International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 25, No. 3, p. 206-216, 2024

RESEARCH PAPER OPEN ACCESS

Influence of cropping associations on maize infestation and the abundance of populations of *Spodoptera frugiperda* (J.E. Smith) and its natural enemies

Ibrahima BA [*1,2], Mariama Faye[1,2], Awa Ndiaye[1,2], Ibrahima Diallo[1,2], Toffène Diome[2], Mbacké Sembene[2], Cheikh Thiaw[3]

[1]*Centre pour le Développement de l'Horticulture (CDH), Institut Sénégalais de Recherches Agricoles (ISRA), Routes des Hydrocarbures, Bel Air, Dakar, Sénégal*

[2]*Équipe Génétique et Gestion des Populations (GENGESPOP), Département de Biologie Animale, Faculté des Sciences et Techniques (FST), Université Cheikh Anta Diop (UCAD), Dakar, Sénégal*

[3]*Université Sine Saloum Elhadji Ibrahima Niass (USSEIN), Sénégal*

Key words: *Spodoptera frugiperda*, Exotic pest, Food security

http://dx.doi.org/10.12692/ijb/25.3.206-216 Article published on September 10, 2024

Abstract

Spodoptera frugiperda is an exotic maize pest that threatens food security in sub-Saharan Africa in general and Senegal in particular. With the aim of contributing to sustainable management of the pest, this study aims to assess the effect of corn/peanut and corn/cowpea associations on population dynamics and pest damage. The experiment was conducted out in 2021 at the Sangalkam Center for Horticulture Development (CDH) station of the Senegalese. Agricultural Research Institute (ISRA) following a Fisher block design with four repetitions. Three treatments including two associated cropping systems and a pure corn crop were tested. The incidence of damage caused by *S. frugiperda* was 28.96 ± 2%, 44.88 ± 3% and 42.59 ± 3% respectively for corn/punead, corn/ cowpea and corn alone. Only the pure corn crop suffered serious damage of around 5%. The vegetative and maturity stages were the most susceptible to attacks by the pest. The average number of larvae was significantly lower in maize in association with groundnuts than in the maize/cowpea system and the pure maize crop, with a very high significant difference. In contrast to the number of larvae, the highest number of natural enemies of *S. frugiperda* was observed on the maize/groundnut combination plots followed by the pure maize crop with a significant difference compared to the maize/ cowpea combination plots. These data constitute an important reference base for the development of sustainable management strategies for *S. frugiperda*.

* **Corresponding Author:** Ibrahima ✉ ibrahima82.ba@ucad.edu.sn

Introduction

The proliferation of new pests could seriously jeopardize the achievement of sustainable development objectives; in particular ensuring food security, especially as climate change and its consequences are raising many questions about the future of the planet. The fall armyworm (FAW) *Spodoptera frugiperda* (J.E. Smith), a major pest of cereal crops in Africa, poses a real threat to food security in sub-Saharan African countries where cereals are the staple food. Since its appearance in Africa in 2016, the FAW has invaded almost all African countries due to its high dispersal capacity. This pest could lead to a reduction in maize yield of up to 70% when maize plants are attacked during the early stages (Hruska, 2019; Ayala *et al.,* 2013).

According to FAO (2018), FAW threatens the food security of more than 300 million people in Africa, mainly small-scale farmers. In Senegal, because of its polyphagia, FAW can cause significant damage and lead to production losses on cereals, the preferred hosts contributing in large part to Senegalese food availability. Because of the caterpillar's resistance to a number of chemical pesticides, and the risks associated with their use, it has become essential to find effective, environmentally-friendly alternative methods. This is why practices that are sometimes very old are currently attracting renewed interest and are being tested in rural areas in order to offer a reasoned management of pests that is not based on the use of pesticides, which are ill-suited to current environmental policies. The reduction in damage caused by insect pests in plant associations compared with pure crops has long been mentioned in the literature (Langer *et al.*, 2007). For example, Raros (1973) mentions the positive effect of combining groundnuts with maize in limiting attacks by codling moths. It was against this backdrop that a study of agroecological approaches, in particular the use of service plants, was conducted out with a view to developing robust integrated pest management strategies for the armyworm, which would be culturally appropriate, inexpensive and easy to integrate into existing systems in order to improve the incomes and resilience of smallholders. Agroecological approaches to pest control are based on three complementary strategies namely improving plant health and resistance to attack through better management of soil fertility; diversifying the agricultural habitat at farm and landscape level to provide living space and resources for natural enemies; and intervening at plot level to disrupt the ability of pests to locate their hosts, while increasing the effectiveness of natural enemies. Thanks to an experiment conducted out under real field conditions, we have studied the role of intercropping with legumes on infestations of maize by the armyworm.

