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Original Article

Field evaluation of cultural control strategies for managing fall armyworm (*Spodoptera frugiperda*) infestations on maize crops

OPEN ACCESS

Lami Wamdeo JINATU*[1], Richmond Enyonam TEGBE[1,2], Babatounde Ferdinand Rodolphe LAYODE[1], Peter OKEKE[3] & Ken Okwae FENING[1,2]

[1]*African Regional Postgraduate Programme in Insect Science (ARPPIS) University of Ghana (UG), Ghana.*
[2]*Soil and Irrigation Research Centre (SIREC) University of Ghana (UG), Ghana.*
[3]*OPEC Research Consult*

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ABSTRACT

This study aims to proffer a solution by promoting minimal use of insecticides using good agronomic practices that suppress pest development. Field trials were conducted during four cropping seasons in 2021and 2022 at Kpong, Ghana. The experiment was laid out in a split-plot design with cropping system as the main factor and planting date as a factor with four replications. Maize was planted with cowpea as the intercrop and was planted at two-week intervals each for three different dates to determine the effects of the factors in FAW infestation and damage on maize. The results revealed that planting dates did not influence the infestation of the pest in terms of larval population across all seasons ($F(2, 12) = 1.27$, $P = 0.3150$); however, the damage caused was significantly different, with maize planted late recording the highest damage. Cropping system shows its impact where maize planted solely recorded high infestation of FAW as well as high level of damage across all seasons examined. Seasonal variation occurred in the total number of FAW larvae ($P < 0.05$) regardless of the factors, and this could be attributed to the prevailing rainfall pattern. However, the yield of maize was not influenced by the cropping system or planting date across seasons. Parasitoids of FAW, including T. remus, Ch. bifoveolatus, and Coccygidium luteum, were observed, with Coccygidium luteum recording the highest abundance (71.43%). The findings in this study have shown the potential of cultural strategies as a sustainable means of fall armyworm management.

KEYWORDS: *Agronomic practices, Cultural control, Fall armyworm, Intercropping, Management*

INTRODUCTION

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is a polyphagous migratory insect pest believed to have originated from tropical regions of the western hemisphere, ranging from the USA to Argentina (Westbrook et al., 2016). It is speculated that FAW was introduced to Africa as a stowaway on a passenger flight through southwestern Nigeria and Ghana in 2016 (Gergen et al., 2016; Cock et al., 2017). The pest spread rapidly to Benin, São Tomé, and Togo (IITA, 2016). In Ghana, its abundance increased fourfold in the second year following its introduction (Nboyine et al., 2019). The infestation has severely impacted the livelihoods and food security of small-scale farmers, particularly maize growers, posing a threat to the United Nations Sustainable Development Goal (SDG) of eradicating hunger by 2030. Economically, FAW infestations have potentially reduced crop yields by 21-35% over three years across Africa, resulting in crop losses amounting to over $13

*Corresponding author: lamijinatu@gmail.com

billion (Maes, 2018; AllAfrica, 2018). In Ghana alone, FAW destroyed 1.4 million hectares of maize and other cereals farms in 2016 across six regions, and over 1,000 hectares in 2017 (SARI, 2017). A farmer survey in Ghana reported a yield loss in maize of 35-50%, estimated at 470,200 tonnes and monetized at $1,773,000 (Rwomashana et al., 2018). Fall armyworm is a destructive pest that can cause significant damage to a wide range of crops, including maize, sorghum, rice, sugarcane, and cotton. Native to the Americas, FAW has spread to Africa, Asia, and beyond, causing substantial economic losses and threatening food security. Its rapid spread and devastating impact on staple crops pose significant challenges to food security and livelihoods. While chemical pesticides have been the primary solution, cultural control strategies offer sustainable and integrated approaches to mitigating the effects of FAW infestations. Farmers in affected countries employ various management strategies, including biological control agents, mechanical control, natural products, chemical insecticides, pest-tolerant crops, and indigenous methods (Kenis et al., 2023).

