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Spodoptera frugiperda in Togo 5 years on: early impact of the invasion and future developments

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Abstract

The infestation of the fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in Africa since 2016 has been a major threat to maize production. Previous studies in Togo and Ghana from 2016 to 2018 did not correlate FAW infestation to yield losses. Thus, the aim of this study which assesses the impact of FAW infestation by inspecting 150 maize farms throughout the five Agro-Ecological Zones (AEZs) of Togo for FAW plant damage, and third instar larvae were used to infest 10-day-old maize plants in netted plots under controlled conditions at an experiment station (Station d'Expérimentations Agronomiques de Lomé) in 2019 and 2020. As control plots at the experiment station, plots were both netted and treated with emamectin benzoate, simply netted, or open to natural infestation. The number of larvae, egg masses, percent damaged plants, and damage proportions of leaves and ears were scored until harvest. Infestations and damages on maize plant throughout Togo were similar between the two years but were higher in the southern part of the county (AEZ5). At the experiment station, the yield losses were significantly considerable and increased from 25% infestation. The losses were 0.37 t ha^{-1} for 25% infestation, 0.34 t ha^{-1} for 30%, 0.59 t ha^{-1} for the open plots, 0.70 t ha^{-1} for simple netted and 50% infestation, 1.03 t ha^{-1} for 75%, and 1.27 t ha^{-1} for 100% infestation. This current study suggested thorough inspection on maize farms to set off management practices from 25% of infestation.

Introduction

Maize (*Zea mays* L.) is one of the most important crops in the world (Bosque-Perez, 1995). Despite efforts to improve its production, poor agronomic practices, pests, and diseases cause maize yield reduction up to 31% worldwide (Oerke, 2006). Insect pests are a dominant component of maize production and impact negatively on yields during production and post-harvest periods. The agricultural regions of the Americas ranging from Argentina to southern Canada have hosted one of the important pests of maize called the fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) (Luginbill, 1928; Clark *et al.*, 2007; Adamczyk *et al.*, 2008; Farias *et al.*, 2008). This noctuid is a destructive pest that caused important economic loss to maize in Brazil (Cruz and Turpin, 1983; Cruz *et al.*, 1999; Diez-Rodrigues and Omoto, 2001; Carvalho *et al.*, 2013; Huang *et al.*, 2014) and is an important yield-limiting pest of maize plants in the southern United States of America (Buntin *et al.*, 2004; Chilcutt *et al.*, 2007; Hardke *et al.*, 2011).

Unfortunately, Africa has been invaded by *S. frugiperda* (Goergen *et al.*, 2016; Nagoshi *et al.*, 2017; 2018; Koffi *et al.*, 2020*a*, 2020*b*) which occur in at least 44 African countries (Prasanna *et al.*, 2018; Rwomushana *et al.*, 2018). The females of this pest lay eggs on the tender tissues of maize plants, hatch about 2.5 d later (Sharanabasappa *et al.*, 2018). The newly hatched larvae disperse within the plant or migrate to adjacent plants by ballooning and then feeding on young leaves (Ali *et al.*, 1989, 1990). The damage on maize leaves reduces the photosynthetic areas and indirectly causes yield losses (Cruz and Turpin, 1983; Pitre and Hogg, 1983; Buntin, 1986; Melo and Silva, 1987; Capinera, 2000; Vilarinho *et al.*, 2011). Moreover, larvae attack all phenological stages of maize (Flanders *et al.*, 2007; Knutson, 2009), from young leaves at plant emergence to ears at harvest time. Plant injury of *S. frugiperda* on maize ears facilitates disease infection of grain causes direct loss of yields (Capinera, 2017). The documented yield losses caused by *S. frugiperda* was estimated up to 72% in Argentina (Murúa *et al.*, 2006), 40% in Honduras (Wyckhuys and O'Neil, 2006), 35% in Zambia, 26.6% in Ghana (Rwomushana *et al.*, 2018), between 21 and 53% in 12 African countries (Abrahams *et al.*, 2017), and 11.57% in Zimbabwe (Baudron *et al.*, 2019). The variations in yield losses can be due to *S. frugiperda* infestation levels, abiotic factors such as heavy rainfall or temperature extremes, biotic factors such as natural enemies, and agronomic and control methods used by farmers. Recent studies in Togo and Ghana from 2016 to 2018 on *S. frugiperda* showed differential infestation among the Agro-Ecological Zones (AEZs) that vary between the southern and northern parts of each country (Koffi *et al*., 2020a). Also, plant infestations from 2016 to 2018 have been reduced due to several factors such as agricultural practices that include insecticide applications, a rise of natural enemies (Koffi *et al*., 2020*a*, 2020*c*).