Material and methods

Presentation of the study area

The study was conducted out at the Sangalkam experimental site located between latitude 14° 46' 44.30'' N and longitude 17° 13' 33.65'' W at an altitude of 19 meters (CDH, 2005), in the department of Rufisque in the Niayes ecological zone (Fig. 1). The climate is subcanar and the soils are sandy-clay, rich in organic matter. The wet or rainy season runs from June to October, with temperatures ranging from 27.5°C to 28.1°C (Faye, 2010).

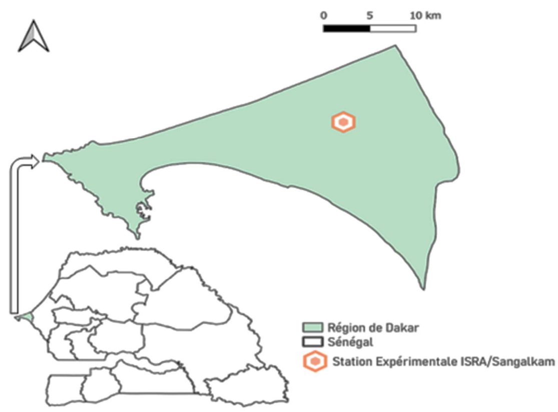

Fig. 1. Study area

Experimental design

A Fischer block design with three modalities and four replications was adopted (Fig. 2). The treatments consisted of 10 m x 10 m elementary plots separated by a 2 m aisle, while the blocks were 5 m apart. The treatments consisted of one plot with a pure corn crop and two plots with corn/legume combinations (one plot with corn/ cowpea and one plot with corn/peanut).

	Plot 1	Plot 2	Plot 3
Rep 1	Corn alone	Corn Cowpea	Corn-Peanut
Rep 2	Corn-Peanut	Corn alone	Corn Cowpea
Rep 3	Corn alone	Corn Cowpea	Corn-Peanut
Rep 4	Corn Cowpea	Corn-Peanut	Corn alone

Fig. 2. Experimental setup

Rep = Replication

Description of associated cropping systems and experimental set-up

Grasses (*Poaceae*) and legumes (*Fabaceae*) are the two most important botanical families for agriculture. Growing them in association (simultaneously on the same plot) is a long-established practice that makes the most of the ecological, agronomic and nutritional differences between the two families. The performance of these combined crops in terms of production, quality and environmental benefits is closely linked to the ability to control the proportion of grasses and legumes in the mixture.

Two types of association have been set up namely corn/peanut and corn/cowpea. The association plot units alternated between a row of legumes and a row of corn. The plant material used in this study comprised three species: maize (var. Noor 96), cowpea (var. Yacine) and peanut (local variety). The varieties were selected on the basis of the length of their cycle, as well as their high level of use by farmers. The maize variety, with an 80-day cycle, is resistant to helminthosporiosis, root lodging and stalk breakage. Its kernels are horny and yellow in color. Its average yield potential varies from 2 to 3 t/ha. he cowpea variety used has a determinate growth with a 95% maturity cycle of 62 days after sowing. The groundnut variety has a growth cycle of 90 days. All the crops were sown simultaneously, with two seeds per plot, at spacings of 80 cm × 30 cm, 80 cm × 15 cm and 80 cm × 30 cm respectively for corn, peanut and cowpea. Hand-pulling was carried out for corn, which allowed one plant to be maintained per stake after emergence. Maintenance work was carried out as required following field observations. All treatments were fertilized with synthetic chemical fertilizers at the current recommended rate for maize (200 kg/ha of NPK 15-15-15 at 15 and 100 kg/ha of urea 46% N at 15 and 30 days after sowing respectively).

Data collection

Observations were made on corn plants and focused on looking for egg clusters, live larvae or fresh droppings. Data are collected on corn plants following the methodology established by FAO (2018). Thus, data collection was carried out in five points drawing the letter "W". Therefore, at each "W" point, ten (10) corn plants are inspected by observing the different parts, mainly the upper and lower leaf surfaces and the whorl (Fig. 3). A total of fifty (50) corn plants were surveyed per elementary plot. Leaf damage caused by the caterpillar was assessed using the Devis rating scale every fortnight from the 15th day after sowing. The larvae found on the corn plants surveyed were counted. The data collected was used to determine the percentage of infestation, the level of damage, the number of larvae and the yield for each treatment.

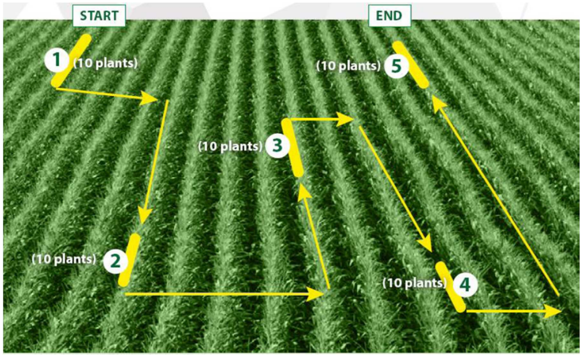

Fig. 3. FAO W method ; Source : FAO Guidance Note 2, FAW scouting

Assessing the percentage of infestation

A plant is considered to be infested when the following are observed: the presence of clusters of eggs, live larvae, fresh droppings and characteristic damage to the plant. For each elementary plot, the percentage of infestation is calculated in relation to the fifty (50) plants surveyed. This percentage is determined by the formula:

I (%)=nN×100

I: infestation percentage; n: number of infested plants; N: total number of plants surveyed (N=50).

