will also affect the potential distribution of *S. frugiperda*. As an important economic pest, understanding its potential distribution in different regions and future changes in suitable areas is the basis for the monitoring of early warning and effective prevention and control of invasive pests. The results are similar to (Dahi *et al.,* 2020) study the lower threshold of development ($t_0$) and average thermal units were 12.49˚C and 527.3 DD's for a complete generation of FAW reared on castor oil plant leaves. In Addition, it can be said that the mid-Jun plantation observed an increase in the average number of FAW, with the entry into the summer months, which are characterized by high temperatures which were agreed with (Cruz *et al.,* 2008 and Clark *et al.,* 2007). Also, these results agree with (Olyme *et al.,* 2022) show that the planting dates (Mid-May, early June, and mid-June) also affected its population. The mid-May plantation date recorded a lower infestation rate than other planting dates. The highest population density in both hybrids was recorded in the first of June and mid-June. Significant differences were found between the two hybrids in the first and mid-June. The average incidence was the highest number recorded on hybrids in mid-June cultivated. At the end of August and the beginning of September. The FAW *S. frugiperda* has ten generations per year, distributed in the following seasons: The winter generation appeared on green fodder corn, which is the lower generation due to the impact of climatic factors on its population. FAW feeding affects the quality of green fodder crops during this season. The spring generations appeared in the maize crop, which is the least generation due to the impact of climatic factors on its population. The summer and autumn generations appeared on maize crop which is high generation due to the Suitability of climatic factors for population. They are among the most infestation seasons for maize plants.

**Table (1): Annual generations of *Spodoptera frugiperda* in the field during 2021 and 2022 years.**

| Year | Generation | Expected | Observed | Degree Days in field (DD's) | Generation season | No. Days of Gener. | Host plant |
|---|---|---|---|---|---|---|---|
| 2021 | First | 5 Jan. | 7 Jan. | 575.6 | winter | 88 | Green fodder corn |
| | Second | 3 Apr. | 7 Apr. | 478.6 | Spring | 41 | Maize crop |
| | Third | 14 May | 20 May | 472.2 | | 38 | |
| | Fourth | 21 Jun. | 25 Jun. | 470.7 | Summer | 20 | |
| | Fifth | 13 Jul. | 18 Jul. | 477.9 | | 22 | |
| | Sixth | 3 Aug. | 7 Aug. | 473.2 | | 24 | |
| | Seventh | 27 Aug. | 1 Sep. | 473.7 | | 27 | |
| | Eighth | 22 Sep. | 27 Sep. | 474.2 | Autumn | 28 | |
| | Ninth | 20 Oct. | 24 Oct. | 473.4 | | 35 | |
| | Tenth | 25 Nov. | 1 Dec. | 472.9 | Autumn | 42 | Green fodder corn |
| 2022 | First | 7 Jan. | 9 Jan. | 570.8 | winter | 89 | Green fodder corn |
| | Second | 5 Apr. | 6 Apr. | 476.6 | Spring | 39 | Maize crop |
| | Third | 14 May | 18 May | 473.0 | | 38 | |
| | Fourth | 21 Jun. | 26 Jun. | 473.0 | Summer | 22 | |
| | Fifth | 13 Jul. | 18 Jul. | 476.7 | | 21 | |
| | Sixth | 3 Aug. | 8 Aug. | 473.0 | | 24 | |
| | Seventh | 27 Aug. | 3 Sep. | 472.7 | | 26 | |
| | Eighth | 22 Sep. | 26 Sep. | 473.9 | Autumn | 28 | |
| | Ninth | 20 Oct. | 25 Oct. | 472.0 | | 36 | |
| | Tenth | 25 Nov. | 1 Dec. | 472.1 | Autumn | 43 | Green fodder corn |