Since 2018, infestation levels of FAW on maize in Togo are not yet investigated as well as the impact on plant phenological stages and yield losses under different infestation levels. Consequently, this study was conducted in the five AEZs during the cropping seasons of 2019 and 2020 to assess the infestation and damage levels in the countryside and FAW's impact on maize plants and yields in an on-station experiment.

Materials and methods

Study sites

Farm inspections were conducted in different localities of the five AEZs, numbered from one in the north to five in the south. AEZ1 has Sudan Savannah characteristics of tropical grassland and warm temperatures. AEZ2 is characterized by dry savannah with a mix of dry forest and savannah plants. These two AEZs have one rainy season from May to October and one dry season from November to April. AEZ3 is the largest zone in Togo and contains a mix of savannah plants and small wooded forest areas located in mid-eastern Togo. AEZ4 is characterized by a semi-deciduous mountain forest habitat located west of AEZ3. AEZ5 is a mix of small wooded forest and coastal savannah habitats in the south of Togo. The southern three AEZs have two rainy seasons from April to July and September to November, and two dry seasons in August and from December to March. The experiments were conducted at the Station d'Expérimentations Agronomiques de Lomé, Lomé, Togo located in AEZ5 (fig. 1).

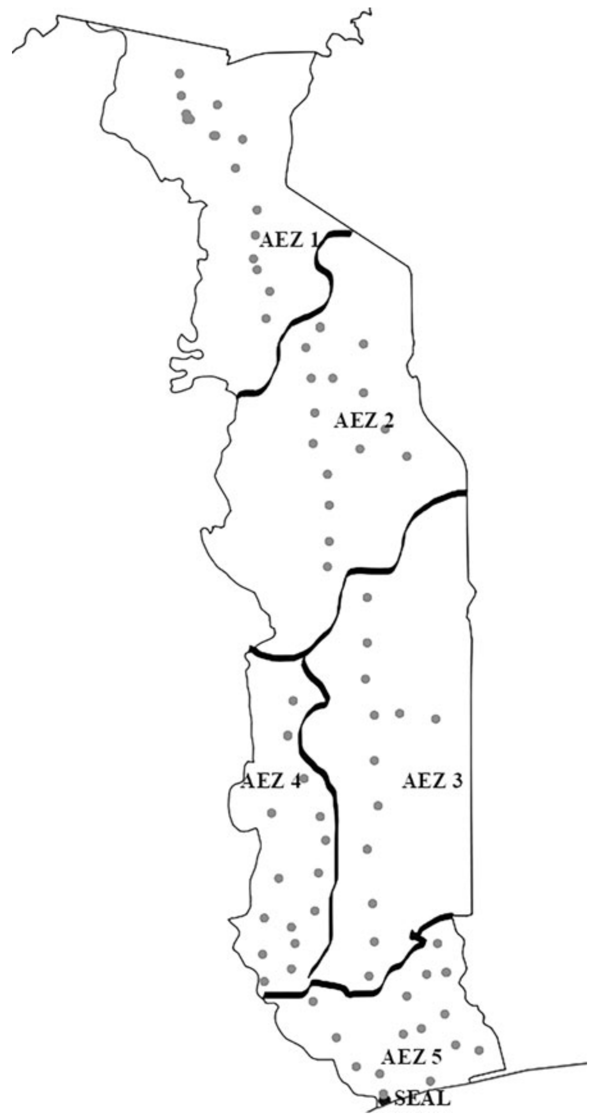

Figure 1. The five Agro-Ecological Zones (AEZs 1–5) of Togo with the location of the sampling sites and Station d'Expérimentations Agronomiques de Lomé (SEAL).

Inspection of maize farms within AEZs

From each AEZ, 15 farms growing maize (variety Ikene) at vegetative stages V_1 to V_{12} leaves were inspected each year, for a total of 150 farms in the 2019 and 2020 seasons. During the two years, farms in AEZs 3, 4 and 5 were inspected in June while those in AEZs 1 and 2 were visited in July. At each farm, all instar larvae and egg masses were collected, and the number of infested and damaged plants by *S. frugiperda* were recorded on inside quadrants designed in the four corners and one in the center of the inspected farm (Koffi *et al*., 2020*a*). The selected plants were distributed as 12 plants per quadrant and carefully examined using forceps and a hand magnifying glass without destroying the standing plants (non-destructive sampling). The larval and egg mass population densities, infestation level, and percentage of damaged plants were then calculated for each farm.

