Journal of Integrated Pest Management, (2020) 11(1): 20; 1–7
doi: 10.1093/jipm/pmaa015
Issues

OXFORD

Assessment of impacts of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on maize production in Ghana

Djima Koffi[1,8], Rosina Kyerematen[2], Vincent Y. Eziah[3], Yaa Oguabi Osei-Mensah[4], Kwame Afreh-Nuamah[1], Ebenezer Aboagye[5], Michael Osae[6], Robert L. Meagher[7]

[1]African Regional Postgraduate Programme in Insect Science, University of Ghana, Legon, Accra, Ghana, [2]Department of Animal Biology and Conservation Science, University of Ghana, Legon, Accra, Ghana, [3]Department of Crop Science, University of Ghana, Legon, Accra, Ghana, [4]Department of Agricultural Economics and Agribusiness, University of Ghana, Legon, Accra, Ghana, [5]Plant Protection and Regulatory Service Directory, Ministry of Food and Agriculture, Accra, Ghana, [6]Biotechnology and Nuclear Agriculture Research Institute, Ghana Atomic Energy Commission, Accra, Ghana, [7]USDA-ARS CMAVE, Insect Behavior and Biocontrol Research Unit, Gainesville, Florida, USA, and [8]Corresponding author, email: kdeskos@gmail.com

Received 23 March 2020; Editorial decision 1 July 2020

Abstract

Spodoptera frugiperda was considered an insect pest only in the Americas until its first report in African countries in 2016. In this study, farmers and agricultural officials in Ghana were interviewed on their perceptions and knowledge of the pest, on infestation and maize yield variations across years, and on management practices. Farms were inspected to determine the infestation level of 100 plants per hectare. Interviews revealed that farmers were familiar with the larval stages of this pest and noticed that the pest occurred throughout the year, but populations of *S. frugiperda* increased only during cropping seasons. Infestation levels reported by farmers in surveys were much lower in 2018 (30.38%) than in 2017 (80.92%). Farm inspections confirmed that infestation levels were much lower in 2018 (20.90%) than 2017 (73.70%). The belt formed by Guinea Savannah, Transitional Zone, and Semi-Deciduous Forest Agro-Ecological Zones (AEZs) recorded the highest infestations while the lowest were observed from the Sudan Savannah and Tropical Rain Forest AEZs. Insecticides were the most commonly used tactic to manage populations of this new pest. Maize yields increased across Ghana between 2013 and 2015 from 1.52 to 1.73 t/ha, decreased between 2015 and 2017 to 1.55 t/ha, and increased to 1.69 t/ha in 2018. The impact of fall armyworm injury to maize production is discussed.

Key words: Fall armyworm, perceptions, infestation, management, maize yield.

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith 1797) is a polyphagous species that occurs on over 80 different host plants with maize as the primary host (Luginbill 1928, Capinera 2017). The female moth lays eggs mostly on the young maize leaves or other tender tissues of the plant (Capinera 2017). The newly hatched larvae feed and vertically disperse on the plant or horizontally to adjacent plants (Ali et al. 1989, 1990) leading to high damage on maize farms. The last instar larvae pupate in the soil (Capinera 2000). The emerged moth exhibits high dispersal with long-distance flights overnight (Mitchell et al. 1991, Nagoshi and Meagher 2008) that facilitates wide geographical dispersion in the Americas (Knipling 1980).

Reports of this pest in several African countries in early 2016 (Goergen et al. 2016) represented its first establishment in the Eastern Hemisphere (Nagoshi et al. 2017). The voracious feeding and long-distance flight behaviors exhibited by the fall armyworm indicated a significant threat to African agriculture with the potential for rapid dispersion throughout the hemisphere (Nagoshi et al. 2017, 2018). The Centre for Agriculture and Bioscience International (CABI) estimated from some sub-Saharan African countries that 13.5 million tons of maize or over 20% of total production for the region valued at US$3 billion was at risk from FAW for the 2017–2018 maize production season.

In Ghana, agriculture is one of the largest sectors of the economy, with a high contribution to the nation's Gross Domestic Product (GDP) (ISSER 2010) and employing about 44.7% of the country's labor force of persons older than 15 years in 2015 (MoFA 2016). Although the presence of fall armyworm was recorded in 2016, the general outbreak of the pest was observed at the onset of the cropping season in 2017. The new pest caused significant damage to maize crops whose demand for higher yields increases yearly due to rising populations and urbanization, as well as the growing poultry and fish sectors of the economy. The consumption of maize increased from 38.4 kg in 1980 to 45.0 kg per capita in 2015 (MoFA 2010, 2012, 2016). Maize used for the poultry industry as feed was estimated to have grown by 10% annually between 2000 and 2009 with the possibility to surpass 540,000 million tons (Hurelbrink and Boohene 2011). This new challenge that faces maize production is viewed as a serious threat for the country's food security and has direct implications for the economic outlook of farmers and the nation's GDP. However, farmer's perceptions and management practices, FAW infestation levels, and maize yield losses due to this new pest is not very well known.

