The Journal of Agricultural Sciences - Sri Lanka
Vol. 19, No 1, January 2024. Pp 131-141
https://doi.org/10.4038/jas.v19i1.10007

Impact Assessment of Fall Armyworm (*Spodoptera frugiperda* J.E. Smith) Damage and Control on Smallholder Maize Fields of Anuradhapura District, Sri Lanka

D.K. Hettiarachchi[1*], H.H.M.I.D. Hearth[1], A.V. Weerakoon[1], R.P.U. Prasad[1], S.M.M.T. Senarathne[1], K.M.R.K.T. Herath[1], M.K.D.D. Sandaruwan[2], N.D.A.D. Wijegunawardhana[3] and N.W.B.A.L. Udayanga[4]

Received:01st November 2022 / Accepted: 14th November 2023

ABSTRACT

Purpose: *Limited information is available on Fall Armyworm (FAW) and its agricultural burden in Sri Lanka. This is the first study conducted aimed at evaluating the level of economic damage caused by FAW in maize fields in the Anuradhapura district during the Maha season 2019-2020, along with the economic impacts on small-scale farmers.*

Research Method: *Five small-scale maize farming sites were selected, along with another maize-cultivated area as the control site. General farming practices were allowed and observed in the sampling sites, while the maize cultivation at the control site was not treated with any pest management practices. A total of 150 maize plants were monitored. The percentage of damage was calculated for each study site, and the expenditures from the land preparation to harvesting were recorded, along with the final yield.*

Findings: *The highest percentage of mean FAW-damaged plants was reported during the fifth week as 28.5% in farmer fields, while the control site reported a >80% rate of damaged plants. The average dry yield received from the investigated sites was 1,162.2 kg/acre and the average income was Rs. 75,543, along with an average profit of Rs. 31,051 per acre. Meanwhile, the control plots yielded only 224.8 kg of maize/acre.*

Research Limitation: *Collecting information from the farmer's side and unexpected attacks from elephants on the selected corn fields has been the biggest challenge.*

Originality/value: *The study highlights the need for sustainable Integrated Pest Management (IPM) options, along with due attention to biological control methods in controlling FAW.*

Keywords: *Agriculture, Biological Control, Economic Impact, Insecticides, Integrated Pest Management*

INTRODUCTION

Maize, which is considered the second most important cereal crop in Sri Lanka, is widely used in both food and feed industries (Hamangoda and Pushpakumari, 2020). Maize has received increased attention in recent years, especially among small-scale farmers, due to increased local demand with the expansion of the animal feed industry. It is grown in the dry and intermediate zones in Sri Lanka, mainly as rain-fed cultivation during the *Maha* (September to March) and *Yala*

[1*] *Department of Biological Sciences, Faculty of Applied Sciences, Rajarata University of Sri Lanka, Mihintale, Anuradhapura, Sri Lanka.*

dilanikh@as.rjt.ac.lk

[2] *Department of Physical Sciences, Faculty of Applied Sciences, Rajarata University of Sri Lanka, Mihintale, Anuradhapura, Sri Lanka.*

[3] *Department of Bioprocess Technology, Faculty of Technology, Rajarata University of Sri Lanka, Mihintale, Anuradhapura, Sri Lanka.*

[4] *Department of Bio-Systems Engineering, Faculty of Agriculture & Plantation Management, Wayamba University of Sri Lanka, Makandura (NWP), Kurunegala, Sri Lanka.*

https://orcid.org/0000-0002-9160-6686

season (May to August). The Anuradhapura District receives a higher degree of rainfall during the *Maha* season due to the Northeast -Monsoon (Malaviarachchi *et al.*, 2014; Perera *et al.*, 2019). Even though this cropping system is characterized by lower productivity due to erratic weather patterns, biotic stress, and poor adoption of agricultural practices in comparison to irrigated agriculture, maize has shown a high potential yield (Sudeera *et al.,* 2019). The average production of maize per hectare has increased from 3.68 tons per hectare (t/ha) in 2016/17 to 3.80 t/ha in 2017/18, and to 3.87 t/ha in 2018/19 *Maha* seasons (Hamangoda and Pushpakumari, 2018; 2019; 2020). Even though, the expected production of maize in Sri Lanka was 303,244 MT (metric tons) during the 2019/2020 *Maha* season, only 76% (230,465 MT) was achieved. Further, around 34% (103,725 MT) of the total production came from the Anuradhapura district, followed by Monaragala (33%; 99,258 MT) and Ampara (17%; 50,054 MT) districts (Sudeera *et al.,* 2019). Therefore, the Anuradhapura district remains the major maize-producing region in the country.