Assessing the level of damage

Damage is assessed on leaves and ears. To do this, a percentage of screening attributable to *S. frugiperda* is assigned to each plant attacked. Each percentage assigned corresponds to a score on the Davis *et al.* (1989) numerical scale used to assess leaf damage. The damage level of an infested plant is calculated according to the formula:

$$Nd = \sum_{i=1}^{n} (ni\ xi/n)$$

Nd = Damage level; xi = score assigned to the attacked plant; ni = number of plants having received the score xi; n = total number of plants sampled.

Determining the number of larvae per treatment

The average number of larvae per treatment was deduced directly from the count of larvae found on the maize plants inspected in the elementary plots.

Determination of maize yield

The yield per hectare was determined by extrapolating the production of each elementary plot from the ten (10) ears of maize from the five (5) lines of observation points. The yield was calculated as follows:

Grain yield (t/ha)= (Number of ears/yield square x Number of grains/ear x Grain weight (g))/2.4 m²

Statistical analysis

The data were subjected to the Shapiro - Wilk normality test (Shapiro and Wilk, 1965) before being analyzed. As the data set was not normally distributed, non-parametric tests were used. Where the Kruskal-Wallis test revealed significant differences between treatments, the ranks of the different treatments were separated using the Wilcoxon multiple separation test at the 5% threshold. All data analyses were performed using R software version 4.1.0, more specifically the R Cmdr. package.

Results

The extent of the pest's damage is assessed by the percentage of attack and the level of damage to maize plants.

Influence of cropping associations on the incidence of the pest

The average percentages of damage caused (i.e. number of plants attacked compared to the total number of plants sampled) by the armyworm on corn plants in the different cropping associations (or treatments) were 28.96 ± 2%, 44.88 ± 3% and 42.59 ± 3%, respectively for the corn/peanut, corn/ cowpea and corn alone treatments. The results of the statistical analysis of the Kruskal-Willis test showed that the corn/peanut combination had a significant effect on the average percentages of plants attacked by the caterpillar (chi-squared = 15.984, df = 2 and p-value < 0.001). The Wilcoxon multiple comparison test showed that the lowest percentage of maize plants attacked was recorded in the corn/peanut plots, while the highest damage was recorded in the corn monoculture and corn/cowpea plots (Fig. 4).

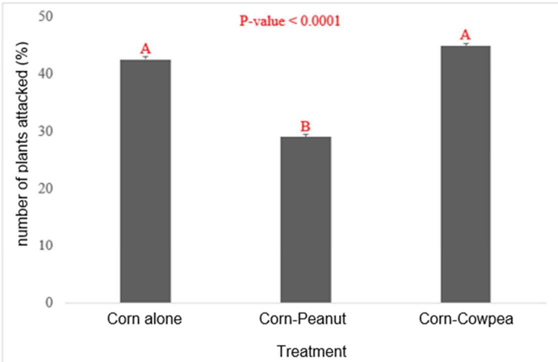

Fig. 4. Average percentage of corn plants infested by the fall armyworm depending on the treatments

Influence of cropping associations on the severity of FAW damage

Monitoring the severity of damage caused by the armyworm by observing leaf symptoms showed that the majority of plants sampled showed little or no damage for all treatments. Only the pure corn crop showed serious damage of the order of 5% and much less damage compared with the corn/peanut and corn/cowpea combinations, although statistical tests showed no significant difference (Fig. 5).

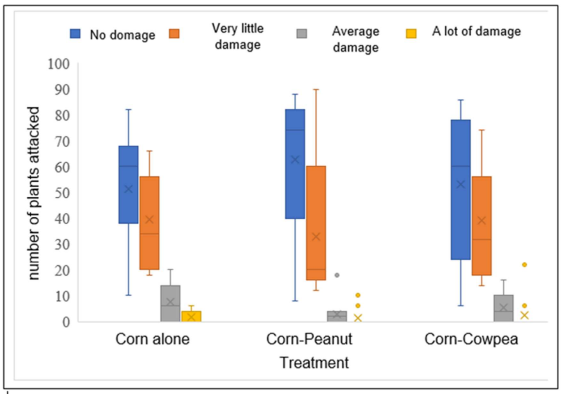

Fig. 5. Proportion of plants sampled showing different levels of severity of infestation by the armyworm

Impact of CLA damage on maize growth stages

The observations made on FAW infestation for the different treatments at different stages of corn growth are presented in Fig. 6. In the three treatments studied, significant variations (P<0.001) were observed between the heading stage and the vegetative and maturity stages. Infestation symptoms at the vegetative and mature stages ranged from 47% to 68% and 49% to 52%, respectively, compared with the bolting stage, where 19% to 33% of infested plants were recorded depending on the treatment. FAW infestation of maize in corn/peanut association plots was lower than in corn/cowpea association plots and in pure maize crop plots irrespective of plant growth stage.

