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Impact of Fall Armyworm *Spodoptera frugiperda* on Maize Yield and Economic Assessment of Losses under Different Insecticidal Sequences

Ragab S. Kandil[a], **Mohsena R. K. Mansour**[a], **Fatma M. Abdelrahem**[b], and **Noha A. Dabour**[c]

[a]*Field Crop Pests Research Department, Plant Protection Research Institute, Agricultural Research Center, Dokki, Giza, Egypt.*
[b] *Economic Evaluation and Environmental Department, Central Laboratory for Design and Statistical Analysis, Agricultural Research Center, Giza, Egypt.*
[c] *Zoology Department, Faculty of Science, Tanta University, Tanta, Egypt.*

BY MAY of 2019, it was the first time to report fall armyworm, *Spodoptera frugiperda* (Smith) at Upper Egypt. So, two field experiments were conducted at Nubaria region, Behaira Governorate to find out the relationship between population of *S. frugiperda* larvae and maize grain yield, and to assess yield loss%, voltinism (annual number of generation) and to evaluate the economics of maize production under the circumstances of some insecticidal applications. The RCBD with four replicates was used and treatments included two insecticides (methomyl and emamectin benzoate) applied in trinary or binary sequences against fall armyworm. There was a negative correlation between population of *S. frugiperda* larvae and maize grain yield. Applying methomyl and emamectin benzoate in a trinary sequence produced the highest maize yield; 4.249 and 3.416 t/fed in the 1st and 2nd seasons, respectively. The highest quantitative yield losses were found in untreated check plots;77.76 and 78.89% in 1st and 2nd seasons, respectively. Methomyl, emamectin benzoate and methomyl sequence produced the highest net benefit over untreated check and net benefit/ total costs (%).The insect pest had 5 generations on maize plants during the growth period from May1stto November 30th in both seasons. To avoid the widespread off all armyworm, in Egypt, the growers are recommended to spray a sequence of insecticides, including methomyl 15 days after planting, emamectin benzoate, and methomyl at recommended doses with 10 day-interval between each two pesticide applications.

Keywords: Fall Armyworm; Corn; Voltinism; Pesticides Schedule; Grain yield.

1. Introduction

Fall Armyworm (FAW), *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae), is one of the deadliest insect pests for economic crops, having arrived to Egypt from South African countries, attacking over 353 plant species (Casmuz *et al*., 2010; Rwomushana, 2019 and Montezano *et al*., 2018). *S. frugiperda* was first discovered in Egypt in a corn field at Kom Ombo, Aswan Governorate, Upper Egypt, in May 2019 (Dahi *et al*., 2020; Mohamed *et al*., 2022). The larvae of *S. frugiperda* is the damaging stage, with caterpillars feeding on young leaf whorls, ears, and tassels, producing significant damage to maize crops and severe grain yield loss (Sarmento *et al.*, 2002; Rwomushana *et al.*, 2017 and Prasanna *et al*., 2018). Late larval instars can cut through the whole base of young maize seedlings, damaging the entire plant (Harrison *et al.*, 2019), so, ministry of agriculture encourages the growers to spray insecticides to control this insect

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*Corresponding author e-mail: mohsena.mansour112@gmail.com
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and reduce the yield loss. Crop loss is defined as a drop in crop production, both in quantity and quality that can occur in the field (pre-harvest) or in storage (post-harvest) as a result of biotic or abiotic stress (Oerke *et al*., 1996; Savary *et al.,* 2006). Crop loss includes a decline in crop value and financial returns (Nutter *et al*., 1993). Crop losses also include both primary and secondary losses. The measurement of yield losses, defined as the difference between achievable and actual yield (Nutter *et al.*, 1993) is the first stage in crop-loss evaluation. The actual yield is also a site-specific yield, attained using farm-level practices and influenced by yield-reducing variables such as insect pests (Nutter *et al*., 1993 and Oerke *et al.,* 1996).

Despite the importance of crop loss information, the major reviews on the subject agree that efforts to quantify yield losses and analyses their causes have been limited (Oerke *et al*., 1996; Savary *et al*., 2006 and Savary and Willocquet, 2014). However, in addition to being limited, yield-loss assessments typically do not take into account secondary yield losses.