Design and data collection of on-station experiments

The on-station experiments were conducted using eight treatments of five replications on 'Ikene' maize. The treatments included netting artificially infested plots at different levels – 25, 30, 50, 75, and 100%, netting insecticide-treated plots, netting plots without any treatment, and open plots to natural infestation. The 100D, 24 holes per cm^2 nets of 100% polyester (L3.0 × W3.0 × H2.5 m) (Vestergaard Group SA, Vietnam) were locally manufactured for this study. The mesh sizes were small enough that neonate larvae could not pass through and were set with the bottom sealed in the soil before the emergence of maize. At ten days old, plants were artificially infested with 5-day-old third instar larvae by placing them in the whorl of each selected plant. These larvae were previously fed under laboratory conditions with tender maize leaves. The insecticide plots were sprayed with emamectin benzoate (Emacot 019EC™) at 1.5 ml in 1 liter of water at ten days old plants. Treatment plots were arranged in a Latin square design and plots were distanced 2 m apart (fig. 2). The numbers of larvae, egg masses, and damaged plants, leaves and ears were recorded weekly from *in situ* 10 plants per plot to calculate the percent damaged plants, leaves and ears. After harvesting, 10 healthy ears and 10 damaged ears by *S. frugiperda* were selected from each plot and grain (kernels) were separately

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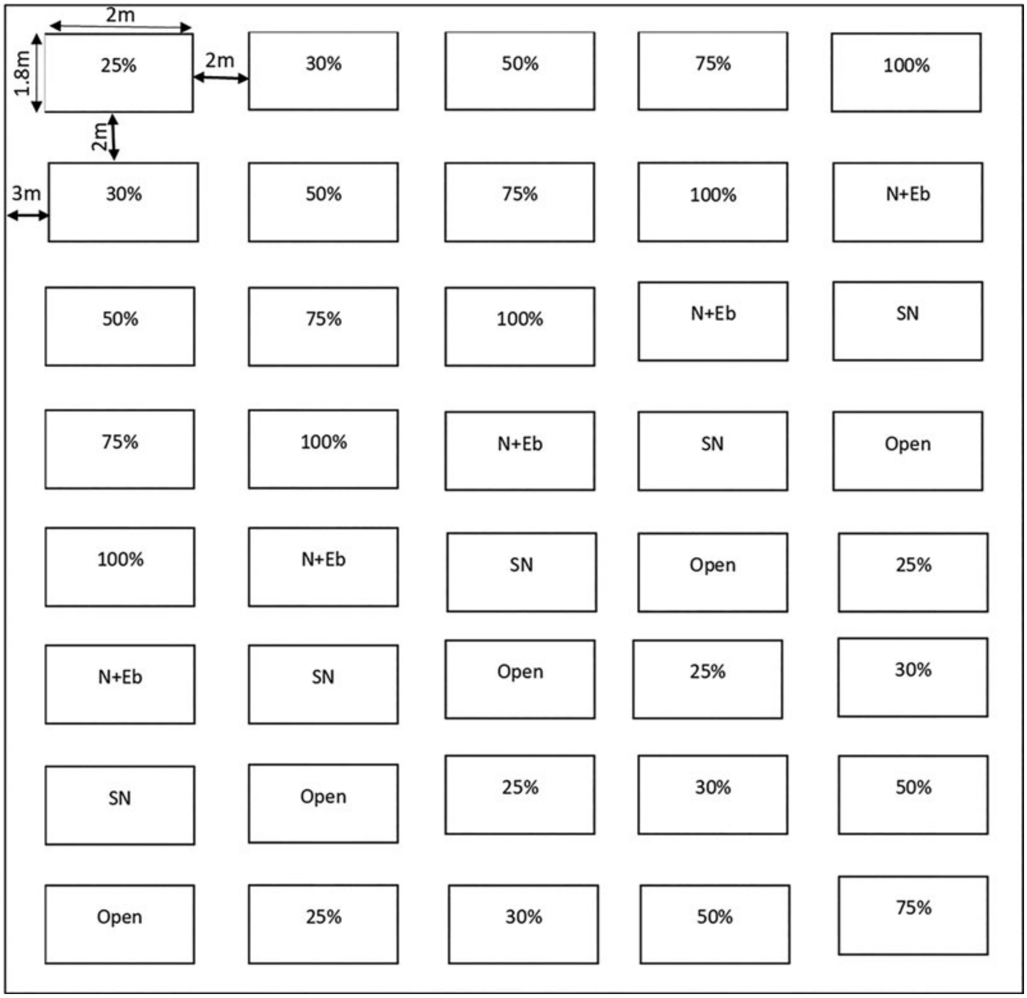

Figure 2. On-station experiment design of netted plots infested to 25, 30, 50, 75, 100% with third instar FAW larvae, netted plot sprayed with emamectin benzoate (N + Eb), simple netted plots (SN), and open plots.

weighted to calculate losses from direct feeding on ears. Total grain in each plot was weighted to determine the yield per treatment, which was extrapolated into area (hectare) based on the density of maize plants within plots.