To minimize these losses and safeguard the modest gains made in securing the country's food and nutrition security, several actions have been undertaken by both farmers and the Government. This study was therefore carried out to get information from the agricultural community and inspect farms to determine the general status of the pest and its impact on maize production in Ghana.

Materials and Methods

Surveys

The surveys were carried out during the cropping seasons of 2017 (May-July and August-November) and 2018 (July to November) in the six Agro-Ecological Zones (AEZs) of Ghana. The AEZs, from north to south are: the Sudan Savannah (SS) which consists of a tropical grassland and warm temperatures; the Guinea Savannah (GS) which contains a mix of tropical grassland and small trees that shows variation of weather patterns; the Transitional Zone (TZ) which contains a mix of forest and savannah; the Semi-Deciduous Forest (SDF) which contains forest trees that shed leaves seasonally; the Tropical Rain Forest (TRF) which contains large forest trees with little understory plants; and the Coastal Savannah (CS) in southeastern Ghana which has warm temperatures and grasslands (Zindzy 2018). In each AEZ, the interviews and farm inspections were chosen randomly from different localities. Questionnaireswere designed based on previous studies of integrated crop and pest management practices (Dabrowski 1997, Labanowska et al. 2002, Sang et al. 2003, Brown et al. 2008). Farmers who have been producing maize and Agricultural Officers (AO) who have been practicing assistances to farmers during the last six years were individually interviewed. Agricultural officers were interviewed in English on only knowledge of this new pest, while farmers interviews were more thorough on knowledge, infestation, control practices, and yields. Farmers were interviewed in English or in an appropriate local language with the help of the local AO, assistant, or surveyed partner. The interviews of farmers were conducted only on maize variety Obatanpa in the presence of either local AO or family members whose role is to assist in cases of uncertain responses from a repondent.

Interviews

Interviews were conducted in 2017 from May to July and from August to November, and in 2018 from July to November using scripts of questions with gaps that were filled by the authors according to the responses of interviewees. The interviews started with the socio-professional status of the respondents that included their sectors in agriculture, ages, education level, and number of years of service or farming experiences. The knowledge and perceptions of FAW were assessed on the identification of life stages, on year of first appearance, identification of other host plants, seasonal occurrence, infestation levels, period of first infestations on maize, parts of maize plants that are damaged, and the critical period(s) when maize is vulnerable to FAW attack. Pictures of all developmental stages and damage types of FAW were used to assist respondents to confirm the pest. The questionnaires on management practices were based on control methods, control method procedures, material suppliers, and efficacy of methods applied to manage populations. Finally, farmers were asked to document the number of harvested hectares of maize and maize production yields from 2013 to 2018.

Inspection of Farms and Data Collection

After interviews, 10 maize farms of Obatanpa variety per AEZ were inspected each year or a total of 120 maize farms during the two years to assess infestation levels of FAW. Maize plants were considered infested when there was fresh leaf damage or the presence of frass, larvae, or egg masses. In a hectare, 100 maize plants were randomly selected, and carefully examined nondestructively then, the number of infested plants were recorded per farm. Inspections were taken inside four designated plots in each corner and one in the center of each farm (Koffi et al. 2020A). Each plot represented 20% of a hectare in which 25 maize plants were inspected.

Data Analysis

To analyze the information generated from the interviews, the number of people who gave the same or similar answers were put together for each question per AEZ. Percentage values of the number of responses to a specific question were calculated based on the number of total responses. Farmers who did not respond to a particular question were removed from the counts on this question. Maize yields were calculated by dividing the grain weights by the harvested acreage. Infestation levels were all arcsine square root transformed. Yields and infestation levels were grouped per year and AEZ, and then submitted to normality tests using the Shapiro test in GenStat Twelfth Edition GenStat Procedure Library Release PL20.1. One way analysis of variance (ANOVA) was used when data followed a normal distribution (5% significance level). Data that were not normal were logarithmic transformed and the non-parametric test Kruskal-Wallis was performed at the 5% significance level in absence of normality after transformation. Multiple yield and infestation level means were compared using the Tukey test, while comparisons between two yield or infestation level means were separated by Student-Newman-Keuls' significant test.