The major recorded pest of maize was elephants, until 2018 (Santiapillai *et al.,* 2010). The first emergence of the Fall Armyworm (FAW) [*Spodoptera frugiperda:* Lepidoptera: Noctuidae] in Sri Lanka was reported in 2018 from the Ampara District, as an accidental introduction (Perera *et al.*, 2019). During the *Maha* season (2018/2019) over 50% of the maize cultivation (54,416 hectares) was infested by the pest FAW (Perera *et al.,* 2019). The absence of natural enemies, poor knowledge of FAW management, and the higher abundance of food have resulted in substantial damage to maize cultivations during the later months of 2018 and the first few months of 2019. Further, FAW has several characteristics that make it hard to control such as; the strong flying ability of moths, rapid reproduction, and the ability of the larvae to feed on a wide range of plants including maize, rice, tomatoes, pepper, and many other crops (Barlow and Kuhar, 2005) and to develop resistance to pesticides (Pantoja-Lopez, 1985; Yu, 1991). Therefore, FAW can be considered one of the worst pest species, especially for maize. However, even though the FAW could be controlled with time, the extent of damage that could be caused by FAW within the Sri Lankan agricultural system remained a question.

Perera *et al.* (2019) have addressed the Rathnapura District perspective on FAW epidemics with a thorough description of *Spodoptera frugiperda*. In addition, Wijerathna *et al.* (2020) have studied the feeding preferences of newly hatched FAW larvae in laboratory settings and concluded that in the absence of the preferred host maize, the FAW larvae tend to depend on cabbage, okra, beans, and radish as alternative hosts for oviposition. However, more detailed and reliable data regarding the FAW in Sri Lanka has been limited, since its introduction.

Therefore, it is timely to investigate the actual field observations of FAW and the efficacy of different pest control practices used by the farmers to control FAW. In most of the preliminary surveys conducted, farmers have complained regarding the damage to their maize farms by FAW and the health and financial costs related to the usage of high levels of pesticides to mitigate the damage. Therefore, the current study attempts to investigate the degree of damage caused by FAW in maize fields in selected areas of the Anuradhapura district during the *Maha* season 2020 along with the economic impacts on small-scale farmers, while evaluating the efficacy of pest control methods implemented by the farmers. The findings of this study will be immensely important in decision-making and policymaking, concerning FAW management in Sri Lanka.

MATERIALS AND METHODS

Sampling Sites

Farmers engage in maize cultivation from September to March (*Maha* season) and May to August (*Yala* season) in the Anuradhapura district, depending on the rain. This study was conducted in the *Maha* season in five selected small-scale farmlands (Table 01), namely Mihinthale (S1), Galenbindunuwewa (S2), Horowpathana (S3), Kahatagasdigiliya (S4) and Nuwaragampalatha East (S5). The site selection was done by consulting an agricultural field officer. Most maize cultivar in the Anuradhapura district is concentrated in Villachchiya, Kahatagasdigiliya, Galenbindunuwewa, Kekirawa, and Mihinthale, and this fact was taken into consideration during site selection (personal communication with Agricultural Field Officers). A control plot was cultivated at Mihinthale near Rajarata University of Sri Lanka (8°27′12.054″ N; 80°19′44.022″ E) without applying any pesticides to estimate the actual damage. This land was surrounded by vegetable fields and human dwellings. The control plot contained 150 maize plants, for which only fertilizers were applied without any pesticides.

Methodology

Each field (Fig. 01) was visited once a week from the seed planting stage to the maize harvesting stage, from October 2020 to March 2021. Scouting was done in each sampling site in selected locations (eight locations within each field) that represent the whole maize field.

Sampling plants were selected by walking in a “W” pattern in the field after leaving 4-5 outer rows as shown in Fig. 02 (Suby *et.al.*, 2019). Thirty plants were selected at each stopping point, which represented the corners of “W” and the number of damaged plants, the presence of FAW larval stages (if any), and other pests were recorded along with any other special observations. The morphological descriptions by Bhavani *et al.* (2019) and Perera *et al.* (2019) were used for FAW identification and the assessment of damaged plants. Observations were conducted from the seed planting stage to the harvesting stage. If FAW feeding damage or FAW larvae were found in one maize plant, the percentage of infection was calculated.

Farmer practices in applying pesticides, fertilizers, and other traditional pest control methods were carefully observed and recorded. At the end of the growing season, the harvest received from each plant (dry weight of seeds) was also recorded.