Biorational insecticides involving plant extracts, entomopathogens, and semisynthetic insecticides were reported to be effective in controlling FAW larvae in Sudan and Nepal (Kona et al., 2021; Khanal et al., 2024). A study in Kenya and Burkina Faso reported (39% and 59% respectively) that farmers control FAW through cultural practices (Kumela et al., 2019; Assefa and Ayalew, 2019). Following the invasion of *S. frugiperda* into Africa, emergency responses primarily involved the use of chemical insecticides. The severity of FAW infestations led farmers to repeatedly spray insecticides during the cropping season, often relying on broad-spectrum active ingredients of high toxicity, particularly in the early years following the outbreak (Tambo et al., 2020a). However, frequent application of broad-spectrum insecticides is unsustainable, as it increases production costs, risk of insecticide resistance development, and impacts on biodiversity and the environment (Pimentel and Andow, 1984; Yu, 1991; Togola et al., 2018). Broad-spectrum pesticides also have a high potential to disrupt natural biological control in maize fields, which are typically not or minimally treated with insecticides in Africa and other regions (Hruska, 2019). The current study, therefore, seeks to explore some cultural control interventions as a sustainable alternative to the management of FAW on maize.

MATERIALS AND METHODS

Study Site

The study was conducted in Kpong at the Soil and Irrigation Research Centre (SIREC), School of Agriculture, College of Basic and Applied Sciences, University of Ghana. Kpong is in the coastal savanna agroecological zone of Ghana. The agricultural sector includes trees such as mango, neem, and cassia, as well as cultivated annual crops including rice, roots, tubers, maize, and vegetables. Kpong is traversed by the Volta River, with non-agricultural areas characterized by hills and gallery forests. The annual rainfall ranges between 700 and 1100 mm, with an average annual temperature of 28°C, and relative humidity between 59 and 93%. The rainfall distribution is bimodal, allowing for two growing seasons (Asare-Nuamah & Botchway, 2019).

Experimental Design

The experiment utilized a split-plot design with four replications. The cropping system was considered the main plot, while planting dates were treated as subplots to determine variations during the experiment. The treatments included: Maize + Cowpea (1st early planting); Maize + Cowpea (2nd intermediate planting); Maize + Cowpea (3rd late planting), and a Sole maize plot as a control for each planting date.

Each split plot measured 5m x 10m (50m²) and was separated by a 3m alley, while the main plots were separated by 4m. The land was prepared by deep ploughing to expose possible pupae or other pests to sunlight or predatory birds. Obatanpa maize variety and erect black-eyed cowpea were used as planting materials. Crops were planted on furrowed ridges created by a tractor-drawn implement with an 80 cm row spacing. Maize was planted 60 cm apart within rows for both control and intercropped fields, with cowpea plants spaced 20 cm apart. In the intercrop fields, maize and cowpea were planted in alternate rows. NPK 20-10-10 fertilizer was applied two weeks after maize emergence, followed by urea fertilizer at four weeks at a rate of 60 kg/ha. The experimental plots were weeded manually with hoes when necessary. The details of planting dates of maize for each season are shown in Table 1

Table 1: Planting dates for different seasons

Season/Year	1st Early planting date	2nd Intermediate planting date	3rd Late planting date
Season 1 (major season 2021)	12/04/2021	26/04/2021	10/05/2021
Season 2 (minor season 2021	6/09/2021	20/09/2021	04/10/2021
Season 3 (major season 2022)	12/04/2022	26/04/2022	10/05/2022
Season 4 (minor season 2022)	06/09/2022	20/09/2022	04/10/2022

Data Collection and Statistical Analysis

Fall armyworm infestations were sampled using an X-pattern field sampling method, selecting 5 plants randomly at each point of the X, totaling 25 sampled plants per plot. Each sampled plant was examined for FAW egg masses, larvae, and damage, and the number of natural enemies. The number of FAW larvae and egg masses per plant was recorded, and damage was assessed using the Davis Scale (0-9) for foliar and ear damage. Weather parameters, including rainfall, temperature, and relative humidity, were recorded each season with support from the weather station at SIREC, Kpong. Results were expressed as mean ± standard error (SE). Data were subjected to a split-plot analysis of variance (ANOVA) for response variables (number of larvae and egg masses), considering factors such as block, main plot, subplot, and their interactions. For groups with statistically significant differences, a multiple comparison test identified specific differences. The Shapiro-Wilk normality test assessed whether the normality assumption was violated. Significance was determined at a 5% probability level ($P < 0.05$). For the seasonal distribution of larval and egg populations, descriptive statistics were used to report the level of infestation in each treatment. Statistical analysis was performed using R software (R Core Team, 2014) with the following packages: doebioresearch (Banakara, 2020), plyr (Wickham, 2011), dplyr (Wickham et al., 2021), and ggplot2 (Wickham, 2016).