Results

Demographic of Respondents

The surveys were taken from 259 interviewees in 2017 and 120 in 2018. Most interviews 81.00% (307/379) were with farmers, with the rest 19.00% (72/379) being AOs including Phytosanitary and Extension agents. Four age classes of respondents were recorded – 38% (144/379) were under 25 years, 51% (193/379) were between 25 and 50 years, 10% (38/379) were between 50 and 75 years, and only 1% (4/379) was older than 75 years. About 9% (28/307) of farmers were illiterate, 15% (46/307) completed primary school, 45% (138/307) completed junior secondary school, 29% (89/307) completed senior secondary school, and 2% (6/307) graduated from high school. There was a high number of recent AO recruits, as 47% (34/72) of the AOs had between six and ten years of service and only 15% (11/72) had between 21 and 30 years of service. Only 14% (43/307) of farmers had less than 10 years of farming experience; the majority of farmers had more than 10 years of experience with at least 53% (163/307) of them finishing senior secondary school.

Knowledge and Perceptions of Fall Armyworm

The invasion of FAW came with outbreaks on maize farms and all the interviewees were surprised with the infestation level of this new pest that made them to be rapidly familiarized with the damaging stage (larva) of this pest. Farmers knew that larvae were associated with plant damage, but few farmers (3%, 9/307) knew about the adult stage. Only 13% (9/72) of AOs had observed egg-masses on plants while pupae were unknown by the respondents. However, 65% (200/307) of farmers never observed larvae throughout the year. Larval populations were observed to be increased between May and June and then from September to October, which coincide with the two cropping seasons. Maize was the main host plant where larvae were found, but larvae were also observed occasionally on rice, cowpea, onion, millet, sorghum, tomato, and eggplant reported by 13.6%, 9.21%, 6.18%, 5.79%, 5.41%, 3.86%, 3.46% of respondents, respectively.

This new pest was reported to infest all phenological stages of maize plants. Most farmers (72%, 221/307) identified the vegetative stages of maize as the most critical for FAW infestations, as confirmed by 25% (77/307) of farms who had abandoned a portion or all of their maize production after severe infestations during the vegetative stage. About 68% (209/307)of farmers had observed fall armyworm damage on maize ears and reported that this stage of maize can also be critical because of direct grain losses. When farmers were asked about the infestation situation on their farms taking an example of 10 plants randomly selected, they reported variation on infestations. This assement was based on level of zero to ten (0 - no infestation, 1 & 2 - very low infestation, 3&4 – low infestation, 5&6 – medium infestation, 7&8 – high infestation, and 10 -very high infestation). The infestations were reported to be medium, high, and very high in 2017 by 20%, 56%, and 24% of farmers, respectively. While the infestations were reported to be low in 2018 by all the interviewees.

When farmers were interviewed on the status of 10 plants from their maize farms to assess the infestation levels, it revealed that infestations were higher in 2017 (80.92%) than 2016 (39.08%) and 2018 (30.38%) (F=189.57; df=2, 359; P<0.001). According to the reports from farmers, in 2016, the FAW infestation was rarely observed in SS while the highest infestation was recorded in SDF. Infestations in 2017 stayed lower in SS than other AEZs except TRF, which recorded a similar infestation level as SS. In 2018, infestations were generally low compared to the previous years. However, comparisons among AEZs in 2018 revealed that the SS recorded highest infestation and the TRF the lowest. In 2017, the highest infestation level of fall armyworm on maize plants in all the six AEZs of Ghana was recorded (Table 1).

Management Practices and Inspections of Maize Farms

About 89% (273/307) of interviewed farmers used synthetic insecticides to control the fall armyworm on their maize farms. However, 57% (175/307) of farmers also practiced physical control by hand-killing of larvae, and 3% (9/307) tested pheromone-baited traps to capture adults. In 2017 when infestations were high, 57% (156/273) of farmers started insecticide applications beginning the second week after maize plant emergence; while, the rest started applications after observing feeding damage or presence of larvae on plants. The number of applications varied from two to four and the application frequencies varied between every week to every other week. The first applications in 2016 targeted maize leaves and 64% (175/273) of farmers reported that insecticides were ineffective. However, farmers that were trained on larval behavior targeted their applications to the maize whorl and were very satisfied with the effectiveness of synthetic pesticides for control (92%, 251/273).

The Government through its Plant Protection and Regulatory Service Directory department assisted farmers with locating sources of pesticides (Table 2). Most farmers (95%, 259/273) purchased or obtained other insecticides from local markets. About 35% (96/273) of the farmers applied insecticides distributed only by the Government, 42% (115/273) applied insecticides purchased only from the local markets, and 23% (63/273) applied insecticides from both the Government and local markets.

The inspections of maize farms showed higher infestations in 2017 (73.70%) than 2018 (20.90%) (t=351.72; df=119; P<0.001). The area formed by the SDF, TZ, and GS AEZs recorded the highest infestations during the two years. The infestations of fall armyworm were lower in 2018 than 2017 in all the AEZs of Ghana (Table 3).