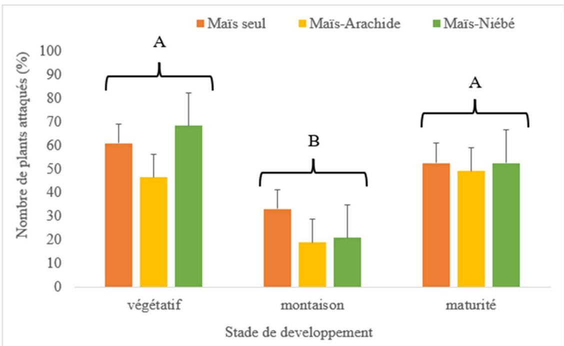

Fig. 6. Average percentage of corn plants infested by the fall armyworm depending on the treatments

Influence of cropping associations on the number of larvae of the pest and its natural enemies

The results of the number of *S. frugiperda* larvae per treatment are presented in Fig. 7. Larvae were observed only on maize plants grown pure or in association with peanut or cowpea. The average number of larvae was significantly lower in corn in association with peanut (38 larvae) than in the corn/cowpea association (52 larvae) and the pure corn crop (64 larvae), with a very high significant difference. Contrary to the number of larvae, the highest number of natural enemies of FAW was observed on the corn/peanut association plots (29 individuals) followed by the pure corn crop (10 individuals) with a significant difference compared to the corn/cowpea association plots (5 individuals).

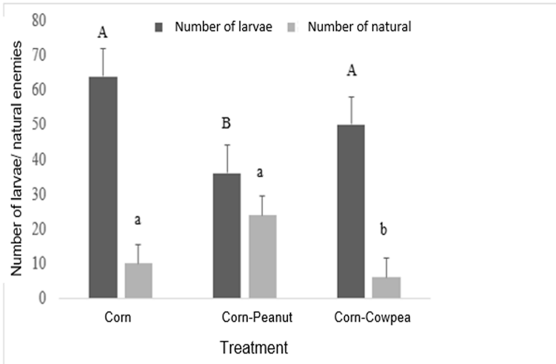

Fig. 7. Average number of larvae of the pest and its natural enemies in the various treatments

Effect of different cropping combinations on maize seed yields

Average corn seed yields by treatment are shown in Table 1. Statistical analysis of yields showed no significant differences between treatments. However, corn grain yields obtained with the corn/peanut and corn only plots were similar, with increases of 5.40% compared with the corn/cowpea plots.

Table 1. Average corn seed yield per treatment

Treatments	Average yield (kg/ha)	Sd
Corn alone	3568,67	219.0923
Corn-Peanut	3568,67	208.6408
Corn-Cowpea	3375,77	273.4830

Discussion

Within the framework of integrated pest management and agroecological approaches, several practices include manipulation of the biological environment of the crop in the field in order to regulate pests, and in particular manipulation of vegetation, such as mulching, uncultivated habitats and intercropping (Landis *et al*., 2005). In this case, we refer more specifically to habitat management or manipulation, defined as "an intervention on the vegetation of an agroecosystem with the consequence of suppressing pest densities" (Gurr *et al*., 2017). Habitat manipulation can suppress pests through cultural control, which covers a wide range of agronomic practices and techniques that directly or indirectly influence the behavior of pests towards their host plant; or through conservation biological control, defined as "the modification of the environment or existing practices to protect and enhance certain natural enemies or other organisms to reduce pests" (Eilenberg *et al.,* 2001). Intercropping, widely practiced by smallholder farmers in sub-Saharan Africa, has long been recognized as an efficient farming system allowing for better resource utilization and increased productivity (Matusso *et al.,* 2014; Ngwire *et al.,* 2012). The data collected on the network of experimental plots show that combining maize with cowpea or groundnut legumes is an effective way of reducing army worm populations compared with pure monospecific cropping.

The average percentages of damage caused by the armyworm on corn plants in the different cropping combinations were 28.96%, 44.88% and 42.59% respectively for the corn/peanut, corn/cowpea and corn only plots. The corn/peanut and corn/cowpea combinations resulted in a very significant reduction in the incidence of the pest *Spodoptera frugiperda* compared with corn grown alone. Peanut and cowpea are plants with yellow and white flowers that are classified as recruiters of beneficials, which play a very important role in the natural regulation of the pest, thereby reducing the incidence of the pest in corn. According to Colley and Luna (2000), the yellow and white flowers of the plants are reputed to be attractive and to facilitate feeding by beneficials, particularly hoverflies. This effect of intercropping can be explained by a dilution of resources, a change in the general appearance of the canopy (shape, color, smell and microclimate) and an increase in the abundance of natural enemies. Taken together, these factors would make it more difficult for the pest to recognize the host plant, and would reduce both the establishment and mobility of the pest in the canopy, affecting its propagation dynamics. This result supports the resource concentration hypothesis (Root, 1973), which suggests that phytophagous insects are more likely to find and stay on host plants growing in dense or almost pure stands.