**Gene. = generation.**

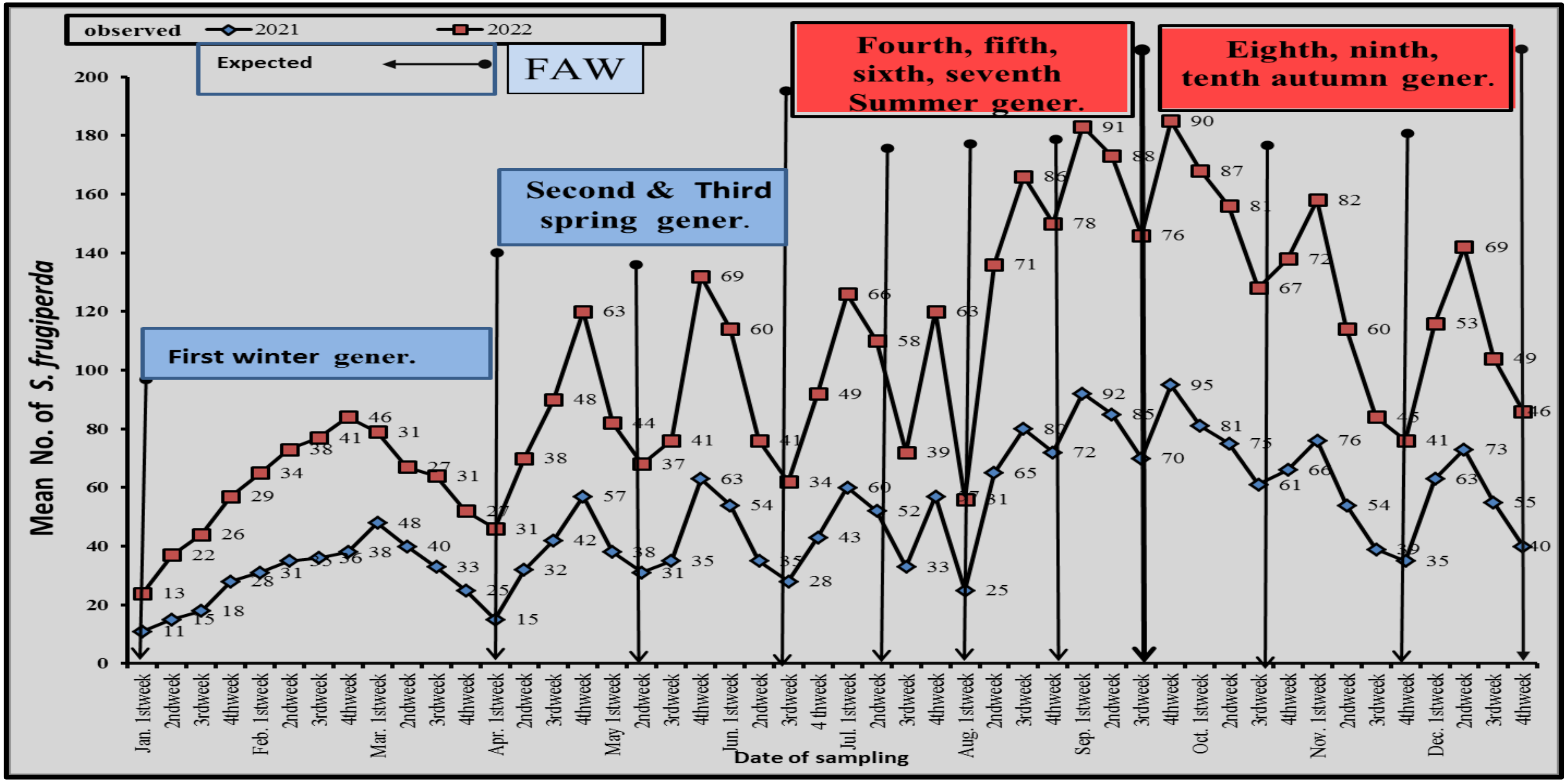


**Figure (1): Annual generations of *Spodoptera frugiperda* FAW in the field during 2021 and 2022 years.**

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