Table 01: Details of study sites considered for the investigation of the degree of damage of falls armyworm on small-scale farmers during the *Maha* season 2020 in Anuradhapura district.

Study Site	Reference Number	Coordinates		Extent acres	Boundaries
		Latitude	Longitude		
Mihinthale	S1	8°20′36.444″ N	80°34′53.412″E	5	North maize fields, South human dwelling, West maize fields, East human dwelling.
Galenbindunuwewa	S2	N8°19′30.894″	E80°39′52.758″	2	East government storage facility, North and West small forest patches with a water body, South is the main road.
Horowpathana	S3	N8°28′27.03″	E80°45′15.186″	1	North maize fields, East, South and West are human dwells.
Kahatagasdigiliya	S4	N8°24′23.947″	E80°39′13.932″	2	East there is a mahogany land; West and South maize fields and North paddy fields.
Nuwaragampalatha East	S5	N8°27′12.054″	E80°19′44.022″	3	Surrounding lands were maize fields.
Control	C1	8°27′12.054″ N	80°19′44.022″ E	1	Surrounded by vegetable fields and human dwellings.

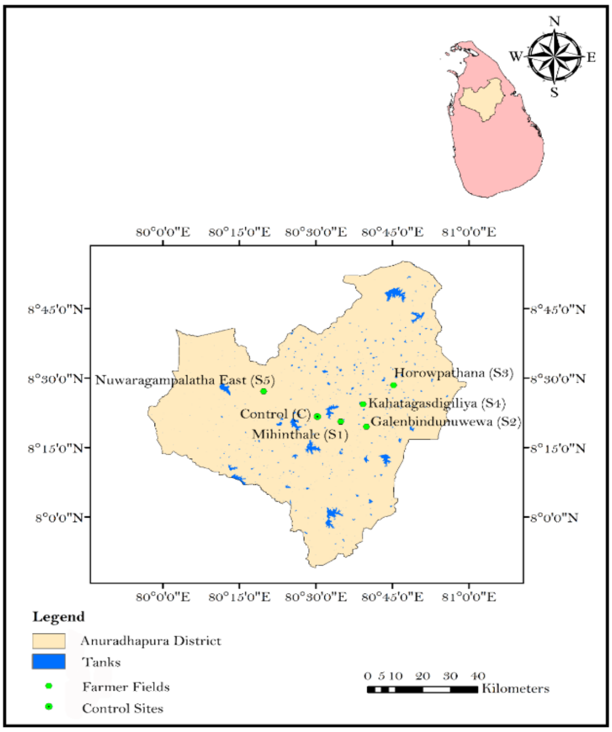

Figure 01: **Location of the study sites selected to investigate the damage to small scale farms by fall armyworm at Anuradhapura District in *Maha* season 2020.**

Data Interpretation and Statistical Analysis

The mean percentage of FAW-damaged plants was calculated for all the study sites at weekly intervals. The paired Chi-square test was used to investigate the significance of the mean percentage of FAW-damaged plant rates in sampling sites and control sites. The market price of 1 kg of dried maize grain ranged from Rs 60 to Rs. 70 in 2021 and the average of this range (Rs. 65) was taken to calculate the total income received from maize cultivation from each study site within the study period. The potential income that can be expected under a scenario without FAW damage was calculated by using the maize production data for 2016/2017 during the *Maha* season (Hamangoda and Pushpakumari, 2018). A similar price for 1 kg of 1 kg dried maize (Rs. 65) was used during calculation, while other expenses from land preparation to harvesting were assumed to be equal under each scenario.