RESULTS

Effect of Cropping System and Planting Date on FAW Infestation

The cropping system (main plot) significantly affected the mean number of FAW larvae ($F_{(1, 12)} = 132.20$, $P = 0.0010$), with the sole maize (SM) cropping system recording the highest number of larvae (Figure 1). Differences in the mean number of larvae for different planting dates (subplots) were not statistically significant ($F_{(2, 12)} = 1.27$, $P = 0.3150$). The cropping system did not significantly impact the mean number of FAW egg masses ($F_{(1, 12)} = 0.078$, $P = 0.798$), nor did planting dates ($F_{(2, 12)} = 0.354$, $P = 0 .7090$) (Figure 2)

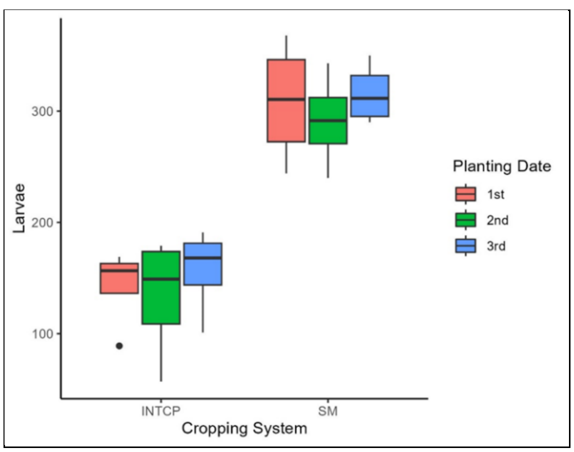

Figure 1: Effect of Cropping System and Planting Date on FAW Larvae.
INTCP = Intercrop. SM = Sole maize.

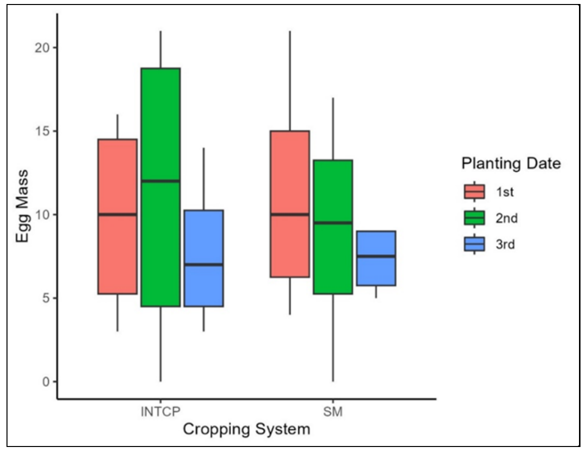

Figure 2: Effect of Cropping System and Planting Date on Egg Masses.

INTCP = Intercrop. SM = Sole maize.

Seasonal Distribution of Larvae and Egg Masses for Each Cropping System

Over four data collection seasons, the highest mean number of FAW larvae (106) was observed in the control plots (SM cropping system) during the 1st season, while the lowest number (20) was recorded in the intercropped plots (INTCP cropping system) during the 3rd season. Generally, the cumulative number of larvae declined with each progressing season. Both cropping systems recorded the lowest number of larvae and egg masses in the 3rd season, while the highest number of egg masses was recorded during the 4th season (Table 2).