Maize Yields and Estimation of Yield Losses

According to the self-reporting by farmers, maize yields were 1.52 t/ha in 2013, 1.55 t/ha in 2014, 1.73 t/ha in 2015, 1.58 t/ha in 2016, 1.55 t/ha in 2017, and 1.69 t/ha in 2018, showing the highest in 2015 and 2018, and the lowest in 2013 (F=31.57; df=5, 119; P<0.001).. During the three years prior to the invasion of FAW, maize yield was annually increasing, but it decreased in 2016 (year of FAW invasion) and 2017 (year of outbreak). Maize yield rebounded in 2018 but was still lower than the yield in 2015.

Maize yields were higher in the forest zones of TZ, SDF, and TRF than the savannah zones of SS, GS, and CS during the last six years of maize production in Ghana. The highest yields were recorded from TRF while the lowest yield was from SS and CS before the FAW

Table 1. Infestation levels reported by farmers on ten maize plants randomly selected in their farm from the six AEZS and during the three years after the invasion of fall armyworm in Ghana

AEZs	2016	2017	2018	df	*F*	*P*
SS	2.50aA	62.50aC	40.50dB	2, 59	286.08	<0.001
GS	48.50bcA	88.50bB	32.00bcdA	2, 59	28.16	<0.001
TZ	40.00bA	89.50bB	29.50abcA	2, 59	109.29	<0.001
SDF	63.00cB	89.50bC	34.75cdA	2, 59	65.01	<0.001
TRF	47.50bcB	70.00aC	21.00aA	2, 59	86.04	<0.001
CS	33.00bA	85.50bB	24.50abA	2, 59	103.10	<0.001
df	5, 119	5, 119	5, 119			
F	27.37	17.64	8.60			
P	<0.001	<0.001	<0.001			

AEZ-Agro-Ecological Zones, SS-Sudan Savannah, GS-Guinea Savannah, TZ-Transitional Zone, SDF-Semi-Deciduous Forest, TRF-Tropical Rain Forest, CS-Coastal Savannah, *F*-Fisher, *P*-Probability; Means in a column followed by the same lower case letter are not statistically different; means in a row followed by the same upper case letter are not different.

Table 2. Type of insecticides distributed by the Government of Ghana with their active ingredients, source, and manufactory instructions

Commercial name	Active ingredient	Rates
Bypel	*Bacillus thuringiensis*	15 g/15 L H_2O/ha
Agoo	*Bacillus thuringiensis*	50 g/15 L H_2O/ha
Eradicot T	*Maltodextrin*	50 mL/15 L H_2O/ha
Emastar 112 EC	*Emamectin+ Benzoate+Acetamiprid*	20 mL/15 L H_2O/ha
Control 5WDG	*Emamectin +Benzoate*	30 g/15 L H_2O/ha
Ataka Super EC	*Emamectin +Benzoate*	75 mL/15 L H_2O/ha
Pyrinex Quick 256 EC	*Chlorpyrifos+Deltametrin*	70 mL/15 L H_2O/ha
Viper 46 EC	*Acetamiprid + Indoxacarb*	40 mL/15 L H_2O/ha
Adepa	*Ethyl palmitate*	100 mL/15 L H_2O/ha
Super top	*Lambda-cyhalothrin+Acetamiprid*	30 mL/15 L H_2O/ha
K-Optimal EC	*Lambda-cyhalothrin+Acetamiprid*	50 mL/15 L H_2O/ha
Thunder 145 OD O-TEQ	*Imidacloprid+Bectacyflutherine*	50 mL/15 L H_2O/ha
Galil 300 SC	*Imidacloprid+Bifenthrin*	15 mL/15 L H_2O/ha
Chemaprid	*Acetamiprid+Cypermethrin*	100 mL/15 L H_2O/ha

Table 3. Infestation levels on 100 maize plants per hectare of inspected farms from the six AEZS in 2017 and 2018 in Ghana.

AEZs	2017	2018	df	*t*	*P*
SS	62.10a	20.00ab	19	217.21	<0.001
GS	84.00bc	27.60c	19	68.93	<0.001
TZ	75.00ab	22.10bc	19	264.29	<0.001
SDF	92.10c	21.80bc	19	180.77	<0.001
TRF	67.70a	15.40a	19	58.10	<0.001
CS	61.40a	18.30ab	19	94.89	<0.001
df	5, 59	5, 59			
F	10.00	7.70			
p	<0.001	<0.001			

AEZ-Agro-Ecological Zones, SS-Sudan Savannah, GS-Guinea Savannah, TZ-Transitional Zone, SDF-Semi-Deciduous Forest, TRF-Tropical Rain Forest, CS-Coastal Savannah, *F*-Fisher, *P*-Probability; Means in a column followed by the same letter are not statistically different.

invasion. After invasion of this pest, the lowest yields were recorded from GS in 2017 and 2018 when larval infestations were high. This pest infestation in 2018 reduced, yet low yields were recorded in SS (Table 4). Maize yields increased slightly between 2013 and 2015 in all AEZs and decreased from 2016 to 2017. By 2018 maize yields were beginning to increase in Ghana (Table 4).