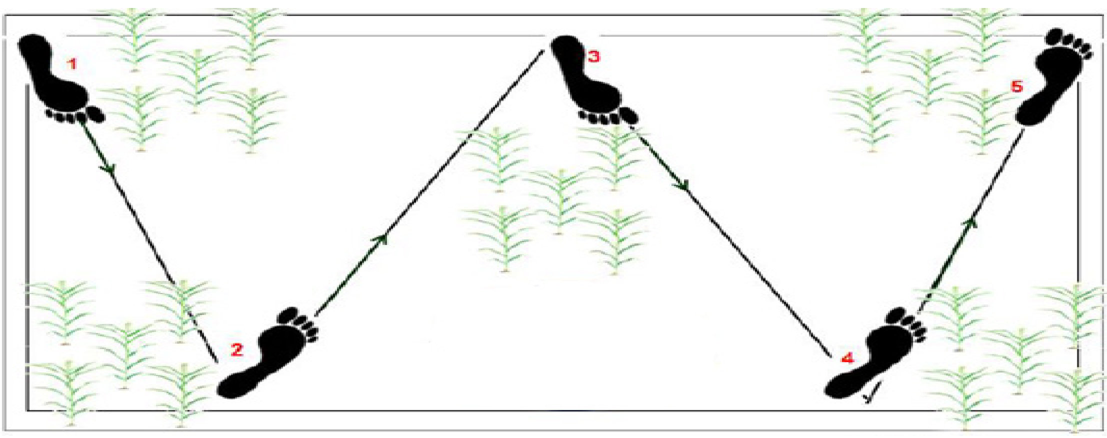

Figure 02: **Scouting methodology used in identifying the damage of fall armyworm at each selected small scale farm site located at Anuradhapura district [source: Suby 2019].**

RESULTS AND DISCUSSION

Maize fields were prepared using a tractor and the seed planting spacing was maintained as 30 cm x 60 cm. The starting time of seed planting was not similar in all five sampling sites. After seed planting, a weedicide was sprayed by the farmers. After 7 – 8 days seedlings started to emerge and fertilizers were applied to the field between the second and fourth weeks. First FAW damage was reported in the third week since seed sowing, at all the study sites, where the seedlings had only 3 - 4 leaves, along with an average plant height of 6.0±0.1 inches. Among the sampling sites, the FAW damage was more prominent in Nuwaragampalatha East (S5) site (20%), while Mihinthale (S1) and Horowpathana (S3) sites reported relatively lower (2%) FAW damage rates in maize seedlings for the first three weeks (Fig. 03). Light tan-colored FAW larval stages having three yellowish-white lines (first instar larvae), with a total length of 2 – 4 mm were observed during this stage. As a whole, the mean percentage of damaged plants in all five sites remained around 10.7% during the third week after seed sowing.

It was witnessed that there was no synchronization when planting maize. Starting maize cultivation in adjacent fields at different times could also be a key reason for the elevated damage rates by FAW. Having different planting stages around a field will give opportunities for FAW moths to survive throughout and transfer from one nearby field to another for egg-laying (Bhavani *et al.* 2019). Farmers need to be aware of this and they have to organize and initiate maize cultivation during the same planting period. For this, the extension officers of the Agrarian Service Departments and the Agriculture Instructors of the Department of Agriculture have to play a key role in raising awareness among the farmers regarding the aforementioned aspects.

Based on the mean percentage rates of FAW-damaged plants, the highest FAW damage rates had been reported during the 4th to 5th week, which had declined gradually due to the pesticide applications (Fig. 04). A similar trend was observed from the control site also, while the percentage of FAW-damaged plant rates was significantly higher (*P<0.01* at 95% degrees of confidence). The FAW damaged plant rates, which were initiated during the 3rd week, have reported the peak during the 5th week, denoting that the first pesticide application should be done in the 3rd week, rather than waiting for the 4th week (Fig. 04).

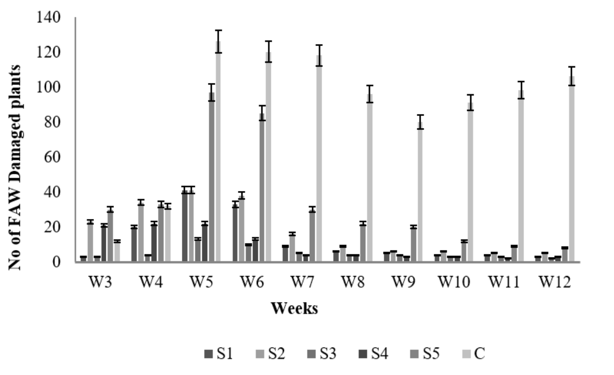

Figure 03: **Number of maize plants damaged by fall armyworm (FAW - *Spodoptera fugiperda*) at weekly intervals. Number of plants per site= 150; S1 – Mihinthale, S2 – Galenbindunuwewa, S3 - Horowpathana, S4 - Kahatagasdigiliya, S5 – Nuwaragampalatha East, C- Control plot at Mihintale.**

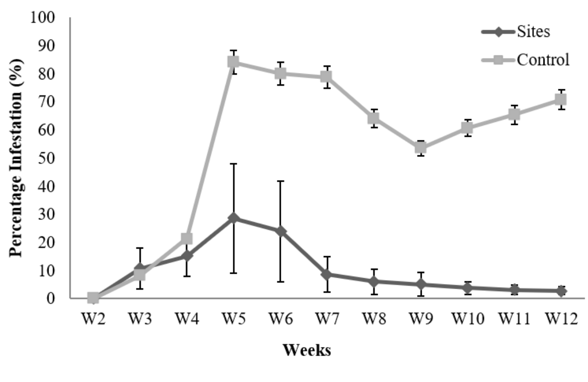

Figure 04: **Variation of the mean percentage of fall armyworm infestation at selected sampling sites (Mihinthale, Galenbindunuwewa, Horowpathana, Kahatagasdigiliya, Nuwaragampalatha East) in *Maha* season 2020 and at the control plot at Mihintale. Total number of observed plants = 150 per site.**