The densities of larvae and egg masses were calculated by dividing the number of collected larvae or egg masses by the total number of selected plants. Infestation levels were calculated by dividing the number of infested plants by the total number of sampled plants. The percent damaged plants or ears were calculated by dividing the number of damaged plants or ears by the total number of sampled plants or ears. Direct grain losses were determined by subtracting the grain weight from damaged ears from the grain weight from undamaged ears per plot.

Data analysis

For the whole country study, densities of larvae and egg masses and percent damaged plants were calculated for each inspected farm before being grouped into AEZs and years. While calculations of larval and egg masses densities, grain losses, and percent damaged plants were determined for each plot, damage to leaves and ears were calculated for each on-station experiment plot and grouped by infestation treatment. The calculated percentages and infestations were arcsine square root transformed prior to analysis. All calculations and transformations were carried out in Excel. All data were submitted to a Shapiro test in GenStat Twelfth Edition GenStat Procedure Library Release PL20.1 to test for normality. A non-parametric test (Kruskal-Wallis) was performed at the 5% significance level for non-normal data while the normal data were submitted to ANOVA. Means were determined from data subjected to one-way analysis of variance at 95% confident interval. Multiple mean comparisons were separated using Tukey tests while t-tests were used to separate two means in the GenStat software.

Results

Infestation and damage levels across AEZs

The larval and egg mass densities of *S. frugiperda* on maize plants in Togo were similar between 2019 and 2020. The infestations ($18.7 \pm 1.1\%$ and $17.1 \pm 0.87\%$ in 2019 and 2020, respectively; $t_{149} = 0.44$, $P = 0.507$) and percent damaged plants ($16.3 \pm 1.8\%$ and $18.1 \pm 1.7\%$ in 2019 and 2020, respectively; $t_{149} = 1.49$, $P = 0.224$) were also similar between years. Collected larvae from plants were from third instar or older.

Table 1. Larvae and egg densities, infestation levels, and percent of damaged plants on 60 maize plants selected per farm in the five AEZs of Togo during the cropping seasons of 2019 (A) and 2020 (B)

Variable	*N*	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	df	*F*	*P*
Larval density 2019	15	0.09 ± 0.01a	0.12 ± 0.01a	0.13 ± 0.02a	0.26 ± 0.05b	0.25 ± 0.04b	4, 74	7.48	<0.001
Larval density 2020	15	0.10 ± 0.01a	0.12 ± 0.001a	0.14 ± 0.02ab	0.22 ± 0.03bc	0.30 ± 0.03c	4, 74	13.93	<0.001
Egg density 2019	15	0.00a	0.00a	0.00a	0.02 ± 0.01a	0.01 ± 0.01	4, 74	1.36	0.225
Egg density 2020	15	0.00a	0.01 ± 0.00a	0.01 ± 0.00a	0.01 ± 0.01a	0.02 ± 0.01a	4, 74	1.21	0.315
Infestation 2019	15	9.13 ± 2.17a	14.20 ± 1.66a	13.07 ± 3.06a	13.00 ± 1.36a	24.00 ± 2.15b	4, 74	14.16	<0.001
Infestation 2020	15	13.33 ± 0.83a	16.13 ± 1.86a	16.40 ± 1.55a	17.07 ± 1.03a	22.67 ± 2.98b	4, 74	14.99	<0.001
% Damaged plants 2019	15	8.78 ± 2.44a	16.00 ± 3.99a	12.44 ± 2.87a	8.33 ± 1.42a	35.89 ± 3.74b	4, 74	14.18	<0.001
% Damaged plants 2020	15	9.33 ± 1.34a	13.00 ± 0.96a	15.78 ± 2.09a	16.78 ± 5.53a	35.78 ± 2.92b	4, 74	9.93	<0.001

Means within each variable followed by the same letter are not significantly different ($P > 0.05$). Z-Agro-Ecological Zone followed by the mean number attributed to the zone in Togo.