The aims of this study were to find out the relationship between insecticidal applications and number of *S. frugiperda* larvae, maize yield, and yield losses. In addition, number of annual pest generations were evaluated in 2021 and 2022 seasons. Also, the economics of maize production under insecticidal applications were assessed.

2. Materials and methods

2.1. Field experiments

Two field trials were carried out at Saad Zaghloul village, West Nubaria area, located at 30.90 latitude and 29.96 longitude, El-Behaira Governorate, Egypt during 2021 and 2022 summer seasons. The treatments were as follows:

1. Trinary spray sequence:

methomyl (Goldben 90%® SP) at a rate of 300 g/feddan 15 days after planting, emamectin benzoate (Speedo 5.7%® WG) at a rate of 80 g/feddan 25 days after planting and methomyl at a rate of 300 g/feddan 35 days after planting.

2. Binary spray sequence:

methomyl at a rate of 300 g/feddan 15 days after planting and emamectin benzoate at a rate of 80 g/feddan 25 days after planting.

3. Single spray:

methomyl at a rate of 300 g/feddan 15 days after planting.

4. Untreated check:

Spraying with water.

The four treatments were randomly allocated in a Randomized Complete Block Design (RCBD) with four replicates. The plot area was 80 m^2 (8 ×10 m), each plot had 13 rows with a width of 60 cm, and seeding was done in hills with a 30 cm apart. The variety of maize was yellow single cross hybrid 3444 and the sowing dates were on May 20th in 2021 and on May 25th in 2022. In both seasons, all agricultural practices were carried out in accordance with the Egyptian Ministry of Agriculture recommendations. Buffer areas, of four lines between each of the two adjacent plots, were planted with untreated maize plants to avoid any contamination or interference of spray drift. One hundred labelled maize plants were randomly cut at the base weekly from each plot after spraying to estimate number of *S. frugiperda* larvae, then the seasonal mean of *S. frugiperda* larvae per 100 maize plants was calculated. The data were:

- Mean No. of *S. frugiperda* larvae/100 plants.
- Maize grain yield (t /feddan).

Maize grain yield losses and percentage of quantitative loss according to the following equations: (Nutter *et al*., 1993 and Savary and Willocquet, 2014)

- Yield loss (t/feddan) = Highest potential yield – actual yield of a treatment
- Quantitative loss (%) = Highest potential yield – yield of a treatment /Highest potential yield× 100

2.2. Economic evaluation

In order to determine the most profitable insecticidal treatments to be followed by the growers (Thimmiah and Kulkarni, 1974); gross income, total cost/feddan, net benefit, and net benefit/total cost were calculated on the maize crop for two experimental seasons; 2021 and 2022.

2.3. Calculation of *S. frugiperda* voltinism

Voltinism of *S. frugiperda* on maize growth period from May 1st to November 30th, were calculated according to Dahi *et al.* (2020) using a lower threshold temperature (T0) of 12.49 °C with a 527.3 degree day's unit (D.D.U) for estimating the possible voltinism per year in the field under normal conditions, the two following formulas were utilized: When T min is lower than (T0) 12.49 °C, the following equation is used:

$$DDU= (T_{max} – T_0)^2 / 2 (T_{max} - T_{min})$$

When T min is higher than (T0) 12.49 °C, the following equation is used:

$$DDU= (T_{max} + T_{min}) / 2 – T_0$$

DDU was calculated according to the abovementioned formulas by employing the maximum and minimum temperatures as collected from NASA Power for the West Nubaria region (30.90 latitude and 29.96 longitude) during 2021 and 2022 seasons.

2.4. Statistical analysis

The expected maize grain yield/feddan was calculated using the equation: $\hat{Y}= a \pm bx$ (Golden, 1960): where, $\hat{Y}$ = expected yield, a = intercept, b = slope of the regression line and x = mean No. of *S. frugiperda* larvae/100 plants. Data were examined using the statistical package for the social sciences (SPSS, 2006) system. The least significant differences (LSD) at the 5% level were calculated to statistically compare the mean values in each column.