The most potential stage of damage for FAW starts after the third week and persists up to the sixth week from seed planting, making it necessary for farmers to take measures during this period to safeguard their maize fields. Detecting the presence of initial stages of FAW, before they cause economic damage is a key step in FAW management (Assefa and Ayalew, 2019). It is recommended to apply an effective control measure if 5% of the seedlings are cut or 20% of the whorls of small plants are infested with FAW during the first 30 days (Gebreziher, 2020).

Notably, high rainfall was received during October, November and December 2020 and January 2021. The authors observed a re-emergence trend in plants that were heavily infested with larvae of FAW, after exposure to heavy rain for a prolonged period during this investigation. Once the whorl is covered with water most larvae were found dead in some maize plants. Maize plants need water during the growing season. It has been estimated that a total of 456.9 mm of water, with a mean daily consumptive rate of 4.22 mm is essential for the plant based on the Blaney-Criddle method (Udom and Kamalu, 2019). However the effect of rainfall on the longevity of FAW larval stages was not found in the literature.

Further, it was noted that application of insecticides was used by the farmers, as soon as the larval stages were detected, without considering other traditional and manual controlling methods. Pesticides were applied, directly to the whorl of the plant, in all five sites at the beginning of the fourth week, which reported a slight decrease in the number of damaged plants (Fig. 04). Direct application of insecticides can cause adverse effects on the soil and negatively influence other naturally occurring insect fauna and potential biocontrol agents (Damalas and Eleftherohorinos, 2011). This may be one of the reasons for not observing any other insects in the field during site visits. However, a study of the diversity of insect fauna in maize farmlands needs to be conducted to arrive at a precise conclusion as this was not one of the main objectives of this study. The most commonly used insecticide for FAW control in Sri Lanka is Proclaim– Emamectin benzoate (4 g with 10 liters in water), Radient - Spinoperam 25% WG (4.8 g in 16 liters of water), Coragen - Chlorantraniliprole 200 g (3 ml in 10 liters of water) and Silo – Diatomaceous Earth 100% WP (240 g in 16 liters of water). The later three, Radiant - Spinoperam 25% WG, Coragen - Chlorantraniliprole 200 g, and Silo – Diatomaceous Earth 100% WP, were used in the investigated five farming sites. One packet of wettable powder of Radiant pesticide cost Rs. 1,620 and for an acre of land six packets were sprayed after dissolving in water. In the Horowpathana site (S3), the farmers used manual removal of damaged plants and sprayed ash simultaneously with the pesticide. However, in all five states, the percentage mean FAW-damaged plants increased up to 28.5% by the fifth week, reporting the highest percentage rate of damaged plants (Fig. 04), where 6 - 7 leaves were in the plants, with an average plant height of 14±0.2 inches. Third and fourth larval instars of FAW were detected at this stage, which led farmers to reapply pesticides again in all the sites during the sixth and seventh weeks. The control site was not sprayed with insecticides even though there were visible damage signs. It is noteworthy that farmers did not apply pesticides at the same time during the day. In four sites pesticides were applied during the evenings, whereas pesticides were applied during the morning (around 9 a.m.) at the Nuwaragampalatha farmer field site (S5).

The effect of pesticides seemed to be less in this site (S5) compared to other sites (Fig. 03 and Fig. 04). It was evident that the Nuwaragampalatha farmer field (Site S5), reported the relatively highest FAW damage rates among the studied sites, except for the control site (Fig. 03 and Fig. 04). This might be due to several reasons: the farmer applied the insecticides in the morning around 9 a.m. when most of the larvae were hiding inside the whorl. In other sites, insecticides were applied during the afternoon, when larvae were visible outside. The promising results attained by other farmers (decline in the infestation rates of FAW) suggest that the best time to spray insecticides for FAW control is after 3 pm. However further investigations need to be done to conclude regarding the best time to spray the insecticide, which may be influenced by the mode of action of the insecticide and the mode of entry. Thus , careful analysis of the chemicals sprayed is also essential when determining the best time to apply the chemical insecticides. A few recent studies conducted in controlling invasive pests while protecting pollinators and other beneficial insects have suggested that the application of insecticides during the evening is more effective in FAW control (Karbassioon and Stanley, 2023). However, poor awareness of the farmers regarding the phase of insecticide application and the ideal time for application has resulted in a notable level of damage to their fields by the FAW. Even though these insecticides are effective for the time being it should be noted that the FAW can acquire resistance against insecticides if exposed to a prolonged period, which makes it more difficult to control (Storer *et al.,* 2010; Yu, 1991).