Without consideration of climatic factors or agronomic practices, the yield of 2015 previous to the invasion of FAW was fixed as a baseline from which yield losses caused by FAW were calculated, the losses of 0.15, 0.18, and 0.04 t/ha were recorded in 2016, 2017, and 2018, respectively. The area of maize production in Ghana was estimated to 0.883, 1.00, and 0.90 million hectares in 2016, 2017, and 2018, respectively (Index Mundi 2019). National maize losses caused by fall armyworm were therefore calculated to be 132,450, 180,000, and 36,000 tons in 2016, 2017, and 2018, respectively. Yield losses in all the AEZs were higher in 2017 than the two other years. In SS, yield losses in 2016 and 2018 were similar. Yield in GS in 2018 was equal to yield in 2015; whereas, yield losses in 2018 from TZ, SDF; TRF, and CS were much lower than the yield losses in 2016 (Fig. 1).

Discussion

The impacts of FAW on maize was conducted across the six AEZs of Ghana. The investigations were conducted to assess knowledge and perceptions on this invaded insect pest. The interview attempted to assess farmers on their understanding of the infestation situation and their management practices for this pest, and on determination on their yields obtained from 2013 to 2018. Farms were visited and inspections were carried out in 2017 and 2018 to scientifically assess the real stuation of FAW infestation reported by farmers.

The average life expectancy in Ghana is 63.4 years, with 62.5 for males and 64.4 for females (WHO 2017), which explains the young age structure of the respondents. In recent years farmers started understanding the importance of education and made the literacy rate an important priority. Since 2008 literacy and school attendance has increased (UNICEF 2014) with 71.5% of children enrolled in school in 2010, 84% in 2011 (UNICEF 2012), and 90% in 2015 (Rustin 2015). These achievements decreased illiteracy rates in farming areas and increased the rate of educated farmers. The young ages, literacy rates, and years of farming experience or long service of AOs are the assets for good practices to manage the FAW in Ghana.

The invasion of FAW made it important for farmers and other agricultural officials to quickly familiarize themselves with the larval stage that caused damage to maize plants. Since maize is a preferred host, it is understandable that farmers reported high larval populations during the maize cropping seasons from May to June and September to October. Indeed, the first period from May to June coincided with the major cropping season (April-July) in southern Ghana and the beginning of the season in the north, while the second period from September to October coincided with the beginning of the minor cropping season (August-November) in the south and the end of the only cropping season in the north (MoFA 2016). The high

Table 4. Maize yield means per hectare reported by farmers during the period from 2013 to 2018 in the six AEZs of Ghana.

AEZs	2013	2014	2015	2016	2017	2018	df	*F*	*P*
SS	1.31aA	1.38aAB	1.59aC	1.53bC	1.50bBC	1.52aBC	5, 119	8.85	<0.001
GS	1.41abA	1.47abA	1.63aB	1.46aA	1.42aA	1.63bB	5, 119	13.83	<0.001
TZ	1.56bcA	1.56bA	1.76bB	1.60cdA	1.59cA	1.73cB	5, 119	0.97	0.041
SDF	1.70cdAB	1.71cBC	1.83bD	1.64dAB	1.61cA	1.80dCD	5, 119	12.91	<0.001
TRF	1.75dAB	1.76cB	1.91cC	1.71eAB	1.68dA	1.87eC	5, 119	21.24	<0.001
CS	1.31aA	1.42aA	1.66aD	1.55bcBC	1.52bB	1.61bCD	5, 119	26.34	<0.001
df	5, 119	5, 119	5, 119	5, 119	5, 119	5, 119			
F	14.91	22.86	38.25	48.82	51.54	63.59			
P	<.001	<.001	<.001	<.001	<.001	<.001			

AEZ-Agra-Ecological Zones of SS-Sudan Savannah, GS-Guinea Savannah, TZ-Transitional Zone, SDF-Semi-Deciduous Forest, TRF-Tropical Rain Forest, CS-Coastal Savannah, *F*-Fisher, *P*-Probability; Means in a column followed by the same lower case letter are not statistically different; means in a row followed by the same upper case letter are not different.