Table 2: Seasonal Distribution of Larvae and Egg Mass for Each Cropping System

Season	Cropping System	Larvae	Egg Masses
Season 1 (major season 2021)	INTCP	46.00 ± 4.76	3.00 ± 0.61
	SM	106.00 ± 3.47	3.00 ± 0.54
Season 2 (minor season 2021)	INTCP	34.00 ± 3.31	3.00 ± 0.79
	SM	84.00 ± 8.45	2.00 ± 0.56
Season 3 (major season 2022)	INTCP	20.00 ± 3.23	0.00 ± 0.08
	SM	39.00 ± 3.06	1.00 ± 0.23
Season 4 (minor season 2022)	INTCP	44.00 ± 4.56	4.00 ± 0.85
	SM	76.00 ± 7.40	4.00 ± 0.84

Seasonal Distribution of Larvae and Egg Masses for each Planting Date

Across planting dates, the highest mean number of FAW larvae (80) was observed during the 2nd season in the late planting date, while the lowest number (27) was recorded during the 3rd season in the 3rd planting date. The highest mean number of egg masses (5) was observed during the 4th season in the early planting date, and the lowest number of egg masses was observed during the 3rd season across different planting dates (Table 3).

Plant Damage Across the Cropping Systems and Planting Dates

In the first season, planting dates had no significant impact on FAW damage levels. In the second season, late planting recorded significantly higher damage levels, and still, the lowest level was recorded in the same planting dates. In the 3rd and 4th seasons, intermediate planting dates recorded significantly higher damage levels than early and late planting dates, which were statistically similar. Across all seasons, a statistically significant difference was observed between cropping systems ($P < 0.05$). (Figure 3)

Table 3: Seasonal Distribution of Larvae and Egg Masses for Each Planting Date.

Season	Planting Date	Larvae	Egg Mass
Season 1 (major season 2021)	1st	74.00 ± 12.53	2.00 ± 0.53
	2nd	78.00 ± 15.52	3.00 ± 0.94
	3rd	77.00 ± 8.53	2.00 ± 0.56
Season 2 (minor season 2021)	1st	50.00 ± 8.85	3.00 ± 0.82
	2nd	48.00 ± 7.79	3.00 ± 0.94
	3rd	80.00 ± 15.13	2.00 ± 0.80
Season 3 (major season 2022)	1st	30.00 ± 4.93	0.00 ± 0.26
	2nd	32.00 ± 5.59	0.00 ± 0.26
	3rd	27.00 ± 5.14	0.00 ± 0.16
Season 4 (minor season 2022)	1st	72.00 ± 11.29	5.00 ± 1.16
	2nd	55.00 ± 8.68	3.00 ± 0.94
	3rd	52.00 ± 7.28	2.00 ± 0.80

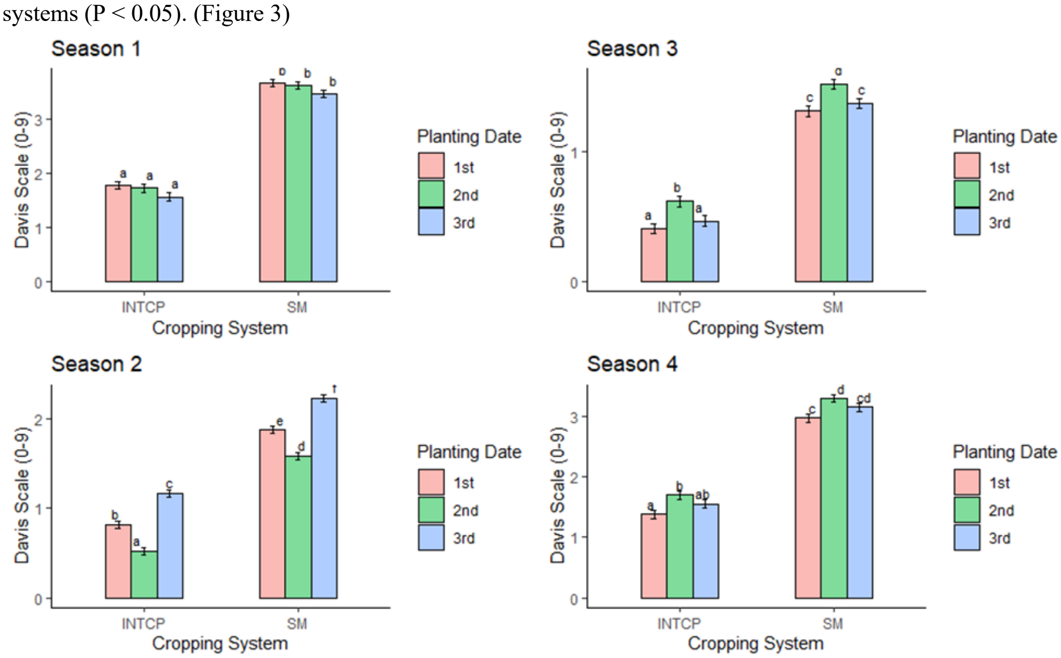

Figure 3: Plant Damage Across the Cropping Systems and Planting Dates Based on Davis Scale (0-9).