Generally, larval densities, infestation levels, and percent damaged plants were higher in AEZ5 than the other AEZs during the cropping seasons of 2019 and 2020. Egg masses were rarely found, leading to similarities among AEZs (Table 1). No egg masses were found in AEZ1-3; only one egg mass was found in AEZ4, and two masses in AEZ5. The mean numbers of larvae on 60 maize plants within AEZ1 were nine in 2019 and 10 in 2020, AEZ2 were 12 in the two years, AEZ3 were 13 in 2019 and 14 in 2020, AEZ4 were 22 in 2019 and 25 in 2020, AEZ5 were 22 in 2019 and 30 in 2020. The infestation levels were low in AEZ1 to AEZ4 during the two years, ranging between 9 and 17%, while the infestations were higher in AEZ5 (24%). Percent damaged plants from 9 to 17% were recorded in AEZ1-4, and increased to 35% in AEZ5 (Table 1).

Impacts on maize plants and yields

A success artificial infestation was observed during this study with larval densities in plots following the infestation patterns. High densities were recorded in high infested plots and low densities in low infested plots (Table 2). The netted plots which were sprayed with Emamectin benzoate and simple netting plots surprisingly hosted larvae but with different densities. Larval density was slightly lower in treated plots than the simple netted plots (Table 2), whereas larval density in open plots was similar to densities from plots artificially infested at 30 and 50%. Egg masses were rarely found, therefore, egg mass densities were similar among all eight treatments. The percent damaged plants and leaves followed the infestation pattern. Unless in plots infested at 30 and 50% where similarities were observed, the percent damaged plants and leaves were high in high infested plots and low in low infested plots. However, the open plots which recorded similar larval density to the 30 and 50% infested plots recorded percent damaged plants similar to the 75% infested plots, and percent damaged leaves slightly higher than the 30 to 50% artificial infestations. The percent damaged plants in the simply netted plots were similar to those in the 30 and 50% infestation plots. The insecticide-treated plots recorded low percent damaged plants.

Larval densities recorded on ears were similar among the artificially infested plots. Densities were low in the simply netted plots, very low in open plots, and were rare in the netting insecticide plots. In contrast, the percent damaged ears were similar between plots of simply netted, 30 and 50% infestations, then became high in plots of 75 and 100% infestations which were similar. Except from the insecticide-treated plots, the open plots recorded lower percent damaged ears than other netted plots.

The higher the infestations, the lower were the yields, with the yield from open plots similar to yields from the simply netted and 50% infested plots. A slightly higher yield was observed from the treated plots than other plots. Direct grain losses due to FAW feeding on ears were high in open plots and in plots with more than 30% infestations. But the lowest grain loss was recorded from the insecticide-treated plots. Generally, yield losses due to FAW larval feeding on plants and ears were high in plots infested at 75 and 100%, similar between open plots, simply netted plots and 50% infested plots, which were all slightly higher than recorded in 25 and 30% infested plots. To verify if the infestation levels of plants can affect the size or weight of single maize grain, similarities were observed between weights of 1000 grains sampled from the eight treatments (Table 2).

Severities across maize plant phenology

At the emergence stage of maize plants, with totally plants checked, larvae were rarely collected and observed larvae were younger than the third instar. Ten days post emergence, plants were at V_{4-6} leaves and were artificially infested by 5-day-old larvae. The first adults were observed in netted plots at the beginning of the tasseling stage when plants were at 42 days old. This marked a new generation of FAW under nets. However, egg masses were not found on the nets. The objective of treating the netted plot with emamectin benzoate was to exempt these plots of FAW infestation. However, a few larvae were observed in treated plots during the V_{6-8} stage with slight feeding damage to plants. About 25% of plants were damaged, up to 4 and 15% of leaves were chewed at emergence and at the flowering stages, respectively (Table 3). There were low numbers of larvae in the simply netted plots during the vegetative stages and became rare when plants were at the V_{8-10} stage. But larval density and percent chewed leaves were similar among plant phenological stages in the simple netted plots. However, half of the ears were damaged in these plots (Table 3). In the open plots, larval densities and percent damaged plants were different among phenological stages. About one larva was observed on four examined plants from emergence to V_8 stages. About 30% of plants were

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Table 2. Means of larval and egg mass densities on plants and ears, percent of damaged plants, leaves and ears, yields, grain losses caused by *S. frugiperda* feeding on ears, total yield losses, and weights of 1000 grains recorded from 60 maize plants and ears submitted to different infestation levels and controls