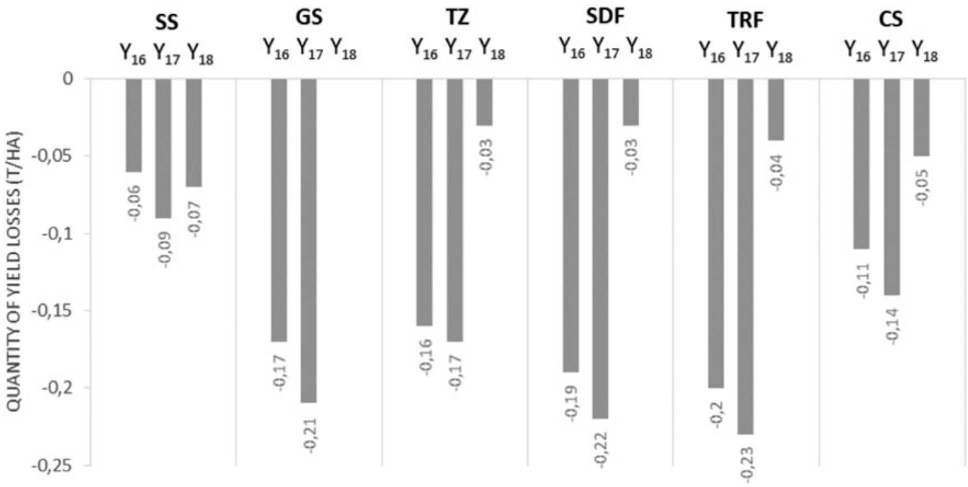

Fig. 1. Yield losses (t/ha) caused by the fall armyworm in the six AEZs of Ghana during the three years following its invasion. AEZ-Agro-Ecological Zones: SS-Sudan Savannah, GS-Guinea Savannah, TZ-Transitional Zone, SDF-Semi-Deciduous Forest, TRF-Tropical Rain Forest, CS-Coastal Savannah, Y-year.

number of reports of FAW on maize farms in Ghana is similar to reports from the U.S. that document maize as a preferred crop for FAW (Luginbill 1928; Ashley 1979; Sparks 1979, 1986; Pitre et al. 1983; Wiseman et al. 1983; Pashley 1986, Nagoshi and Meagher 2004). However, FAW larvae were also reported on other crops of economic important in the Americas (Bass 1978, Pitre 1979, Young 1979, Pitre and Hogg 1983), and they were occasionally observed on other crops in Ghana. Vegetative stages of maize are vulnerable to neonate larvae feeding on young leaves before moving to the whorl (Cruz 1999). Therefore, high infestations during this phenological stage can lead to high feeding damage and can force farmers to abandon their farms, which is why farmers reported this stage as the most critical to FAW infestation.

The FAW was first reported in some areas of Ghana in 2016 (Cock et al. 2017, Koffi et al. 2020a) and that was followed by the extention nationally with high high infestation in 2017 (Koffi et al. 2020a). Farmers reported higher infestations in 2017 than in 2016. This invasion and outbreak may be the key factors causing maize yield reduction between 2016 and 2017, right after there had been a slight increase in yield from 2013 to 2015. To reduce yield losses, insecticide applications were applied for high infestations in the production of maize, sorghum, millet, cowpea, and rice, based on previous studies in the U.S. (Luginbill 1928, Straub and Hogan 1974, Bass 1978). The application of insecticides may have contributed to the reduction of FAW population in 2018 as reported by farmers and confirmed by maize farm inspections. These lower infestation levels observed in 2018 corresponded to increased maize yield. However, the effectiveness of insecticides was not tested in this study and therefore it cannot be concluded that the reduction of infestation in 2018 was due to insecticide applications, as reported by the farmers. Indeed, other natural factors that included larval and egg parasitoid species and predator species were active in maize fields (Agboyi et al. 2020, Koffi et al. 2020b). For the best protection of these natural enemies, insecticide applications should be limited to farms with high infestations.

The changes in maize yields during the six years of this study suggested that efforts were successful to slightly increase annual maize yields. Unfortunately, the invasion of FAW affected these efforts especially during maize productions in 2016 and 2017 when infestations were high and reoriented farmers and agricultural players to be more focusing on this pest management by applying insecticides from 2017. This practice adding to the natural factors that can affect the FAW populations in the field, lowered infestation and increased yield per hectare in 2018. However, this study did include assessment of variations in climatic factors and agronomic practices that can also affect yield as observed across the AEZs within the six years included into this study.

This study showed that maize producers in Ghana are young with minimum education level. Respondents became familiar with the larval stage of FAW due to the injury level that larvae cause to maize plants. These injuries were observed by the respondents in all the developmental stages of plants. The infestation of FAW on maize was reported to be much lower in 2018 than the previous years. This was confirmed by the two years of inspections conducted in farms that revealed high infestation in 2017 than 2018. To prevent or reduce infestations, different locally available or government distributed insecticides were used. The yields per hectare were increased between 2013 and 2015, than decreased during maize production of 2016 and 2017, but rise up again in 2018. This suggests that efforts were made to increase yield of maize in Ghana, but the invasion with high infestation of FAW observed in 2016 and 2017 were an impediment for maize production which heightened in 2018 when infestation was much lower. The real factors that affet the FAW population in the field rest undetermined and should be investigated to develop a good IPM program to sustain this pest management. The insecticides uses to control FAW should thoroughly evaluated at the farmer level from all the AEZs to assess their efficacy on this pest.Then, the relationship between the infestation levels and yield should be clearly investigated.