Weather Parameters and Relationship to FAW Infestation

The monthly parameters (i.e., temperature and rainfall) showed no significant difference among rainfall occurring in the months of the seasons during which the experiment took place (April to August 2021; September to December 2021; April to August 2022, and September to December 2022) (P = 0.827, F = 0.0490). Similarly, significant variations were not recorded in the temperature among the seasons (P = 0.0640). (Figure 4)

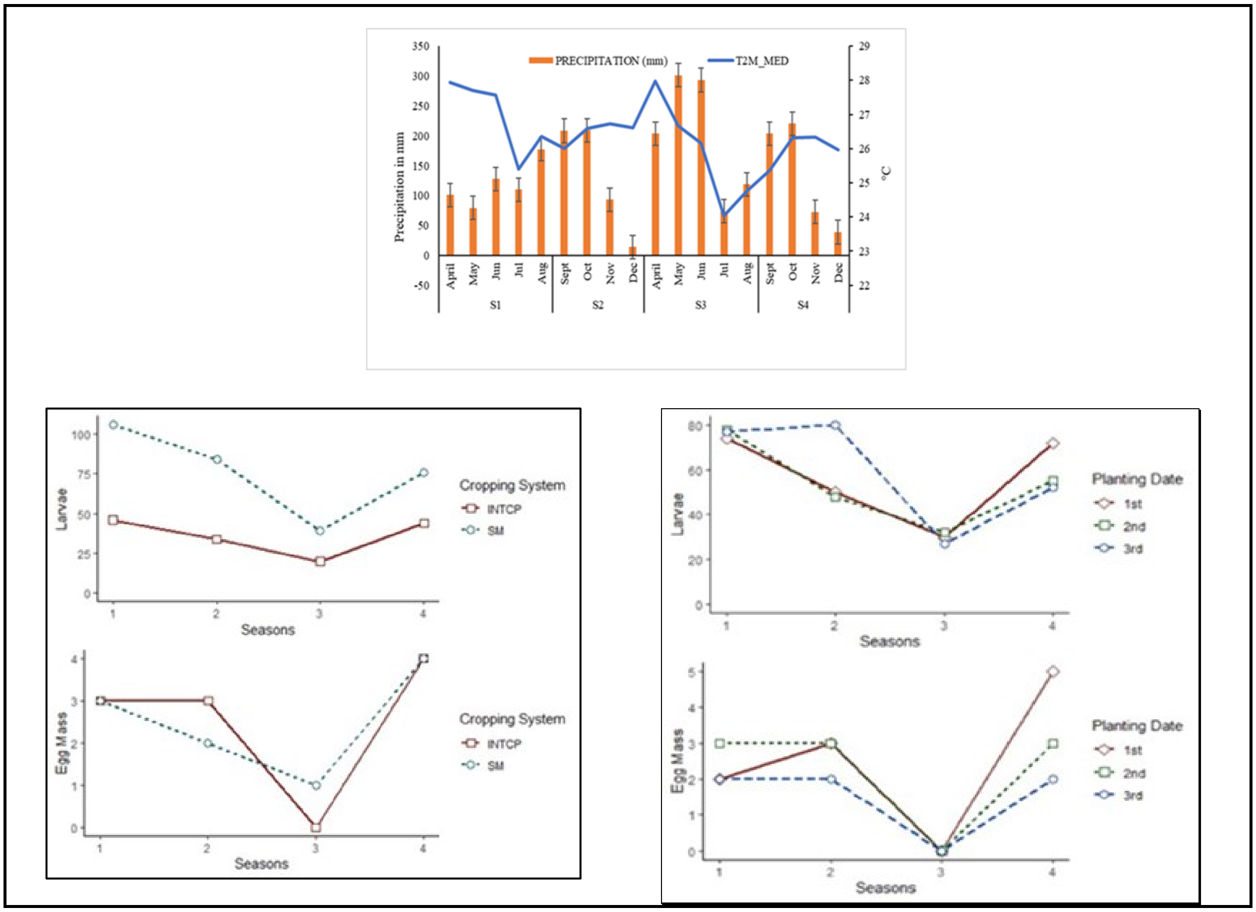

Figure 4: Weather Parameters and Trend of FAW Infestation per season

Table 4: Seasonal Relative abundance and parasitism rate of parasitoids

Season	Parasitoid species	Relative Abundance (%) N=120	Parasitism rate (%)
S1 (major season 2021)	*C. luteum*	62.96	14.17
	Ch. bifoveolatus	37.04	8.33
	T. remus		
S2 (minor season 2021)	*C. luteum*		2.50
S3 (major season 2022)	*C. luteum*	63.16	10.00
	Ch. bifoveolatus	36.84	5.83
S4 (minor season 2022)	*Coccygidium luteum*	71.43	4.17
	Ch. bifoveolatus	28.57	1.67

Relative Abundance and Parasitism Rate of Larval and Egg Parasitoid

One species of larval parasitoids, one species of egg–larval parasitoid, and two species of egg parasitoids were collected during the course of the data collection seasons of 2021 and 2022. The most commonly found species were *Chelonus bifoveolatus* Szépligeti (Hym.: Braconidae), *Coccygidium luteum* (Brullé) (Hym.: Braconidae), *Telenomus remus*, and *Trichogramma* sp (Table 4). The parasitism rate of the various parasitoids