Treatments	T	SN	Open	I25	I30	I50	I75	I100	df	F	P
Larval density on plant	0.01a	0.09ab	0.20bcd	0.14abc	0.21bcd	0.22bcd	0.23cd	0.31d	7, 319	5.91	<0.001
Egg density on plant	0.00a	0.01a	0.01a	0.00a	0.00a	0.00a	0.00a	0.00a	7, 319	0.97	0.456
Damaged plants (%)	16.53a	44.50bc	44.50bc	33.76b	34.51b	43.75b	55.99bc	66.47c	7, 319	9.84	<0.001
Injured leaves (%)	8.44a	20.23b	23.49bc	19.31b	21.00b	19.31b	32.82cd	36.37d	7, 319	10.44	<0.001
Larval density on ear	0.00a	0.22b	0.07a	0.28bc	0.32bc	0.29bc	0.40c	0.40c	7, 319	11.29	<0.001
Damaged ears (%)	0.04a	55.42cd	22.31b	49.71c	61.70cd	66.27cd	70.84d	71.98d	7, 319	48.36	<0.001
Yields (t ha^{-1})	*2.55c	1.85abc	1.96abc	2.18bc	2.11bc	1.85abc	1.52ab	1.28a	7, 39	4.82	<0.001
Grain losses (t ha^{-1})	0.05a	0.26ab	1.58c	0.42ab	0.49ab	0.69bc	0.99bc	1.72c	7, 39	3.23	<0.001
Yield losses (t ha^{-1})	*	0.70ab	0.59ab	0.37a	0.34a	0.70ab	1.03bc	1.27c	7, 39	4.82	<0.001
1000 grains (kg)	0.26a	0.23a	0.25a	0.22a	0.25a	0.24a	0.22a	0.21a	7, 39	0.58	0.773

Treatment means within each variable followed by the same letter are not significantly different ($P > 0.05$).
*Baseline yield used to calculate yield losses. Treatments: T – treated, SN – simple netted, I25 – 25% infestation, I30 – 30% infestation, I50 – 50% infestation, I75 – 75% infestation, and I100 – 100% infestation.

damaged during the emergence, flowering and ear stages, and higher than 50% during vegetative stages. Between 20 and 30% of leaves were injured during the vegetative stages, this decreased to 12% when plants aged during the flowering stage in the open plots (Table 3).

Before artificial infestation of plots, larvae were rarely found in the plots until plants reached 10 days old, which resulted in very low larval density during maize plant emergence. After artificial infestation, larval densities followed the expected increasing trends, although plants that had been naturally infested resulted in higher than expected densities from the AEZ5. Plots of 25, 30 and 50% infested plants resulted in slightly higher larval densities (0.31, 0.44 and 0.58, respectively) of $V_{4–6}$ leaves than the expected densities (0.25, 0.3 and 0.5, respectively). Whereas, plots of 75 and 100% infested plants resulted in lower densities (0.63 and 0.74, respectively) during the $V_{4–6}$ stage than expected (0.75 and 1.00, respectively). The highest percent of damaged plants and chewed leaves was recorded during the vegetative stages in the artificially infested plots.

Discussion

Infestations of *S. frugiperda* on maize in Togo observed during this study suggest population stability across the country. The larval and egg mass densities, infestations, and percent damage plants were low and similar between 2019 and 2020 as observed in 2018 (Koffi *et al*., 2020*a*). The infestations 14.7% (2019) and 17.1% (2020), are closer to the 15.7% infestation reported in 2018 by Koffi *et al*. (2020*a*). They were four times lower than the 70.8 and 67.8% infestations recorded early years after the invasion in 2016 and 2017, respectively (Koffi *et al*., 2020*a*). This suggests that the invasion of *S. frugiperda* in Togo has stabilized since 2018. The stabilization of densities observed in Togo does not completely explain the economic impact of the infestation. Thus, the importance of assessing different artificial infestations under human control can clarify the impacts on maize plants and yields.

The artificially infested plots compared with the open plots show some concordance between the open plots and 50% infested plots. They recorded similarities in larval density (open = 0.20; 50% infestation = 0.22), percent damaged plants (open = 44.50%; 50% infestation = 43.75%), percent damaged leaves (open = 23.49; 50% infestation = 19.31%), and yields (open = 1.96 t ha^{-1}; 50% infestation = 1.85 t ha^{-1}). However, during 2019 and 2020 the national infestation was about three times lower than 50% infestation, which shared similarities with the open plots at the station. This suggests that other factors such as other insect species, free movement and migration may impact our parameters for the open plots. The higher densities than the expected observed in some infested plots during the early stages of maize plants should due to possible accidental introduction into netted plots or emergence of adults from the soil. From the $V_{6–8}$ stage of maize plants, the larvae used to infest plots began to pupate reducing then larval densities plant damage in the next stages ($V_{8–12}$). From the $V_{8–10}$ stage, plant tissues become hard and therefore unsuitable for larvae which limited food for newly hatched larvae and favored higher mortality (Williams *et al*., 1998). During the tasseling stage, the new generation of *S. frugiperda* emerged in the netted plots. This coincided with the emergence of tassels and ears which maintained a low larval population. Even though females have a high oviposition capacity and high hatching rate of eggs (Sparks, 1979), these poor nutritional conditions reduced larval density and kept the population at a lower level compared