Acknowledgements

We would first of all, like to acknowledge the Ministry of Food and Agriculture (MoFA) of Ghana and the Plant Protection and Regulatory Service Directorate (PPRSD), for the assistance they provided to us during the data collection. We acknowledge the German Academic Exchange Service (DAAD) for sponsoring a part of this research. We acknowledge Dr. Maxwell Billah, Coordinator of the African Regional Postgraduate Programme in Insect Science, University of Ghana, Legon, for suggestions he provided during the research

References Cited

Agboyi, L. K., G. Goergen, P. Beseh, S. A. Mensah, V. A. Clottey, R. Glikpo, A. Buddie, G. Cafá, L. Offord, R. Day, *et al.* 2020. Parasitoid complex of fall armyworm, *Spodoptera frugiperda*, in Ghana and Benin. Insects. 11: 68.

Ali, A., R. G. Luttrell, H. N. Pitre, and M. Davis. 1989. Distribution of fall armyworm (Lepidoptera: Noctuidae) egg masses on cotton. Environ. Entomol. 18: 881–885.

Ali, A., R. G. Luttrell, H. N. Pitre. 1990. Feeding sites and distribution of fall armyworm (Lepidoptera: Noctuidae) larvae on cotton. Environ. Entomol. 19: 1060–1067. 1067.

Ashley, T. R. 1979. Classification and distribution of fall armyworm parasites. Florida Entomol. 62: 114–122.

Bass, M. H. 1978. Fall armyworm: evaluation of insecticides for control. Ala. Agric. Exp. Stn. Leafl. 93: 7.

Brown, P. R., N. Yee, G. R. Singleton, A. J. Kenney, N. M. Htwe, M. Myint, and T. Aye. 2008. Farmers' knowledge, attitudes, and practices for rodent management in Myanmar. Int. J. Pest Managem. 54: 69–76.

Capinera, J. L. 2000. Fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta: Lepidoptera: Noctuidae). The University of Florida, Institute of Food and Agricultural Sciences. (UF/IFAS), Gainesville, FL..

Capinera, J. L. 1997. Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta: Lepidoptera: Noctuidae). http://edis.ifas.ufl.edu/in255. Accessed 10 October 2017.

Cock, M. J. W., P. K. Beseh, A. G. Buddie, G. Cafá, and J. Crozier. 2017. Molecular methods to detect *Spodoptera frugiperda* in Ghana, and implications for monitoring the spread of invasive species in developing countries. Sci. Rep. 7: 4103.

Cruz, I., M. L. C. Figueiredo, C. A. Oliveria, and A. C. Vasconcelos. 1999. Damage of *Spodoptera frugiperda* (Smith) in different maize genotypes cultivated in soil under three levels of aluminum saturation. Int. J. Pest Managem. 45: 293–296.

Dabrowski, Z. 1997. Integrated vegetable crop management in the Sudan. The ICIPE Science Press. Nairobi, Kenya, 71p.

Goergen, G., P. L. Kumar, S. B. Sankung, A. Togola, and M. Tamò. 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PLoS One 11(10): e0165632.

Hurelbrink, R., and G. Boohene. 2011. Ghana Feed Sector Assessment Report, Accra, Ghana. Report for ACDI/VOCA.

Index Mundi. 2019. Ghana corn area harvested by year. https://www.indexmundi.com/agriculture/?country=gh&commodity=corn&graph=area-harvested

Institute of Statistical Social and Economic Research (ISSER). 2010. The state of the Ghanaian economy in 2009, University of Ghana, Legon, Ghana, 218p.

Knipling, E. F. 1980. Regional management of the fall armyworm: A realistic approach? Florida Entomol. 63: 468–480.

Koffi, D., K. Agboka, D. K. Adenka, M. Osae, A. K. Tounou, M. K. A. Adjevi, K. O. Fening, and R. L. Meagher Jr. 2020a. Maize infestation of fall armyworm (Lepidoptera: Noctuidae) within agro-ecological zones of Togo and Ghana in West Africa 3 Yr after its invasion. Environmental Entomology. XX(XX): 1–6.

Koffi, D., R. Kyremanten, Y. V. Eziah, K. Agboka, M. Adom, G. Goergen, and R. L. Meagher. 2020b. Natural enemies of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in Ghana. Fla. Entomol. 103: 85–90.

Łabanowska, B. H., E. Niemczyk, D. Gajek, and R. W. Olszak. 2002. Zasady i możliwości integrowanej produkcji porzeczki w Polsce. Prog. Pl. Protection/Post. Ochr. Roślin. 42: 46–52.