for larvae and egg parasitoids was not significantly different between the sole maize and the maize intercropped with cowpea, but it varies among seasons, with the major season in 2021 recording the highest parasitism rate. The egg masses collected during the vegetative stage of the maize in every season have some parasitism from *T. remus* and *Trichogramma*. A total of 30 egg masses were collected every season for 4 seasons, giving rise to a total of 120 egg masses being assessed during the experimental period. From these, 38 egg masses were parasitized by *T. remus* as well as *Trichogramma* wasps.

Yield Assessment

Across the four seasons examined, it was observed that various treatments did not significantly impact maize yield. No statistically significant differences were found in the yields of maize grown under different cropping systems or planting dates (Table 4). However, independent of treatment effects, maize yield exhibited significant seasonal variation. Specifically, the minor season of 2021 resulted in the lowest yield, while the minor season of 2022 produced the highest yield (Table 5).

Table 5: Dry grain yield of Maize.

Treatments	Mean (± SE) yield in t/ha			
	S1	S2	S3	S4
1INTCP	1.85 ± 0.30	0.30 ± 0.50	1.90 ± 0.50	2.35 ±0.30
1SM	1.90 ± 0.40	0.40 ± 0.40	1.90 ± 0.40	2.40 ± 0.20
2INTCP	1.85 ± 0.10	0.10 ± 0.40	1.90 ± 0.40	2.40 ± 0.30
2SM	1.90 ± 0.20	0.20 ± 0.50	1.75 ± 0.40	2.45 ± 0.20
3INTCP	1.90 ± 0.30	1.30 ± 0.70	1.850 ± 0.40	2.45 ± 0.20
3SM	1.75 ± 0.40	0.40 ± 0.10	1.95 ± 0.30	2.35 ± 0.40