After the seventh week where the plant had 8 - 9 leaves with an average height of 17±0.1 inches, the FAW infestation showed a declining trend at all the sites. Plant growth was rapid after the 8th week, reporting a rapid increment from an average height of 21±0.1 inches to an average height of 38±0.1 inches by the 9th week, and 45±0.1 inches by the end of the 10th week. Silk and tassels (reproductive structures) emerged after the 8th week. There was a decrease in visual infestation in the maize plants after the 8th week. Even though some FAW-damaged maize plants produced silk and ears, they were relatively smaller in size.

The Larval damage caused by FAW on maize plants varied from scraping and skeletonizing of leaves, holes in the leaves, and damage to tassels (Fig. 05). Occasionally, some FAW larvae were found inside the developing ear, eating away the grain. The presence of a large number of fecal pellets in whorls was also commonly observed. The sampled 150 maize plants in the control plot, which was kept without using any controlling methods, resulted in a yield of 1.5 kg of dry grains, only. Considering the planting space (60 cm x 30 cm), 1 acre of land (22,483 maize plants) under a similar situation shall produce 224.8 kg/acre. On the contrary, the sampling sites that underwent pest management strategies reported an average yield of 1,162.2 kg/acre.

Figure 05: Various forms of visible damage by fall armyworm to maize plants in the field

The average expenditure rates for maize cultivation from the land preparation to the harvesting are presented in Table 02. It was noted that a total of approximately Rs. 45,200 has to be spent for the cultivation and maintenance of 1-acre land of maize. Once harvested farmers sundry the grains for about 3 - 5 days and sell them to intermediate buyers. In 2020, 1 kg of dry maize grains was priced between Rs. 60 to Rs. 70. Therefore, an average price rate of Rs. 65 for 1 kg of maize was assumed for the income calculation shown in Table 03. The highest maize yield was reported from the Horowpathana (S3) site as 1,302 kg/acre. The average yield per acre of the farmer's fields was 1,162.2 kg/acre and the average income was around Rs. 75,543 per acre, resulting in an average profit of Rs. 31,051 per acre. From the data extracted from the Agricultural Department of Sri Lanka, in the 2016/2017 *Maha* season a maize yield of 1,489.24 kg/acre was reported (Hamangoda and Pushpakumari, 2018). If the income uses the selling price of 2021 (Rs. 65), the income could be estimated as Rs. 96,800 per acre. As there were no FAW infestations reported in 2016/17, the profit of maize cultivation could be estimated at approximately Rs. 54,900 per acre, assuming similar costs as experienced in 2021, along with a situation where minimal or no insecticides are used. Meanwhile, the control site, which was not applied with any insecticide yielded only 224.8 kg of maize per acre, resulting in a loss of Rs. 15,388.

Table 02: Average expenditure levels of maize cultivation for a one-acre land of a small-scale farm in Anuradhapura district for the *Maha* season of the year 2020 (Labor requirements depend on the farmer's needs).

Activity	Description	Cost (Rs)
Land preparation		5,000
Seeds	1 pack	7,950
Labor for planting	4 people x Rs. 1500	6,000
Weedicide	1 pack	4,950
Fertilizer		
1st round (2nd week)	Urea 50 kg	1,500
	MOP (Mud fertilizers) 25 kg	1,000
2nd round (4th week)	Urea 50 kg	1,500
	TSP 25 kg ("Rathu Kudu")	1,000
Labor for fertilizer application	Rs. 1500 x 2 days x 2 people	6,000
Insecticide for FAW	Radiant (6 packs x Rs. 270) x 2	3,300
Harvesting	2 people x 2 days x Rs. 1500	3,000
Grain separator machine		1,500
Miscellaneous		2,500
Total		45,200

Table 03: Expenditure, yield, income and profit per acre of land of the small-scale farming sites selected to investigate the damage of falls armyworm at Anuradhapura district in 2020.

