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Research

Pest Management

Maize Infestation of Fall Armyworm (Lepidoptera: Noctuidae) Within Agro-Ecological Zones of Togo and Ghana in West Africa 3 Yr After Its Invasion

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Abstract

The fall armyworm *Spodoptera frugiperda* (J. E. Smith) invaded several West African countries in 2016 causing severe injury to maize plants and economic damage. This study assesses variations in the occurrence of this species in different Agro-Ecological Zones (AEZs) in Togo and Ghana during the 3 yr following its discovery. The surveys were conducted on 120 farms in Togo and 94 farms in Ghana by collecting larvae from 200 maize plants per hectare. Infestation levels were 68.46% in 2016, 55.82% in 2017, and 17.76% in 2018. The number of larvae recorded per hectare and infestation levels were higher in Togo than in Ghana. The lowest number of collected larvae and infestation levels of *S. frugiperda* were in 2018, compared to the other 2 yr. Larvae per hectare and the infestation level varied regionally inside the two countries. The southern part of Togo (AEZ five) contained higher numbers of larvae and higher infestation levels during the 2 yr following the invasion of the pest. We concluded that infestation levels of *S. frugiperda* are much lower in 2018 than the two previous years and it is therefore necessary to determine the factors that affect the population dynamics of *S. frugiperda* in the field, which is a perquisite for developing management interventions.

Key words: fall armyworm, Agro-Ecological Zone, distribution pattern, infestation, maize

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is a destructive insect pest that feeds on 353 host plants in 76 families with the most agriculturally important found in Poaceae (106), Asteraceae (31), and Fabaceae (31) (Luginbill 1928, Pogue 2002, Capinera 2017, Montezano et al. 2018). Fall armyworm was known to occur only in the Americas, but a surprise occurrence was observed in 2016 in several West African countries and it has since become established, resulting in severe outbreaks with significant feeding damage on maize farms (Nagoshi et al. 2017). Since its invasion, *S. frugiperda* is viewed as one of the most destructive pests for African agriculture, which is already difficult due to droughts, poor soil fertility, poor maintenances, and pests and diseases (Ruttan 2005). It was estimated that 13.5 million tons of maize valued at US$3 billion were at risk in sub-Saharan Africa during the 2017–2018 maize production season (CABI 2017). *Spodoptera frugiperda* caused maize losses between 8 and 21 million tons per year in 12 African countries, valued up to US$6.1 billion, and affected over 300 million people in Africa (Midega et al. 2018).

In West Africa, fall armyworm was reported in 2016 from Benin, Ghana, Guinea-Bissau, Mali, Niger, Nigeria, São Tomé and Príncipe, Senegal, Sierra Leone, and Togo (Goergen et al. 2016; Abrahams et al. 2017; Cock et al. 2017; FAO 2017; IPPC 2017; Nagoshi et al. 2017, 2018; EPPO 2018), in 2017 from Burkina Faso (IPPC, 2017, EPPO 2018), and in 2018 from Cote d'Ivoire (EPPO 2018, FAO 2018) and Liberia (EPPO 2018, FAO 2018, IPPC 2018). In Ghana, the recent average maize loss was reported to be 26.6% extrapolated to an annual value of US$177 million, which was much lower than the loss in 2017 (Rwomushana et al. 2018). Information from Togo is not yet available.

The current study was conducted to compare fall armyworm larval numbers and infestation levels from five Agro-Ecological Zones (AEZs) of Togo and six AEZs of Ghana during the 3 yr following the invasion of this pest in these West African countries. The objectives are to determine if fall armyworm infestation levels in maize are continuing to increase since its invasion, and if certain areas of each country have higher maize infestation.