3. Results and Discussion

3.1. Effect of insecticidal treatments on *S. frugiperda* larval population and maize yield

Data presented in Table (1) and Figure (1) pointed out that spraying maize with a sequence of methomyl, emamectin benzoate and methomyl induced the lowest mean number of *S. frugiperda* larvae (3.00±0.41 and 5.00±0.41 /100 plants) in 2021 and 2022 seasons, respectively. This treatment achieved the highest grain yield (4.249±0.02 and 3.416±0.03 t/feddan) in 1st and 2nd seasons, respectively. The treatment of methomyl followed by the single treatment of emamectin benzoate came in the second rank, followed by single treatment of methomyl, while the untreated check gave the highest mean number of *S. frugiperda* larvae (80.00±1.96 and 81.25 ±2.87 /100 plants) and the lowest grain yields (0.945±0.09 and 0.721±0.06 t/feddan) during the two seasons, respectively. These results could be attributed to the inversely relationship between *S. frugiperda* larval population and maize grain yield. Additionally, the coefficients (R^2 = 0.996 and 0.991) and regression coefficients (b=-0.04 and -0.04) in the 1st and 2nd seasons were consecutively significant (Fig 1). Losses, due to attacks of *S. frugiperda*, in maize yield were estimated by Lima *et al* (2010) as 43%. Also, Bakry and Abdel-Baky (2023) indicated that the great damage of *S. frugiperda* occurred to maize plants at the third week of June (in Egypt) up to harvest, and the damaged plants ranged between 60 and 68%.

The findings of the current research are in agreement with Cerda *et al.* (2017) who calculated yield losses by comparing actual yields of specific treatments with the estimated attainable yield obtained in plots which had complete chemical protection. Results showed that pest attacks led to high primary yield losses. Salem *et al. (*2021) reported that the fall armyworm, *S. frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) cause severe damage to maize and other crops. However, the late detection of infestations may result in irreversible damage (Rwomushana *et al.*, 2017).

Table 1. Seasonal average number of *Spodoptera frugiperda* larvae and maize grain yield under different chemical treatments

Treatment	1st season (2021)		2nd season (2022)	
	Mean No. of *S. frugiperda* larvae /100 plant± SE*	**Maize grain yield (t/feddan) ±SE***	**Mean No. of *S. frugiperda* larvae /100 plant± SE***	**Maize grain yield (t/feddan) ±SE***
methomyl → emamectin benzoate → methomyl	3.00±0.41d**	4.249±0.02a**	5.00±0.41d**	3.416±0.03a**
methomyl → emamectin benzoate	11.50±1.55c	3.969±0.03b	13.50±2.53c	3.241±0.06b
methomyl	40.00±0.91b	2.541±0.01c	41.00±1.22b	2.324±0.07c
Untreated check	80.00±1.96a	0.945±0.09d	81.25±2.87a	0.721±0.06d

*SE = Standard Error

**In a column,Means with the same letters are not significantly different at 0.05 probability level.

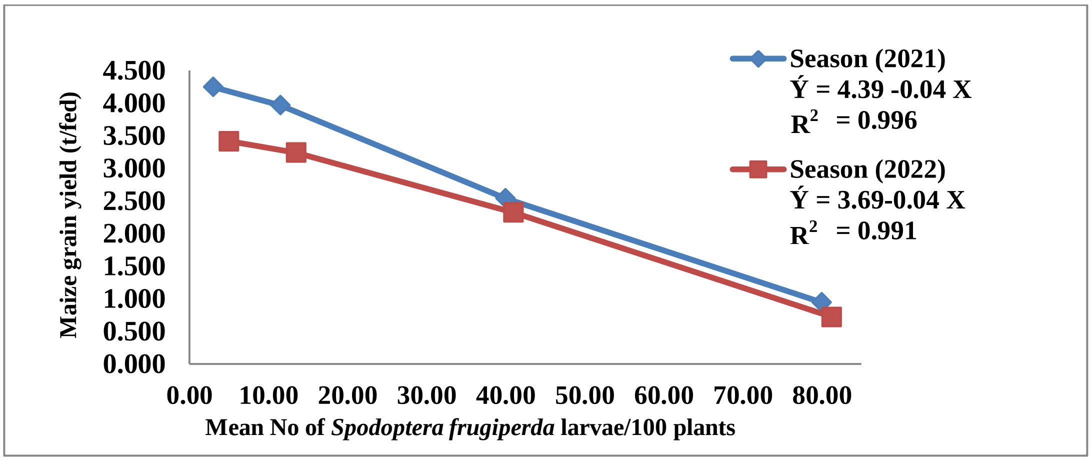

Fig. 1. Relationship between mean No. of *Spodoptera frugiperda* larvae and maize grain yield