This study is consistent with the reported results that corn grown in association with leguminous crops results in significantly lower FAW infestation compared to corn grown as a pure crop. Studies in Uganda and Cameroon have shown that intercropping corn with beans or peanut significantly reduces fall armyworm infestation and damage severity on corn (McGrath *et al.,* 2018; Osborne *et al.,* 2002). Studies by Hailu *et al.* (2018) and Musubao *et al.* (2022) showed that corn grown in association with leguminous crops (soybean, peanut, bean) resulted in significantly lower FAW infestation, compared with corn grown as a pure crop. In addition to these results, another study by Degri *et al.* (2014) shows that the incidence of stem-boring pests was lower in pearl millet (*Pennisetum glaucum* L.) in association with peanut (*Arachis hypogea* L.) than in pure-cropped pearl millet. Another study by (Boyombe *et al.,* 2021) showed that pure corn fields were more attacked than corn fields mainly associated with peanut, cassava, banana and rice. Studies by Scheidegger *et al.* (2021) show a lower incidence of FAW in areas where cereal-legume intercropping is part of cropping practices compared with areas where pure cropping is more common. Although further studies are needed to determine the mechanism by which intercropping reduces damage caused by FAW, the barrier effect, the emission of repellent volatiles and the increase in the abundance of natural enemies are thought to be key mechanisms (Deshmukh *et al.,* 2021).

A slight variation in the severity of FAW damage on corn grown in association with legumes was observed, although the differences were not significant. In fact, only the pure corn crop recorded serious damage of the order of 5% and much more minor damage. All the damage in the corn-legume association plots was very moderate. Hailu *et al.* (2018), obtained similar results with higher infestation severity on corn grown as a pure crop compared to corn grown in association with legumes. In addition, they showed that severely infested corn plants were also lower in corn intercropped with legumes (6.6% in bean, 7.5% in soybean and 8.3% in peanut) compared with 42% observed in corn in pure cultivation. In the same vein, Mytyambai *et al.* (2022) found in their study that mixed cropping systems, in particular corn-legume intercrops, had lower levels of damage than pure corn crops.

In view of the results obtained, the susceptibility of corn plants to FAW damage varies greatly according to the different growth stages. These results are in line with those of Gross *et al.* (1982) who stated that the different growth stages of corn vary in their susceptibility to FAW attack. It has been reported that plants are most susceptible to damage during seedling emergence and early whorl stages, and again during the panicle preformation period (Gross *et al.,* 1982; Buntin, 1986). The study by Musubao *et al.* (2022) showed that the average incidence of armyworm in fields during the vegetative stage was higher than during the other phenological stages. Navik *et al.* (2021) also found a negative correlation between the age of corn plants and the incidence of *S. frugiperda*. This same trend was observed and could be due to the fact that during the early stages of the whorls, the corn leaves are tender and therefore easily destroyed by the caterpillars. The low percentage of infestation during the heading stage could also be explained by morphological characteristics. Older plants have a fairly dry and generally dehydrated cuticle, which is not easily accessible to caterpillars, and older plant tissues may have a detrimental effect on the survival and/or growth of larvae. The concentration of cell wall components, in particular lignin content, increases as tissues gradually mature (Morrison *et al.,* 1998; Wiseman, 1994), making them less attractive to caterpillars. Adult butterflies might avoid laying their eggs in these tissues, preferring softer, more nutritious ones for their offspring. Our results corroborate the work of Mytyambi *et al.* (2022), who obtained a very high FAW infestation rate in young vegetative plants compared with panicle and mature corn plants. The results of the study support those of Yéboué *et al.* (2002) who noted a gradual decline in flea beetles (*Podagrica decolorata* and *Nisotra dilecta*) on okra crops due to the advanced age of the plant. These results are also close to those of Obodji *et al.* (2016) who reported that the low number of *Leucinodes orbonalis* larvae on eggplant plants at the end of the cycle was due to their ageing. A high diversity of beneficials associated with a lower number of armyworm larvae was noted in the corn/peanut association plots compared with the pure crop and the corn/cowpea association. In fact, a greater number of armyworm individuals were observed on the pure crop plots, as well as the lowest number of natural enemy individuals. This can be explained primarily by the interactions between the host plant and the pest. An herbivorous insect, particularly a specialist insect, favors a particular species of plant (host species), which it seeks out to feed on or lay its eggs. In a mixed crop, the olfactory or visual signals emitted by the other plant species interfere with those emitted by the desired host species, which is thus "hidden" from the insect. The second mechanism at play is that mixed crops encourage the establishment of natural predators such as ladybirds, ants or spiders, which could then control insect pest populations. Some farmers believe that mixed planting systems (polyculture or use of certain plants other than the main crop) cause low egg-laying on corn and/or create environments that attract abundant populations of natural enemies and keep them there (FAO, 2017). Countless studies have shown that habitat diversification at farm level increases the abundance of natural enemies and improves their effectiveness in controlling insect pests (Wyckhuys and O'Neil, 2006).