Site	Expenditure (Rs/acre)	Yeild (kg/acre)	Income (Rs/acre)	Profit (Rs/acre)
Mihinthale (S1)	41,900	1,210	78,650	36,750
Galenbindunuwewa (S2)	46,760	1,066	69,290	22,530
Horowpathana (S3)	43,520	1,302	84,630	41,110
Kahatagasdigiliya (S4)	41,900	1,215	78,975	37,075
Nuwaragampalatha (S5)	48,380	1,018	66,170	17,190
Control	30,000	224.8	14,612	-15,388

Sri Lanka must exercise caution while dealing with the FAW given the significant decline in income from maize farming expected in 2021, particularly given that the nation is moving toward a chemical pesticide-free environment. More traditional and mechanical methods need to be introduced and popularized with the farmer community while promoting integrated FAW management. Extension agents, agriculture instructors, and farmer organizations must all take an active part in this. Regular scouting in the field at 3 -4 day intervals especially during the first 40 days after seed planting, use of light traps during the night, use of specific pheromone traps (involving [(*Z*)–7– dodecyl acetate (*Z*)–7-12: Ac], (*Z*)–9– dodecenyl acetate (*Z*)-9-12:Ac, (Z)-9-tetradecenyl acetate (Z)-9-14: Ac), and (Z)-11hexadecenyl acetate), use of pathogen/ pest free plant materials, avoiding late planting, optimum fertilization, proper irrigation, removal of damaged plants, handpicking of FAW larvae, introducing sand mixed with lime or ash in the whorl of attacked maize, intercropping with repellent plants to repel the pest and attracting plants to attract natural enemies of the pest are some key strategies that Sri Lankan farmers can practice for FAW management (Assefa and Ayalew, 2019; Gebreziher, 2020). In addition, searching for natural enemies of FAW to be used as potential biological control agents is also essential. In South India 5 species of larval parasitoids, 3 predators and 1 entomopathogen have been found as potential biological control agents of FAW larvae (Sharanabasappa *et al*., 2019). Even though economic threshold levels have not been calculated for maize in Sri Lanka, similar damage could lead to significant economic losses with time.

CONCLUSION

It is evident that more than 80% of damage is visible if insecticides are not applied to control the FAW damage but the time of insecticide application and the stage of the plant are two important factors to consider. Farmers should be encouraged to practice a mix of controlling mechanisms without solely depending on chemical controls when dealing with FAW. As FAW is a new pest species in the country there are many information gaps about biology, ecology, dispersal mechanism, host range and effective preventive actions, which need comprehensive monitoring and research. Farmer education is a must, especially because of the extensive impacts caused by FAW on similar cultivations in other countries.

REFERENCE

Assefa, F. and Ayalew, D. (2019). Status and control measures of fall armyworm (Spodoptera frugiperda) infestations in maize fields in Ethiopia: A review. *Cogent Food & Agriculture.* 5: 1641902. DOI:10.1080/23311932.2019.1641902.

Barlow, V.M. (2009). Fall armyworm in vegetable crops. Publication 444–015, Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, Virginia State, Petersburg. https://vtechworks.lib.vt. edu/bitstream / handle/10919/50385/444-015.pdf.

Bhavani, B., Chandra Sekhar, V., Kishore Varma, P., Bharatha Lakshmi, M., Jamuna, P. and Swapna, B. (2019). Morphological and molecular identification of an invasive insect pest, fall armyworm, *Spodoptera frugiperda* occurring on sugarcane in Andhra Pradesh, India. *Journal of Entomology and Zoology Studies*. 7(4), 12-18. https://www. entomoljournal.com/archives/2019/vol7issue4/ PartA/7-3-306-830.pdf.

Damalas, C. A., and Eleftherohorinos, I. G. (2011). Pesticide exposure, safety issues, and risk assessment indicators. *International journal of environmental research and public health*. 8(5), 1402-1419. DOI:10.3390/ijerph8051402.

Gebreziher, H.G. (2020). Review on management methods of fall armyworm (*Spodoptera frugiperda* JE Smith) in Sub-Saharan Africa. *Institutional Journal of Entomological Research*. 5(2): 9-14. https://www.researchgate.net/publication/339713411

Hamangoda, I. and Pushpakumari, G. G. P. (2018). *AgStat*. XV. Agricultural Statistics, Socio-Economics and Planning Centre, Department of Agriculture, Peradeniya. https://doa.gov.lk/wp-content/uploads/2020/05/AgstatBK.pdf

Hamangoda, I. and Pushpakumari, G. G. P. (2019). *AgStat*. XVI.Agricultural Statistics. Socio-Economics and Planning Centre, Department of Agriculture, Peradeniya. http://doa.nsf.ac.lk/handle/1/2839?show=full

Hamangoda, I. and Pushpakumari, G.G.P. (2020). *AgStat*. XVI. Agricultural Statistics Socio-Economics and Planning Centre, Department of Agriculture, Peradeniya. http://doa.nsf.ac.lk/handle/1/3247

Karbassioon, A. and Stanley, D. A. (2023). Exploring relationships between time of day and pollinator activity in the context of pesticide use. *Basic and Applied Ecology*. https://doi.org/10.1016/j.baae.2023.06.001.