3.2. Effect of insecticidal treatments in reducing losses of maize yield

It was found that the trinary schedule of methomyl, emamectin benzoate and methomyl gave the optimum maize yield, which means, hypothetically, without any yield loss (4.249±0.02 and 3.416±0.03 t/fed) in the first and second seasons, respectively (Table 2). Compared to the trinary schedule (Table 2), the binary schedule (methomyl followed by emamectin benzoate) resulted in losses of 0.280 and 0.175 t/fed, and quantitative losses of 6.59 and 5.12% in the first and second seasons, respectively. The quantitative losses in methomyl treatment were 40.20 and 31.97% in the first and second seasons, respectively.

However, the highest quantitative yield losses occurred with the untreated check with values of 77.76 and 78.89% in the first and second seasons, respectively.

3.3. Variable maize costs

Variable costs of one maize feddan were calculated, taken into the consideration the schedule of insecticidal treatments (Table 3). The highest costs (16,780 and 18,750 L.E/fed) were calculated under the trinary treatment, followed by the binary one (16,600 and 18,540 L.E/ fed) and then the single insecticidal treatment (16,430 and 18,310 L.E/fed). However, the untreated check exhibited the least variable costs (16,250 and 18,100 L.E/fed) in 2021 and 2022 seasons, respectively.

3.4. Economics of maize production

Calculations presented in Table (4) show the economics of production of one maize feddan under different insecticidal schedules against *S. frugiperda*. The trinary schedule (methomyl, emamectin benzoate and methomyl) produced the highest gross income, total costs and net benefit with values of 25,494, 16,780 and 8,714 L.E/feddan, respectively. The second rank was occupied by the binary schedule (methomyl and emamectin benzoate), while the third rank was that of single treatment (only methomyl). However, the untreated check gave the lowest values of the abovementioned criteria in both seasons. The net benefits were only profitable under trinary schedule (8,714 and 8,578) and under binary schedule (7,214 and 7,388) L.E/ fedin the first and second season, respectively. In addition, from the economic point of view, the investment ratios were 0.519 and 0.457% for the trinary schedule and 0.435 and 0.398% for the binary schedule in the first and second seasons, respectively. Thus, it is concluded that the investment values in case of a single insecticidal treatment and the check were not profitable.

Table 2. Maize grain yield, yield loss and percentage of quantitative loss due to *Spodoptera frugiperda* infestation

Treatment	1st season (2021)			2nd season (2022)		
	Maize grain yield (t/fed) ± SE*	**Yield loss (t/fed)**	**Quantitative loss %**	**Maize grain yield (t/fed) ± SE***	**Yield loss (t/fed)**	**Quantitative loss %**
methomyl→emamectinbenzoate→methomyl	4.249±0.02a**	0.000	0.00	3.416±0.03a	0.000	0.00
methomyl→emamectin benzoate	3.969±0.03b	0.280	6.59	3.241±0.06b	0.175	5.12
methomyl	2.541±0.01c	1.708	40.20	2.324±0.07c	1.092	31.97
Untreated check	0.945±0.09d	3.304	77.76	0.721±0.06d	2.695	78.89

*SE = Standard Error

** Means with the same letters are not significantly different at 0.05 probability level.

Table 3. Variable costs (1000 L.E) of one maize feddan under different insecticidal sequences against *Spodoptera frugiperda*

	1st season (2021)				2nd season (2022)			
Item	**methomyl→emamectinbenzoate→methomyl**	**methomyl→emamectin benzoate**	**methomyl**	**Untreated check**	**methomyl→emamectinbenzoate→methomyl**	**methomyl→emamectin benzoate**	**methomyl**	**Untreated check**
Land rent	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000
Irrigation	450	450	450	450	450	450	450	450
Seeds	1,000	1,000	1,000	1,000	1,400	1,400	1,400	1,400
Land preparation	1,400	1,400	1,400	1,400	2,000	2,000	2,000	2,000
Fertilizer	2,500	2,500	2,500	2,500	3,000	3,000	3,000	3,000
Energy	400	400	400	400	450	450	450	450
Harvest	2,500	2,500	2,500	2,500	2,800	2,800	2,800	2,800
Insecticides	530	350	180	0,00	650	440	210	0,00
Total	16,780	16,600	16,430	16,250	18,750	18,540	18,310	18,100