Materials and Methods

Study Sites

Sampling was conducted during three consecutive years (2016–2018) in different localities of the six AEZs of Ghana and the five AEZs of Togo (Fig. 1). The AEZs in Ghana from north to south are: the Sudan Savannah (SS) which consists of a tropical grassland and warm temperatures; the Guinea Savannah (GS) contains a mix of tropical grassland and small trees that shows high variations of temperature and relative humidity; the Transitional Zone (TZ) contains a mix of forest and savannah; the Semi-Deciduous Forest (SDF) contains a mix of small and large trees with moderate temperatures; the Tropical Rain Forest (TRF) contains large forest trees with understory plants; and the Coastal Savannah (CS) in southeastern Ghana has warm temperatures and grasslands (Zindzy 2018). Based on the works of Ern (1979), Brunel (1981), Akpagana and Bouchet (1994), Guelly (1994), the five AEZs of Togo from north to south are: Zone One characterized by the Sudan Savannah; Zone Two which has a mix of dry forest and savannah plants; Zone Three which contains Woody Guinean Savannah; Zone Four which is comprised of a dense and semi-deciduous forest; and Zone Five which is characterized by a mosaic savannah mixed with a relic forest and fallow lands. In Ghana, the SS, GS, and TZ are agriculturally dominated by maize and sorghum production, the SDF and TRF are dominated by fruits and other commercial tree crops (coffee and cocoa), and the CS is dominated by vegetables and rice production. In Togo, AEZ1 and 2 are dominated by maize, sorghum, millet, and cowpea production. AEZ3 is dominated by maize, cowpea, soybean, and yam production. The forest zone, AEZ4, contains tree crops of fruit, coffee, and cocoa production. Finally, AEZ5 is dominated by maize, rice, vegetables, and sugarcane.

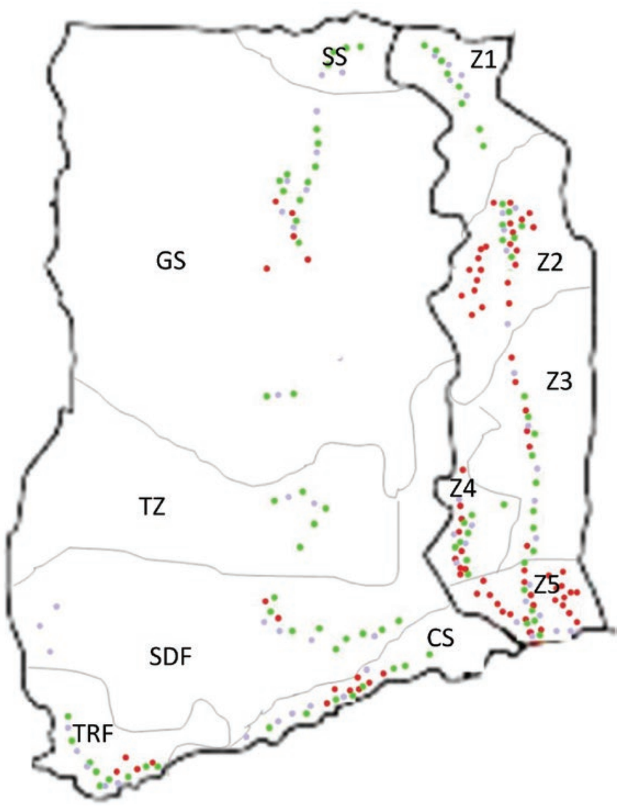

Fig. 1. Maize sites in their AEZs for Ghana (left) and Togo (right). Red dots represent sites visited in 2016, green dots are sites visited in 2017, and gray dots represent the visited sites in 2018. AEZs for Ghana: SS, Sudan Savannah, GS, Guinea Savannah, TZ, Transitional Zone, SDF, Semi-Deciduous Forest, TRF, Tropical Rain Forest, and CS, Coastal Savannah. AEZs for Togo: Z1, Zone One, Z2, Zone Two, Z3, Zone Three, Z4, Zone Four, and Z5, Zone Five.

The two countries have similar climatic conditions to other West African coastline countries that vary from the south to the north. The southern part that includes AEZ3, AEZ4, and AEZ5 in Togo, and TZ, SDF, TRF, and CS in Ghana, has two rainy seasons (April–July and September–November) and two dry seasons (August and December–March). The northern regions with AEZ1 and AEZ2 in Togo, and SS and GS in Ghana, have one rainy season (April–September) and one dry season (October–March). The rainy seasons coincide with cropping seasons in both countries. The average temperature is between 25°C and 30°C with annual rainfall of 1,100–2,400 mm and relative humidity of 85% in the south and 71% in the north.