Malaviarachchi, M., De Costa, W., Fonseka, R., Kumara, J., Abhayapala, K. and Suriyagoda, L. (2014). Response of maize (*Zea mays* L.) to a temperature gradient representing long-term climate change under different soil management systems. *Tropical Agricultural Research*. 25: 327-344. http://dl.nsf.gov.lk/bitstream/handle/1/24124/PGIATAR_25_3 _327.pdf?sequence=2.

Pantoja-Lopez, A. (1985). Biology, Economic Injury, and Plant Resistance Studies With the Fall Armyworm, *Spodoptera Frugiperda* (JE Smith), on Rice, *Oryza Sativa* L.(Screening, Puerto Rico, Louisiana). Louisiana State University and Agricultural & Mechanical College. 9-28.

Perera, N., Magamage, M., Kumara, A., Galahitigama, H., Dissanayake, K., Wekumbura, C., Iddamalgoda, P., Siriwardhana, C. and Yapa, P. (2019). Fall Armyworm (FAW) Epidemic in Sri Lanka: Ratnapura District Perspectives. *International Journal of Entomological Research.* 7: 09-18. DOI: 10.33687/entomol.007.01.2887.

Santiapillai, C., Wijeyamohan, S., Bandara, G., Athurupana, R., Dissanayake, N. and Read, B. (2010). An assessment of the human-elephant conflict in Sri Lanka. *Ceylon Journal of Science (Biological Sciences)*. 39. https://www.researchgate.net/publication/228352008

Sharanabasappa, S., Kalleshwaraswamy, C. M., Poorani, J., Maruthi, M. S., Pavithra, H. B., and Diraviam, J. (2019). Natural enemies of *Spodoptera frugiperda* (JE Smith)(Lepidoptera: Noctuidae), a recent invasive pest on maize in South India. *The Florida Entomologist*. *102*(3), 619-623. https://www.jstor.org/stable/48563335.

Storer, N. P., Babcock, J. M., Schlenz, M., Meade, T., Thompson, G. D., Bing, J. W. and Huckaba, R. M. (2010). Discovery and characterization of field resistance to Bt maize: *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Puerto Rico. *Journal of Economic Entomology*. 103(4): 1031-1038. https://doi.org/10.1603/EC10040.

Suby, S. B., Lakshmi Soujanya, P. and Sekhar, J. C. (2019). Identification, Biology, Symptomatology, Monitoring and Scouting for Management of Fall Armyworm. Compendium of Lectures: Integrated Pest Management in Maize with special reference to Fall Armyworm, *Spodoptera frugiperda* (J. E Smith), India. 41-46. https://krishi.icar. gov.in/jspui/bitstream/123456789/31387/1/Final%20 compendium%20of%20lectures.pdf.

Sudeera, N. L., Herath, A., Premarathne, S., Rajakaruna, P. and Wijesekara, N. (2019). Crop Forecast Maha 2019/2020. 1. Socio-Economics & Planning Centre, Department of Agriculture, Peradeniya. http://www.doa.gov.lk/images/crop_forecast/2020/ December_2019.pdf.

Udom, B. E. and Kamalu, O. J. (2019). Crop Water Requirements during Growth Period of Maize (*Zea mays* L.) in a Moderate Permeability Soil on Coastal Plain Sands. *International Journal of Plant Research*. 9: 1-7. DIO:10.5923/j.plant.20190901.01.

Wijerathna, D. M. I. J., Ranaweera, P. H., Perera, R. N. N., Dissanayake, M. L. M. C. and Kumara, J. B. D. A. P. (2020). Biology and Feeding Preferences of *Spodoptera Frugiperda* (Lepidoptera: Noctuidae) On Maize And Selected Vegetable Crops. *The Journal of Agricultural Science - Sri Lanka.* 16: 126-134. DOI: http://doi.org/10.4038/jas.v16i1.9190.

Yu, S. (1991). Insecticide resistance in the fall armyworm, *Spodoptera frugiperda* (JE Smith). *Pesticide Biochemistry and Physiology.* 39(1): 84-91. https://doi.org/10.1016/0048-3575(91)90216-9.