Table 4. Economics of one feddan of maize production under schedules of insecticides against *Spodoptera frugiperda*

Treatment	1st season (2021)					2nd season (2022)				
	Maize grain yield (t/fed.)	**Gross income (1000 L.E/fed.) (a)**	**Total costs (1000 L.E/fed.)**	**Net benefit (1000 L.E/fed.)**	**Investment ratio (%) (net benefit / total costs)**	**Maize grain yield (t/fed.)**	**Gross income (1000 L.E/fed.) (b)**	**Total costs (1000 L.E/fed.)**	**Net benefit (1000 L.E/fed.)**	**Investment ratio (%) (net benefit / total costs)**
methomyl→emamectinbenzoate→methomyl	4.249	25,494	16,780	8,714	0.519	3.416	27,328	18,750	8,578	0.457
methomyl→emamectin benzoate	3.969	23,814	16,600	7,214	0.435	3.241	25,928	18,540	7,388	0.398
methomyl	2.541	15,246	16,430	-1,184	-0.072	2.324	18,592	18,310	0,282	0.015
Untreated check	0.945	5,670	16,250	-10,580	-0.651	0.721	5,768	18,100	-12,332	-0.681

Note: The experimental farm of West Nubaria region, El-Behaira Governorate. The cost of Maize grain yield was L.E 6000 on 1st season (**a**) and L.E 8000/ton (**b**) in the 2nd season.

Table 5. Assessment of *Spodoptera frugebirda* voltinism on maize plants

1st season (2021)					2nd season (2022)				
Generation	**Start**	**End**	**Duration (day)**	**Accumulated heat units**	**Generation**	**Start**	**End**	**Duration (day)**	**Accumulated heat units**
1st	1/5/2021	12/6/2021	43	539.75	1st	1/5/2022	13/6/2022	44	529.79
2nd	13/6/2021	17/7/2021	35	541.65	2nd	14/6/2022	19/7/2022	36	540.62
3rd	18/7/2021	17/8/2021	31	541.93	3rd	20/7/2022	21/8/2022	33	543.82
4th	18/8/2021	19/9/2021	33	539.65	4th	22/8/2022	23/9/2022	33	528.45
5th	20/9/2021	30/10/2021	41	531.25	5th	24/9/2022	3/11/2022	41	536.31
6th	31/10/2021	31/11/2021	not completed		6th	4/11/2022	31/11/2022	not completed	

3.4. Voltinism of *S. frugiperda* on maize plants/ growing season

Data in Table (5) indicated that the fall armyworm,*S. frugiperda* had 5 generations on maize plants during the growth period from May 1st to November 30th in 2021 and 2022 seasons. The first generation took the longest period (from 1/5/2021 to 12/6/2021 and from 1/5/2022 to 13/6/2022), with durations of 43 and 44 days in the 2021 and 2022 seasons, respectively. On the other hand, the shortest generation was the third one (from 18/7/2021 to 17/8/2021) with a duration of 31 days in the 1st season. In the 2nd season, the shortest generations were the third and fourth ones (from 20/7/2022 to 21/8/2022 and from 22/8/2022 to 23/9/2022) with duration of 33 days each.

As temperature rises, the generation's number of *S. frugiperda* will increase, So this could be explained by the fact that the low temperature contributed to less *S. frugiperda* infestation and damage, as *S. frugiperda* is known not to survive at periods of extreme or mild cold (Sparks, 1979).

Therefore, farmers should use the recommended insecticides to protect the plants and get a profitable maize yield.

4. Conclusion

Based on the current results, *S. frugiperda* infestation to maize plants proved to be dangerous, resulting in severe reduction in maize yields. So, the growers are strongly recommended to spray a sequence of pesticides, including methomyl 15 days after maize planting, followed by emamectin benzoate 10 days later, and methomyl again 10 days after the second treatment. This trinary schedule proved to be very important to obtain an economic and profitable maize yield, due to the effective control of *S. frugiperda*. The current study also revealed that the fall armyworm has five generations in maize season.

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