In Ghana, 18 farms were inspected in 2016, 47 in 2017, and 29 in 2018; in Togo, 61 farms were inspected in 2016, 37 in 2017, and 27 in 2018. No fall armyworm surveys were done in some of the AEZs in 2016 (Table 1).

Sampling Procedures

Fields were inspected during the 3 yr in the cropping seasons that coincided with rainfall from April to July and September to November in the AEZs of CS, TRF, SDF, and TZ in Ghana, and Zones Three, Four, and Five, in Togo. Maize fields in GS and SS in Ghana and Zones One and Two in Togo were sampled from June to September.

About 200 maize plants at vegetative stages V4–V12 were randomly selected per hectare in each maize farm. Forty maize plants were selected in each of the four field corners and in the middle of each field following a 'W' or 'M' plot design. The leaves and leaf whorls of the selected standing maize plants were examined without destroying plants (nondestructive sampling). Forceps were used to open leaves on the stems and leaf whorls to detect the presence of larvae. Small larvae were observed using hand lenses. The farms with small acreage were measured to determine the total area using the Global Positioning System (GPS). Then the quadrants' acreages and the number of maize plants on which data were collected were estimated for those farms. These estimates were used to calculate the size of the farm.

In each field, the number of larvae of all instars collected from the 200 maize plants and the infestation levels were recorded. Maize plants were considered infested when larvae, fresh sawdust-like frass, or fresh larval feeding plant injury were found. Stemborer larvae (Crambidae and Noctuidae) were occasionally found but were not recorded. Fall armyworm larvae collected were reared in the laboratory to adulthood using the procedures of Koffi et al. (2020). To ascertain that the insect samples collected were *S. frugiperda*, feeding injury characteristics of the leaf whorls and morphological characteristics of the larvae were used (Luginbill 1928, Capinera 2000, 2017). Infestation levels per inspected maize farm was calculated using the formula:

$$\%I = \frac{N_i}{N_p} \times 100$$

where I = infestation, N_i = number of infested plants, and N_p = total number of sampled plants.

Table 1. Number of inspected maize farms per AEZ during the 3 yr

Country and AEZ	2016	2017	2018
Ghana			
Sudan Savannah (SS)	0	4	2
Guinea Savannah (GS)	5	12	7
Transitional Zone (TZ)	0	5	2
Semi-Deciduous Forest (SDF)	2	9	7
Tropical Rain Forest (TRF)	4	9	5
Coastal Savannah (CS)	7	8	6
Togo			
Zone 1—Tropical grassland and warm temperature	0	8	5
Zone 2—Dried Forest Mix to Savannah	22	7	5
Zone 3—Woody Guinean Savannah	6	8	5
Zone 4—Dense Semi-Deciduous Forest	9	8	5
Zone 5—Mosaic Savannah of Relic Forest and Fallow	24	6	7

Data Analysis

The infestation level and number of counted larvae per inspected maize farm were recorded for each AEZ during each year and grouped per country. Data were submitted to a Shapiro test with GenStat Twelfth Edition GenStat Procedure Library Release PL20.1 to test for normality. One-way analysis of variance (ANOVA) was applied when the data followed a normal distribution. Otherwise, the numbers of counted larvae were log-transformed and reanalyzed with ANOVA. The calculated infestation levels were arcsine square root transformed prior to ANOVA. A nonparametric test (Kruskal–Wallis) was performed at the 5% significance level in absence of normality after transformation. Tukey tests were conducted to separate multiple mean comparisons while *t*-tests were conducted for two mean separations in GenStat. Pearson correlation analysis (SAS 9.4, SAS Institute 2012, PROC CORR) was used to determine if larval numbers were related to percent infested plants.

Results

Comparison of Populations in Togo and Ghana

In total, 219 maize farms were inspected from the 11 AEZs in Togo and Ghana. The number of larvae from the 200 maize plants per hectare and the infestation levels were similar between the two countries in 2016 but were higher in Togo than Ghana in 2017 (Table 2). In 2018, the numbers of larvae were higher in Togo than Ghana, but infestation levels were similar (Table 2). The cumulative number of larvae and infestation levels for the 3 yr per country showed higher number of larvae in Togo (mean ± SE, 26.26 ± 1.31) than Ghana (17.13 ± 1.50) (t = 20.98; df = 219; P < 0.001). Infestation levels were also significantly higher in Togo (57.97 ± 2.74%) than Ghana (40.66 ± 3.14%) (t = 17.37; df = 219; P < 0.001).