Increasing plant diversity has been shown to regulate pest populations in various agroecosystems (Hooks and Johnson, 2003; Letourneau *et al.,* 2011; Dassou and Tixier, 2016).

This refers to the phenomenon of associative resistance (Tahvanainen and Root, 1972), which can be explained by two ecological processes, namely bottom-up control, which occurs when pests are regulated by the lower trophic level (the plant), and top-down control, which occurs when natural enemies regulate pests (Gurr *et al.,* 2004). The presence of these legumes in mixed cropping systems favors the dispersal of FAW larvae away from the main crop, thereby reducing the damage inflicted on companion host plants. The dispersal ability of FAW, particularly the larval stages, may have been physically hindered where intercrops are not hosts. Dense intercropping is known to be a suitable habitat that harbors several natural enemies for the insects, including parasitoids and predators (Khan *et al.,* 1997), which could therefore have reduced FAW infestation and damage in mixed corn cropping systems as opposed to pure corn cropping. A mixture of crop types can also interfere with the visual stimuli that attract insect pests to their appropriate host crops, completely camouflaging the host crop, particularly young plants in cropping systems such as relay cropping systems (Perrin *et al.,* 1977). It is well established that insect pest populations are lower in relay cropping (Degri *et al.,* 2014).

Similar to the level of pest infestation and density, yield parameters such as the number of attacked ears and the proportion of attacked ears per plant were also higher in the pure crop plots (corn alone) than in the corn/peanut or corn/cowpea combination plots. However, the low infestation rates and damage levels observed on corn plants grown in association were not correlated with an increase in grain yield. In fact, several authors who have worked on corn stem borers have already reported that lower damage levels on a given corn variety do not necessarily translate into higher grain yields. For example, Kumar (2002) reported that some hybrids, even though they had less FAW damage, had significantly lower yields than those with higher damage. Also, Betbeder *et al.* (1994) reported that the susceptibility of cereal plants to stem borers should also be well determined, as the reduction in grain productivity of the cereal does not necessarily depend on the intensity of damage. As a result, they recommended examining genetic material not only at the phenological stages when attacks occur, but also at harvest to better assess the real impact of these pests on cereal production.

In fact, the pure corn crop, although heavily attacked in its vegetative phase, manages to overcome the damage inflicted by the pest from tillering to heading. Several studies into the relationship between AW infestation and crop response have indicated that corn plants can tolerate damage. However, the level of tolerance depends on the particular environment and pest ecology. It has been reported that corn plants recover from injury and are tolerant of damage in agro-ecological zones, where the climate does not allow rapid pest development and continuous re-infestation of the crop (Brown and Mohamed, 1972; Harrison, 1984; Buntin, 1986). The response of corn plants to FAW damage is influenced by several biotic and abiotic factors. However, the absence of control treatments in our trial, i.e. treatments without the pest, does not allow us to go any further into the potential of other factors that could shed more light on the yield losses directly inflicted on each type of crop by FAW attack.

Conclusion

This work aims to develop strategies for the management of the fall armyworm (CLA), *Spodoptera frugiperda*. The study reveals that combining maize with legumes such as groundnuts and cowpeas is an effective method for reducing CLA populations. These results show a significant reduction in damage in intercropped plots compared with pure maize crops, attributed in part to the increased attraction of natural enemies and the dilution of resources for the pest. The maize/arachid combination reduced CLA attacks by around 14% and larvae numbers by 25%, while favouring three times as many natural enemies compared with pure maize cultivation. Despite these damage reductions, moderate levels of damage do not always translate into significant yield increases. Variations in damage at different stages of maize growth highlight the complexity of the interaction between CLA infestation and plant response. These results validate the efficacy of maize/arachid and maize/cowpea associations for the integrated management of CLA, but further research is needed to better understand the mechanisms involved and assess their impact on crop yield.

Acknowledgments

We gratefully acknowledge the Korea- Africa Food and Agriculture Cooperation Initiative KAFACI for funding this work.

References

Ayala OR, Navarro F, Virla EG. 2013. Evaluation of the attack rates and level of damages by the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), affecting corn-crops in the northeast of Argentina. Revista de La Facultad de Ciencias Agrarias **45**(2), 1-12.

Betbeder MM, Goebel FR, Ratnadass A. 1994. Lutte intégrée contre les foreurs de céréales tropicales : évaluation de la résistance variétale aux ravageurs. In : Conférence internationale sur les ravageurs en agriculture 3, Montpellier, France, 7 Décembre 1993.