***INTCP = Intercrop (maize + cowpea); SM = Sole maize.*

DISCUSSION

The purpose of manipulating planting dates in pest management is to disrupt the pest's life cycle by planting synchronously or earlier, thereby escaping the peak pest population. The experiment showed that maize planted at early and intermediate dates recorded significantly lower damage in three out of the four seasons, suggesting that FAW did not exert damaging pressure during the maize's vulnerable stage. The results align with similar research by Sowmiya et al. (2022), which reported lower damage levels on early-planted maize. However, this contrasts with a study in Chad, where FAW damage was highest in early-planted maize (Taambaijim et al., 2023). The synergistic use of legume intercropping showed positive results in reducing both FAW infestation and damage, consistent with studies highlighting the importance of crop diversity in pest management (Hailu et al., 2018; Salim et al., 2022; Liu et al., 2022). The fluctuating pest population across planting dates suggests FAW biology may be synchronized with usual planting dates in the study area. This is contrary to Taambaijim et al. (2023), who reported a significantly lower FAW population in intermediate planting dates. A recent study in Zambia reported a preliminary finding on the effect of planting date on the population built up of FAW in maize, and they found that planting early has the potential of managing the infestation and damage of the moth by evading the population peaks during the growth stage of the maize plants (Durocher-Granger *et al.* 2024).

Abiotic factors have also been reported to contribute to the population of pests in the field. Although no significant variations were observed in the population of the pests when comparing the treatment means, there was a seasonal variation in the infestation level, with a high record of infestation when the rainfall was not consistent. The rainfall also provides a favourable growing condition for the crops, and this supports the results where crops grown in a well-established rainfall season escaped the pest's population peak pressure. It is interesting to note that although there was no statistical variation in the seasonal or monthly amount of precipitation, the consistency of the rainfall was not the same across the four seasons, and the results of damage and infestation showed significantly higher damage during seasons where the rainfall pattern was erratic. However, the yield loss in season 2 was mostly attributed to excessive rainfall during the productive stage of the maize. In terms of diversification of the crops to control the fall armyworm, it was found that damage levels in intercropped plots were significantly lower compared to those in sole cropping systems, despite the fact that the interaction between planting date manipulation and cropping system did not significantly affect the damage levels. The reduced damage in the intercropped system suggests a lower availability of food sources for pests, which in turn discourages their population buildup and results in less damage. The diversity of crops in the intercropping plots also promotes a breeding environment for predators of the fall armyworm. These predators interact with one or more growth stages of the pest, thereby disrupting its normal development or leading to its death. This finding is consistent with studies conducted by Altieri (1999), Tilman et al. (2001), and Fening et al. (2020), which reported that ecological alterations can help control pest attacks. Additionally, Leung et al. (2003) also concluded that crop heterogeneity can significantly reduce pest stress on crops. Similarly, Tanyi et al. (2020) observed that maize-bean intercrop fields exhibited lower pest populations compared to sole maize fields and attributed this phenomenon to the confusion of olfactory cues from beans, which acted as a repellent for the fall armyworm (FAW). Additionally, Khan et al. (2010) and Chamberlain et al. (2006) reported the emission of allelopathic volatiles from broad green bean leaves. These reports confirmed the results of the current study by affirming the presence of semio-chemicals in cowpea acting as a deterrent to FAW activities such as feeding and oviposition.

The findings from this study can positively influence effective FAW management in Ghana and beyond through a holistic approach, involving community engagement, capacity building, and sustainable practices. Policymakers play a crucial role in translating research into actionable policies that benefit farmers and protect crops; therefore, these research findings provide a basis for taking actionable steps towards effective fall armyworm management by encouraging an early warning system of fall armyworm infestation, thereby enabling farmers to adopt planting schedules that align with FAW biology. Also, the agricultural ministry can incorporate the services of extension workers in programmes that support creating awareness on the importance of rainfall patterns and intercropping maize with leguminous crops in FAW population dynamics.

CONCLUSION AND RECOMMENDATIONS

Ultimately, the study concludes that early and intermediate planting dates, combined with legume intercropping, offer promising strategies for mitigating FAW infestations and reducing damage in maize crops, which could be sustainable and acceptable to smallholder farmers and environmentally friendly. Future studies should investigate the scalability and consistency of maize–legume intercropping and planting date manipulation across diverse agro-ecological zones, with emphasis on socio-economic cost–benefit analyses and farmer adoption dynamics to generate holistic insights for sustainable fall armyworm management.

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Authors' Contribution

LWJ was the student carrying out the research, LWJ and KOF were responsible for experimental and project design, literature searches. LWJ and BFRL performed experiments/data collection, and OP and LWJ prepared and analyse the data. KOF supervised research processes, proofread.

Ethical Statement

Not Applicable

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