Infestation in Togo

In 3 yr, 125 maize farms were visited throughout Togo. In year-to-year comparisons, larval numbers were lower in 2018 than in 2016 and 2017 (F = 7.98; df = 2, 124; P < 0.001). A difference was also observed with plant infestation among the 3 yr, as 2018 had the lowest number of plants infested by fall armyworm (F = 34.35; df = 2, 124; P < 0.001). There was a significant correlation between larval numbers and percent infested plants across the 3 yr (r = 0.8225, P = 0.0003).

The number of larvae collected were different among the AEZs when analyzing each year separately. In 2016, the highest numbers were recorded from AEZ5 in southern Togo followed by AEZ4 and then AEZ3 and 2 (Table 3, lowercase letters). In 2017, AEZ1 had the fewest number of larvae collected. However, in 2018, there was no difference in the number of larvae found among the AEZs. Analyzing each AEZ by year, farms in the northernmost zone (AEZ1) were not sampled in 2016; however, the number of larvae counted in 2017 and 2018 were not different (Table 3, uppercase letters). AEZs 2 and 3 had higher numbers of larvae in 2017, whereas AEZs 4 and 5 had the lowest numbers of larvae in 2018. Infestation levels of *S. frugiperda* on maize plants were not different among the AEZs in 2016 and 2018, but in 2017, AEZs 5 and 2 had the highest infestation (Table 4, lowercase letters). All AEZs had their lowest infestation levels in 2018. Additionally, AEZ4 had a higher infestation in 2016 than in 2017 (Table 4, uppercase letters).

Infestation in Ghana

In total, 94 maize farms were inspected during the 3 yr. The number of larvae collected was significantly different among years with the lowest in 2018 (F = 19.77; df = 2, 94; P < 0.001). Infestation level was also lower in 2018 than the previous years (F = 21.49; df = 2, 94; P < 0.001). There was a significant correlation between larval numbers and percent infested plants across the 3 yr (r = 0.8734, P < 0.0001).

In 2016 and 2018, number of larvae collected were not different among the AEZs when analyzing each year separately. However, in 2017, the number of larvae were higher in the belt formed by the SDF, GS, and TZ, and lowest in the SS (Table 5, lowercase letters). Within each AEZ, there was no difference in larval numbers among years in the SS and TZ, whereas in all other AEZs, 2018 had the fewest larvae (Table 5, uppercase letters). As with larval numbers, percent infested plants was not different among the AEZs in 2016 and 2018 (Table 6, lowercase letters). In 2017 the SDF, GS, and TZ had the highest infested plant levels, while TRF, CS, and SS had the lowest levels. When plant infestation was analyzed by AEZs separately, the lowest percentage of plants infested by fall armyworm was in 2018 (Table 6, uppercase letters).

Discussion

In late January 2016, infestations in maize of an invasive *Spodoptera* spp. were documented in southwestern Nigeria and later in the season, larvae were found in northern Nigeria (Kano State) (Goergen et al. 2016). In Togo and Ghana *S. frugiperda* quickly dispersed north into all of the AEZs. Reporting was limited and showed little to no differences for the number of larvae collected or infestation levels across AEZs. The expected range expansion of this pest predicted it would be a threat to important crops in Africa since many plant hosts and favorable climatic factors were available (Goergen et al. 2016, Midega et al. 2018). By 2017, the new insect pest was established within the AEZs and across the two countries with high larval populations and infestation levels in AEZ5 in southern Togo and the agricultural area formed by the GS, TZ, and SDF in Ghana. These regions have similar climate and native plant hosts including abundant grasslands (savannas) that support fall armyworm populations year-round. Population differences among AEZs were not observed in 2018 because the overall density of *S. frugiperda* was significantly reduced.