Boyombe LL, Nguo E, Malaisse F, Monzenga JC. 2021. Incidence de la chenille légionnaire d'automne (*Spodoptera frugiperda* J.E. Smith) et niveau de connaissance de ce ravageur par les agriculteurs de Kisangani et ses environs, R.D. Congo. Revue internationale de géologie, de géographie et d'écologie tropicales **45**(1), 103-111.

Brown ES, Mohamed AKA. 1972. The relation between simulated armyworm damage and crop-loss in maize and sorghum. East African Agricultural and Forestry Journal **37**(3), 237-257. https://doi.org/10.1080/00128325.1972.11662534.

Buntin GD. 1986. A review of plant response to fall armyworm, *Spodoptera frugiperda* (J. E. Smith), injury in selected field and forage crops. Florida Entomologist **69**(3), 549-559. https://doi.org/10.2307/3495389.

Colley MR, Luna JM. 2000. Relative attractiveness of potential beneficial insectary plants to aphidophagous hoverflies (Diptera: Syrphidae). Environmental Entomology **29**(5), 1054-1059. https://doi.org/10.1603/0046-225X-29.5.1054.

Dassou AG, Tixier P. 2016. Response of pest control by generalist predators to local-scale plant diversity: A meta-analysis. Ecology and Evolution **6**(4), 1143-1153. https://doi.org/10.1002/ece3.1917.

Davis FM, Williams WP, Wiseman BR. 1989. Methods used to screen maize and to determine mechanisms of resistance to the southwestern corn borer and fall armyworm, 101-108p.

Degri MM, Mailafiya DM, Mshelia JS. 2014. Effect of intercropping pattern on stem borer infestation in pearl millet (*Pennisetum glaucum* L.) grown in the Nigerian Sudan Savannah. Advances in Entomology **2**(2), 81-86. https://doi.org/10.4236/ae.2014.22014.

Eilenberg J, Hajek A, Lomer C. 2001. Suggestions for unifying the terminology in biological control. Biocontrol **46**, 387-400.

FAO. 2017. Training manual on Fall Armyworm. FAO, Rome, 202p.

FAO. 2018. Gestion intégrée de la chenille légionnaire d'automne sur le maïs. 147p.

Gross HR, Young JR, Wiseman BR. 1982. Relative susceptibility of a summer-planted dent and tropical flint corn variety to whorl stage damage by the fall armyworm (Lepidoptera: Noctuidae). Journal of Economic Entomology **75**, 1153–1156.

Gurr GM, Wratten SD, Landis DA, You M. 2017. Habitat management to suppress pest populations: progress and prospects. Annual Review of Entomology **62**(1), 91-109. https://doi.org/10.1146/annurev-ento-031616-035050.

Hailu G, Niassy S, Zeyaur KR, Ochatum N, Subramanian S. 2018. Maize–legume intercropping and push–pull for management of fall armyworm, stemborers, and striga in Uganda. Agronomy Journal **110**(6), 2513-2522. https://doi.org/10.2134/agronj2018.02.0110.

Harrison FP. 1984. Observation of the infestation of corn by fall armyworm (Lepidoptera: Noctuidae) with reference to plant maturity. Florida Entomologist **67**(3), 333-339.

Hooks CRR, Johnson MW. 2003. Impact of agricultural diversification on the insect community of cruciferous crops. Crop Protection **22**(2), 223-238. https://doi.org/10.1016/S0261-2194(02)00172-2.

Hruska AJ. 2019. Fall armyworm (*Spodoptera frugiperda*) management by smallholders. CABI Reviews, 1-11. https://doi.org/10.1079/PAVSNNR201914043.

Huesing JE, Eddy R, Peschke VM. 2018. Fall armyworm in Africa: A guide for integrated pest management. CDMX, Mexico: CIMMYT, 11-28.

Khan ZR, Chiliswa P, Ampong-Nyarko K, Smart LE, Polaszek A, Wandera J, Mulaa MA. 1997. Utilization of wild gramineous plants for management of cereal stemborers in Africa. International Journal of Tropical Insect Science **17**(1), 143-150. https://doi.org/10.1017/S1742758400022268.

Kumar H, Mihm JA. 2002. Fall armyworm (Lepidoptera: Noctuidae), southwestern corn borer (Lepidoptera: Pyralidae) and sugarcane borer (Lepidoptera: Pyralidae) damage and grain yield of four maize hybrids in relation to four tillage systems. Crop Protection **21**(2), 121-128. https://doi.org/10.1016/S0261-2194(01)00071-0.

Landis DA, Menalled FD, Costamagna AC, Wilkinson TK. 2005. Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes. Weed Science **53**(6), 902-908. https://doi.org/10.1614/WS-04-050R1.1.

Langer V, Kinane J, Lyngkjær M. 2007. Intercropping for pest management: the ecological concept. In: Koul O, Cuperus GW, ed. Ecologically based integrated pest management. Wallingford: CABI Publishing, 74-109.