Luginbill, P. 1928. The fall armyworm. U.S. Dep. Agric. Tech. Bull. 34: 1–91.

Ministry of Food and Agriculture (MoFA). 2010. Agriculture in Ghana: Facts and Figures. Ministry of Food and Agriculture, Statistics, Research, and Information Directorate, Accra, Ghana.

Ministry of Food and Agriculture (MoFA). 2012. Agriculture in Ghana: Facts and Figures. Ministry of Food and Agriculture, Statistics, Research, and Information Directorate, Accra.

Ministry of Food and Agriculture (MoFA). 2016. Agriculture in Ghana. Statistics, Research and Information Directorate, Accra, Ghana, 4 p.

Mitchell, E. R., J. N. McNeil, J. K. Westbrook, J. F. Silvain, B. Lalanne-Cassou, R. B. Chalfant, S. D. Pair, V. H. Waddill, A. Sotomayor-Rios, and F. I. Proshold. 1991. Seasonal periodicity of fall armyworm, (Lepidoptera: Noctuidae) in the Caribbean basin and northward to Canada. J. Entomol. Sci. 26: 39–50.

Nagoshi, R. N., and R. L. Meagher. 2004. Behavior and distribution of the two fall armyworm host strains in Florida. Florida Entomologist 87: 440–445.

Nagoshi, R. N., and R. L. Meagher. 2008. Review of fall armyworm (Lepidoptera: Noctuidae) genetic complexity and migration. Florida Entomologist 91: 546–554.

Nagoshi, R. N., D. Koffi, K. Agboka, K. A. Tounou, R. Banerjee, J. L. Jurat-Fuentes, and R. L. Meagher. 2017. Comparative molecular analyses of invasive fall armyworm in Togo reveal strong similarities to populations from the eastern United States and the Greater Antilles. PLoS ONE 12 (7): e0181982.

Nagoshi, R. N., G. Goergen, K. A. Tounou, K. Agboka, D. Koffi, and R. L. Meagher. 2018. Analysis of strain distribution, migratory potential, and invasion history of fall armyworm populations in northern Sub-Saharan Africa. Sci. Rep. 8:3710.

Pashley, D. P. 1986. Host associated genetic differentiation in fall armyworm: A sibling species complex? Ann. Entomol. Soc. Am. 79: 898–904.

Pitre, H. N. 1979. Fall armyworm on sorghum: Other hosts. Bull. 876. Mississippi Agric. For. Exp. Stn. Mississippi State, MS.

Pitre, H. N., and D. B. Hogg. 1983. Development of the fall armyworm on cotton, soybean and corn. J. Georgia Entomol. Soc. 18: 182–194.

Pitre, H. N., J. E. Mulroony, and D. B. Hogg. 1983. Fall armyworm (Lepidoptera: Noctuidae) oviposition: Crop preference and egg distribution on plants. J. Econ. Entomol. 76: 463–466.

Rustin, S. 2015. Almost 90% of Ghana's children are now in school. Theguardian.com. Retrieved 7 April 2015.

Sang, P. M., N. H. Huan, M. M. Escalada, and K. L. Heong. 2003. Farmers' beliefs and practices in rat management in the Mekong Delta, Vietnam, 426–430. In: Singleton, G. R., L. A. Hinds, C. J. Krebs, D. M. Spratt, eds. Rats, mice and people: Rodent biology and management. ACIAR Monograph 96. Australian Centre for International Agricultural Research, Canberra.

Sparks, A. N. 1979. A review of the biology of the fall armyworm. Florida Entomol. 62: 282–287.

Sparks, A. N. 1986. Fall armyworm (Lepidoptera: Noctuidae): Potential for area-wide management. Florida Entomol. 69: 603–614.

Straub, R. W., and H. J. Hogan. 1974. Feasibility of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), control on late-planted dent corn. N.Y. Food Life Sci. Bull. 49: 4.

UNICEF. 2012. Basic Education and Gender Equality. Unicef.org. United Nations Children's Fund (UNICEF), New York, NY. Retrieved 1 April 2012.

UNICEF. 2014. Education in Ghana. Factsheet. October 2012. p. 1, table comparing sub–Sahara to Ghana, New York, NY. Retrieved 15 May 2014.

Wiseman, B. R., F. M. Davis, and W. P. Williams. 1983. Fall armyworm: Larval density and movement as an indication of non-preference in resistant corns. Prot. Ecol. 5: 135–141.

World Health Organization. 2017. Age Adjusted Death Rate Estimates. www.worlldlifeexpectancy.com/ghana-life-expectancy

Young, J. R. 1979. Fall armyworm: Control with insecticides. Florida Entomol. 62: 130–13.