Maize production in these zones is extensive but may not be the major factor that facilitates the high populations observed. Cultural

Table 2. Annual means (± SE) of *S. frugiperda* larvae collected from 200 maize plants per hectare during 3 yr in Togo and Ghana

Country	2016	2017	2018	2016	2017	2018
	Number of larvae			% Infestation		
Togo	29.02 ± 2.52	29.81 ± 1.67	15.19 ± 0.93	70.75 ± 3.70	67.77 ± 4.18	15.67 ± 1.63
Ghana	22.56 ± 4.64	20.32 ± 1.48	8.87 ± 0.88	60.67 ± 6.81	46.41 ± 3.71	19.65 ± 1.55
df	78	83	56	78	83	56
t	1.50	18.06	24.23	2.29	14.48	2.09
P	0.220	<0.001	<0.001	0.140	<0.001	0.090

Table 3. Mean number (± SE) of larvae collected from 200 maize plants per hectare from the five AEZs of Togo

AEZs	2016	2017	2018	df	*F*	*P*
AEZ1		18.00 ± 2.51Aa	20.0 ± 2.61Aa	1, 12	0.33	0.58
AEZ2	15.82 ± 3.77Aa	32.57 ± 2.69Bb	14.8 ± 2.6Aa	2, 33	11.33	<0.001
AEZ3	16.5 ± 7.23Aa	32.38 ± 2.51Bb	13.6 ± 2.61Aa	2, 18	9.43	0.002
AEZ4	28.55 ± 5.9Bb	31.0 ± 2.51Bb	15.0 ± 2.61Aa	2, 22	6.37	0.007
AEZ5	44.42 ± 3.61Bc	37.33 ± 2.9Bb	13.29 ± 2.2Aa	2, 35	5.21	0.011
df	3, 60	4, 36	4, 26			
F	11.13	7.79	1.14			
P	<0.001	<0.001	0.365			

Means followed by the same lowercase letter within columns are not significantly different; means followed by same uppercase letter within rows are not significantly different.

AEZ = Agro-Ecological Zone.

Table 4. Infestation level (± SE) sampled from 200 maize plants per hectare from the five AEZs of Togo

AEZs	2016	2017	2018	df	*F*	*P*
AEZ1		38.0 ± 4.58Ba	22.1 ± 2.5Aa	1, 12	13.96	0.003
AEZ2	63.41 ± 6.42Ba	83.79 ± 4.59Bb	14.9 ± 2.5Aa	2, 33	5.58	0.008
AEZ3	52.92 ± 12.29Ba	75.88 ± 4.29Bab	11.1 ± 2.5Aa	2, 18	10.57	0.001
AEZ4	82.33 ± 10.04Ca	58.69 ± 4.29Ba	14.7 ± 2.5Aa	2, 22	27.93	<0.001
AEZ5	77.6 ± 6.15Ba	90.08 ± 4.95Bb	15.57 ± 2.11Aa	2, 34	10.39	<0.001
df	3, 60	4, 36	4, 26			
F	1.91	13.6	2.51			
P	0.138	<0.001	0.071			

Means followed by the same lowercase letter within columns are not significantly different; means followed by same uppercase letter within rows are not significantly different.

AEZ = Agro-Ecological Zone.

and agronomic practices applied in the different zones or countries, environmental conditions, and natural enemies influence population dynamics. For example, cultural practices such as land clearing and burning to promote early season grass growth for natural pastures are common in the zones in Ghana where high populations were found. In Togo, AEZ5 has intensive agricultural activities year-round with two cropping seasons, plus sugarcane production and off-crop season vegetable production that may maintain the populations of *S. frugiperda* at high levels. Positive abiotic factors such as temperature, humidity, and rainfall improve *S. frugiperda* development and survival (Barfield and Ashley 1987, Simmons 1992, Murúa et al. 2006, Sims 2008, Varella et al. 2015, Garcia et al. 2019). Natural enemies were not collected during the invasive pest year of 2016, but larval collections from 2017 to 2019 in Ghana recorded three species of predators and native species of larval and egg parasitoids (Agboyi et al. 2020, Koffi et al. 2020) that may bring some measure of control.