Table 3. Means (±SE) of larval densities, percent damage plants and leaves on maize plants from emergence to ears in plots treated with Emamectin benzoate, simple netting, control or open for natural infestation, and artificial infestation plants by third instar larvae of *S. frugiperda* at 25, 30, 50, 75 and 100% levels

Maize stages	Emergence	$V_{4–6}$	$V_{6–8}$	$V_{8–10}$	$V_{10–12}$	Tasseling	Ear	df	F	P
Treated plots										
Larval densities	0.00a	0.00a	0.04 ± 0.01a	0.00a	0.00a	0.00a	0.00a	6, 64	1.56	0.176
Damaged plants (%)	26.00 ± 6.84d	8.00 ± 4.84ab	6.00 ± 6.84ab	14.00 ± 6.84bc	20.00 ± 6.84cd	25.00 ± 4.84d	0.00a	6, 64	7.01	<0.001
Injured leaves (%)	4.02 ± 2.84a	4.11 ± 2.84a	2.67 ± 4.02a	3.56 ± 4.02a	7.64 ± 4.02a	14.67 ± 2.84b	*	6, 39	3.51	0.012
Simple netted plots										
Larval densities	0.04 ± 0.14a	0.05 ± 0.10a	0.02 ± 0.14a	0.00a	0.04 ± 0.14a	0.09 ± 1.10a	0.25 ± 0.064a	6, 64	1.53	0.185
Damaged plants (%)	12.00 ± 13.98a	41.00 ± 9.88b	70.00 ± 13.98c	50.00 ± 13.98b	62.00 ± 13.98c	40.00 ± 13.98b	54.40 ± 6.25bc	6, 64	2.56	0.029
Injured leaves (%)	5.60 ± 7.74a	28.29 ± 5.48a	30.22 ± 7.75a	15.11 ± 7.75a	15.64 ± 7.75a	19.33 ± 5.48a	*	6, 39	1.98	0.107
Open plots										
Larval densities	0.24 ± 0.08ab	0.38 ± 0.06b	0.22 ± 0.08ab	0.18 ± 0.08ab	0.16 ± 0.08ab	0.00a	0.10 ± 0.04	6, 64	4.07	0.002
Damaged plants (%)	34.00 ± 12.10	51.00 ± 8.56	56.00 ± 12.10	68.00 ± 12.10	50.00 ± 12.10	23.00 ± 8.56	28.80 ± 5.41	6, 64	2.27	0.049
Injured leaves (%)	21.60 ± 6.86a	36.06 ± 4.85a	23.56 ± 6.86a	28.44 ± 6.86a	18.18 ± 6.86a	12.00 ± 4.85a	*	6, 39	2.30	0.067
25% infested plots										
Larval densities	0.04 ± 008a	0.31 ± 0.55	0.22 ± 0.07b	0.04 ± 0.78a	0.04 ± 0.08a	0.06 ± 0.06a	0.26 ± 0.04b	6, 64	4.13	0.002
Damaged plants (%)	10.00 ± 9.69a	25.00 ± 6.85b	54.00 ± 9.69c	56.00 ± 9.69c	52.00 ± 9.69	24.00 ± 9.69b	56.00 ± 4.33c	6, 64	6.66	<0.001
Injured leaves (%)	7.20 ± 4.28a	23.71 ± 3.03bc	42.22 ± 4.28c	27.11 ± 4.28bc	13.82 ± 4.28ab	8.33 ± 3.03a	*	6, 39	7.63	<0.001
30% infested plots										
Larval densities	0.04 ± 0.10a	0.44 ± 0.70c	0.30 ± 0.10bc	0.06 ± 0.10a	0.32 ± 0.04bc	0.07 ± 0.07a	0.33 ± 0.04bc	6, 64	4.29	0.001
Damaged plants (%)	14.00 ± 7.34a	30.00 ± 5.22ab	56.00 ± 7.38b	58.00 ± 7.38bc	50.00 ± 7.38b	19.00 ± 5.22a	68.00 ± 3.30c	6, 64	14.04	<0.001
Injured leaves (%)	22.18 ± 4.53b	23.77 ± 3.20b	35.11 ± 4.53c	33.33 ± 4.53c	22.18 ± 4.53b	10.50 ± 3.20a	*	6, 39	5.80	<0.001
50% infested plots										
Larval densities	0.00a	0.58 ± 0.06c	0.32 ± 0.08b	0.06 ± 0.08a	0.04 ± 0.08a	0.09 ± 0.06a	0.28 ± 004ab	6, 64	10.71	<0.001
Damaged plants (%)	6.00 ± 10.07a	44.00 ± 7.12bc	76.00 ± 10.07d	60.00 ± 10.07c	62.00 ± 10.07c	29.00 ± 7.12b	73.60 ± 4.50cd	6, 64	14.18	<0.001
Injured leaves (%)	3.20 ± 4.13a	17.17 ± 2.92b	44.90 ± 4.13cd	32.44 ± 4.13c	14.91 ± 4.13b	12.33 ± 2.92b	*	6, 39	16.33	<0.001
75% infested plots										
Larval densities	0.00a	0.63 ± 0.07c	0.38 ± 0.10b	0.08 ± 0.10a	0.06 ± 0.10a	0.04 ± 0.07a	0.41bc	6, 64	11.02	<0.001
Damaged plants (%)	4.00 ± 9.69a	54.00 ± 6.85c	92.00 ± 9.69d	88.00 ± 9.69d	68.00 ± 9.69c	44.00 ± 6.85b	80.80 ± 4.33cd	6, 64	18.67	<0.001
Injured leaves (%)	4.00 ± 7.32a	44.91 ± 5.17bc	61.33 ± 7.32c	54.67 ± 67c	21.46 ± 7.32ab	15.67 ± 5.17a	*	6, 39	20.17	<0.001