Letourneau DK, Armbrecht I, Rivera BS, Lerma JM, Carmona EJ, Daza MC, Escobar S, Galindo V, Gutiérrez C, López SD, Mejía JL, Rangel AMA, Rangel JH, Rivera L, Saavedra CA, Torres AM, Trujillo AR. 2011. Does plant diversity benefit agroecosystems? A synthetic review. Ecological Applications **21**, 9-21. https://doi.org/10.1890/09-2026.1.

Matusso JMM, Mugwe JN, Mucheru-Muna M. 2014. Effects of different maize (*Zea mays* L.) soybean (*Glycine max* (L.) Merrill) intercropping patterns on soil mineral-N, N-uptake and soil properties. African Journal of Agricultural Research **9**(1), 42-55. https://doi.org/10.5897/AJAR2013.7178.

McGrath D, Huesing JE, Beiriger R, Nuessly G, Tepa-Yotto TG, Hodson D, Kimathi E, Felege E, Abah-Obaje J, Mulaa M, Mendes AP, Amer-Mabrouk AF, Belayneh Y. 2018. Monitoring, surveillance, and scouting for fall armyworm. In: Prasanna BM, Huesing JE, Eddy R, Peschke VM, ed. Fall Armyworm in Africa: A Guide for Integrated Pest Management. CDMX, Mexico, 11-28.

Moïse MK, Eloge KM, Moïse KK, Florence KM, Kanyere P, Difo MS, Paul PMJ. 2022. Influence des systèmes de culture sur l'incidence et sévérité de la mosaïque africaine du manioc en localité de Kivira (Nord-Kivu, RD Congo). International Journal of Innovation and Applied Studies **36**(2), 435-448.

Morrison TA, Jung HG, Buxton DR, Hatfield RD. 1998. Cell-wall composition of maize internodes of varying maturity. Crop Sciences **38**, 455-460.

Mutyambai DM, Niassy S, Calatayud PA, Subramanian S. 2022. Agronomic factors influencing fall armyworm (*Spodoptera frugiperda*) infestation and damage and its co-occurrence with stemborers in maize cropping systems in Kenya. Insects **13**(3), 266. https://doi.org/10.3390/insects13030266.

Navik O, Shylesha AN, Patil J, Venkatesan T, Lalitha Y, Ashika TR. 2021. Damage, distribution and natural enemies of invasive fall armyworm *Spodoptera frugiperda* (J. E. Smith) under rainfed maize in Karnataka, India. Crop Protection **143**, 105536. https://doi.org/10.1016/j.cropro.2021.105536.

Obodji A, Aboua LRN, Tano DKC, Seri-Kouassi BP. 2016. Inventory of entomofauna associated with African eggplant (*Solanum aethiopicum* L.) according to the phenological stages: assessment of damages caused by insect pests. Journal of Advanced Studies in Agricultural and Environmental Sciences **3**, 2455-0221.

Osborne JL, Loxdale HD, Woiwod IP. 2002. Monitoring insect dispersal: methods and approaches. In: Bullock JB, Kenward RE, Hails RS, ed. Dispersal Ecology. Oxford, UK: Blackwell Publishing, 24-49.

Perrin RM. 1977. Pest management in multiple cropping systems. Agro-ecosystems **3**, 93-118. https://doi.org/10.1016/0304-3746(76)90110-4.

Root RB. 1973. The organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards, Brassica oleracea. Ecological Monographs **43**, 95-124.

Scheidegger L, Niassy S, Midega C, Chiriboga X, Delabays N, Lefort F, Zürcher R, Hailu G, Khan Z, Subramanian S. 2021. The role of Desmodium intortum, Brachiaria sp. and Phaseolus vulgaris in the management of fall armyworm *Spodoptera frugiperda* (J. E. Smith) in maize cropping systems in Africa. Pest Management Science **77**(5), 2350-2357. https://doi.org/10.1002/ps.6261.

Tahvanainen JO, Root RB. 1972. The influence of vegetational diversity on the population ecology of a specialized herbivore, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae). Oecologia **10**(4), 321-346. https://doi.org/10.1007/BF00345736.

Wiseman BR. 1994. Mechanisms of maize resistance to corn earworm and fall armyworm. Proceedings of an International Symposium held at the International Maize and Wheat Improvement Center (CIMMYT), Insect Resistant Maize, 46-54.

Wyckhuys KAG, O'Neil RJ. 2006. Population dynamics of *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) and associated arthropod natural enemies in Honduran subsistence maize. Crop Protection **25**(11), 1180-1190. https://doi.org/10.1016/j.cropro.2006.03.003.

Yeboué NL, Foua-Bi K, Kéhé M. 2002. Inventaire de l'entomofaune associée à la culture du gombo (*Abelmoschus esculentus* L.) en zone forestière de la Côte d'Ivoire. Agronomie Africaine (AISA) **14**(3), 165-181.