The 2 yr following the invasion of *S. frugiperda* in Africa recorded high larval populations on maize farms in Togo and Ghana due to farmers and agricultural specialists being unprepared for this pest. Little was known about agricultural practices to manage fall armyworm under African farming systems and conditions; however, governments reacted immediately by purchasing insecticides (Baudron et al. 2019). Rwomushana et al. (2018) reported more farmers used insecticides in Ghana after invasion of the pest, although there has been a major change since a 2017 policy from the Ministry of Food and Agriculture which recommends the use of biopesticides. This policy of low synthetic insecticide use may have caused the numerically higher infestations of *S. frugiperda* in Ghana than Togo in 2018 (15.2% compared to 8.9%, respectively). In Togo, there has not been a policy proposed to limit the application of synthetic insecticides for fall armyworm control.

Since 2018, larval populations and infestation levels have been generally decreasing which may be due to the joint efforts of the governments of several countries, agricultural leaders including farmers and scientists, and natural factors that negatively affected larval populations. As *S. frugiperda* has the potential to affect important economic crops, it is urgent to monitor the spatial and temporary

Table 5. Mean number (± SE) of larvae collected from 200 maize plants per hectare from the five AEZs of Ghana

AEZs	2016	2017	2018	df	*F*	*P*
CS	26.29 ± 3.11Ba	15.13 ± 3.35Bb	6.86 ± 1.35Aa	2, 21	14.86	<0.001
GS	17.6 ± 3.68Ba	24.33 ± 2.73Cc	9.86 ± 1.35Aa	2, 23	7.94	0.003
SDF	32.0 ± 5.81Ba	25.78 ± 3.15Bc	9.0 ± 1.35Aa	2, 17	6.63	0.009
SS	—	5.5 ± 4.73Aa	6.5 ± 2.52Aa	1, 5	0.15	0.718
TRF	17.5 ± 4.11Aa	19.11 ± 3.15Ab	11.4 ± 1.6Aa	2, 17	1.77	0.203
TZ	—	23.2 ± 4.23Abc	8.0 ± 2.52Aa	1, 6	4.7	0.082
df	3, 17	5, 46	5, 29			
F	2.47	3.6	1.26			
P	0.105	0.009	0.314			

Means followed by the same lowercase letter within columns are not significantly different; means followed by same uppercase letter within rows are not significantly different.

AEZ = Agro-Ecological Zone, CS = Coastal Savannah, GS = Guinea Savannah, SDF = Semi Deciduous Forest, SS = Sudan Savannah, TRF = Tropical Rain Forest.

Table 6. Infestation level (± SE) sampled from 200 maize plants per hectare from the five AEZs of Ghana

AEZs	2016	2017	2018	df	*F*	*P*
CS	66.29 ± 6.98Ca	31.0 ± 7.75Ba	14.14 ± 3.71Aa	2, 21	26.03	<0.001
GS	48.2 ± 8.26Ba	65.83 ± 6.33Cc	23.43 ± 3.71Aa	2, 23	7.34	0.004
SDF	85.5 ± 13.06Ca	50.89 ± 7.3Bb	21.07 ± 3.71Aa	2, 17	6.83	0.008
SS	—	37.62 ± 10.96Ba	9.25 ± 6.93Aa	1, 5	21.19	0.010
TRF	54.0 ± 9.23Ba	20.83 ± 7.3Aa	24.3 ± 4.39Aa	2, 17	8.52	0.003
TZ	—	69.5 ± 9.8Bc	19.5 ± 6.93Aa	1, 6	16.82	0.009
df	3, 17	5, 46	5, 29			
F	2.58	6.44	1.47			
P	0.095	<0.001	0.236			

Means followed by the same lowercase letter within columns are not significantly different; means followed by same uppercase letter within rows are not significantly different.

AEZ = Agro-Ecological Zone, CS = Coastal Savannah, GS = Guinea Savannah, SDF = Semi Deciduous Forest, SS = Sudan Savannah, TRF = Tropical Rain Forest.

distributions and environmental limitations that are major factors of population growth, especially in AEZs that provide grasses and crops year-round. Monitoring efforts should include larval sampling (Melo et al. 2006, Farias et al. 2008, Hernández-Mendoza et al. 2008), estimation of plant infestation (Hruska and Gladstone 1988), and collection of males in pheromone-baited traps (Linduska and Harrison 1986, Meagher et al. 2019). This information should provide suitable assistance to farmers on the timing of, and what appropriate management strategies are available.

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