100% infested plots										
Larval densities	0.10 ± 0.08a	0.74 ± 0.06c	0.54 ± 0.09c	0.02 ± 0.09a	0.16 ± 0.09a	0.07 ± 0.06a	0.31 ± 0.04b	6, 64	15.53	<0.001
Damaged plants (%)	16.00 ± 9.12a	61.00 ± 6.45bc	94.00 ± 9.12	100 ± 9.12d	88.00 ± 9.12cd	56.00 ± 6.45b	82.40 ± .08c	6, 64	13.73	<0.001
Injured leaves (%)	15.20 ± 8.18a	54.06 ± 5.78c	58.67 ± 8.18c	38.22 ± 8.18ab	26.18 ± 8.18a	22.33 ± 5.78a	*	6, 39	6.08	<0.001

Means in the same row followed by the same letter are not significantly different ($P > 0.05$).
*No data, % Percentage, V-vegetative stage indexed by the numbers of maize leaves.

to the initial larval density used to infest plots. However, due to the hardness of tissues, the few surviving larvae moved from plant to plant and induced higher percent damaged ears in netted plots than the open plots, where adults were able to locate other suitable plants for their neonates. However, the ears in the open plots were exposed to other biotic factors such as ear borers (Pyralidae) and insect and avian predators, and the direct grain losses became higher as they were in the 100% infested plots. This decreased yield in the open plots was similar to the level found with the 50% infestation plots. The infestation in the open plots were approximatively 20%, and it was expected to yield higher grains than the plots from 25 and 30%. Unfortunately, a lower yield was recorded and these losses can be attributed to other unmeasurable factors. This suggests that yield loss of maize in Togo is not only due to *S. frugiperda* but also other factors that need to be determined. On other hand, yield losses that were much similar to the yield obtained from sprayed plots were found in the 25 and 30% infested plots, which suggests that the economic threshold is reached above 30% infestation.

Practically, farmers need careful observation of maize farms from the emergence of plants to start control measures once infestation reaches 30% to save economic losses. This must be combined with the assumption that 10 day-old larvae generally are fourth instars or less and are susceptible to insecticides and natural enemies (Cruz, 1995; Cruz *et al*., 2012). One management tactic is the use of sex pheromone trapping where insecticides are applied after the collection of 3 males moths and the larval population is less than 10 d old (Cruz, 2008). In absence of control methods, high infestations cause serious damage to leaves (Cruz and Turpin, 1983; Harrison, 1986; Melo and Silva, 1987; Bokonon-Ganta *et al*., 2003; Siebert *et al*., 2008). This reduction in leaf area affects photosynthesis (Cruz and Turpin, 1983; Pitre and Hogg, 1983; Buntin, 1986; Melo and Silva, 1987; Capinera, 2000; Vilarinho *et al*., 2011), and favors yield reduction.

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