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Awareness creation of smallholder farmers and adoption of push-pull technology reduce the infestation of fall armyworm (Spodoptera frugiperda) on maize in Hawzien Woreda, Northern Ethiopia

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Recently, maize (Zea mays L.) production by smallholder farmers in Ethiopia has been threatened by an exotic pest called fall armyworm (FAW) (Spodoptera frugiperda J.E. Smith; Lepidoptera, Noctuidae). Devising or adopting sustainable, effective, affordable and smallholder farmer-friendly management strategies for the control of this pest are, therefore, vital. Push-Pull Technology (PPT) is considered one of the management methods for the control of FAW in East Africa. Therefore, this study aims to determine pre- and post-training perceptions of smallholder farmers on FAW and PPT, and evaluate the status of the pest and plant damage on PPT adopted maize fields through rain-fed and irrigated farming. The results revealed that smallholder farmers had little or no knowledge of biology, identification, and management methods of FAW and about PPT before training. However, the farmers responded to the acquisition of adequate knowledge and skills on these topics after training. FAW eggs and larvae and the proportion of damaged plants were significantly lower in PPT maize plots relative to maize monocrop plots. This study depicts the adoption of PPT by smallholder farmers, that along with training resulted in the reduction of FAW. Thus, adoption and extension of PPT are expected to play a vital role in the management of FAW, mainly in the smallholder farming system.

1. Introduction

In Ethiopia, maize (Zea mays L.) is one of the major cereal crops grown for its food and feed values, that serves as a stable food and feed source for millions in Ethiopia (Abate et al., 2016; CSA, 2016; Tefera et al., 2016). Maize plays an important role in Ethiopia's food security (CSA, 2016). Insect pest problems have been reported as one of the major challenges of maize production in the country (Waktole & Amsalu, 2012; Shiberu, 2013; Tefera et al., 2016). Moreover, recently, the maize productions in different states of the country have been threatened by an exotic pest called fall armyworm (FAW) (Spodoptera frugiperda Smith; Lepidoptera, Noctuidae) (FAO, 2017; Midega et al., 2018; Harrison et al., 2019; Gebreziher, 2020a). FAW, believed to be originated in the tropics and subtropics of America, causes damage to almost 100 plant species including maize, rice, sorghum, wheat, and sugarcane but also vegetable crops and cotton (Andrage et al., 2000; Abrahams et al., 2017; Midega et al., 2018).

FAW is one of the most devastating pests in terms of loss of livelihoods and economic impact in high-income countries, let alone developing countries, where it causes substantial loss to maize and other crops (Hailu et al., 2018). Kenya has lost approximately 15,000 ha of maize to FAW, valued at Shilling 1.3 billion (Oketch, 2018). Similarly, this pest caused considerable damages to maize production in other Eastern countries (Kassie et al., 2018; Gebreziher, 2020a, 2020b).

FAW was first detected on the African continent in 2016 (Goergen et al., 2016; FAO, 2017; Day et al., 2017; Harrison et al., 2019), and outbreaks of the pest have been reported in West and Central Africa including Botswana, Democratic Republic of Congo, and Ghana. It spread quickly from West and Central Africa across the continent, causing extensive damage to maize crops (Goergen et al., 2016; Abrahams et al., 2017) such as Kenya, Malawi, Namibia, South Africa, Swaziland, and Zambia in the same year FAW was detected in the continent (Abrahams et al., 2017; Midega et al., 2017). Further spread of Fall Armyworm was observed in Ethiopia, Tanzania, and Zimbabwe in February 2017 (Midega et al., 2018). As of December 2017, 54 African countries were surveyed, and FAW was found to be spreading very fast, having covered about 38 countries in Africa (Westbrook et al., 2016; FAO, 2017; Harrison et al., 2019). The finding shows that the spread of FAW in the continent has been dramatically fast. The spread has not been confined to Africa; it has subsequently spread across Asia. In 2018 countries such as India and Yemen (by July 2018), Bangladesh, Sri Lanka and Thailand (by December 2018), Myanmar, China, Indonesia, Laos, Malaysia and Vietnam, and the Republic of Korea (by June 2019) and to Japan (by July 2019) all reported incidences (Harrison et al., 2019). The rapid spread of FAW might be because of its sporadic and long-distance migratory behaviour, with the adult moths capable of flying over 100 km in a single night (Andrade et al., 2000; Guerrero et al., 2014; Westbrook et al., 2016; FAO, 2020). In Ethiopia, the FAW infestation was reported in the Southern Nations, Nationalities and Peoples' State in March 2017 and spread fast to other states becoming an epidemic pest in June 2017 (Gebreziher, 2020a).

Therefore, devising sustainable, effective, affordable, and smallholder farmers-friendly management strategies for the control of these pests is vital. In many countries, management of FAW is mainly monitor-based Integrated Pest Management. Monitoring methods for FAW in various countries such as the USA, mainly involve use of specific pheromone traps (involving [(Z)-7- dodecenyl acetate), (Z)-9-dodecenyl acetate), (Z)-9-tetradecenyl acetate, and (Z)-11-hexadecenyl acetate] (Andrade et al., 2000; Guerrero et al., 2014). Pheromone-based monitoring has been proven effective in controlling the adult stage of many lepidopteran species (Guerrero et al., 2014) including FAW (Malo et al., 2002; Malo et al., 2004). Based on monitoring results, different management approaches are applied depending on the status of the pest. For instance, in America and Brazil, different strategies have been used to manage FAW including cultural practices, biological control using [parasitoids Cotesia marginiventris (Cresson), Chelonus texanus (Cresson) and Archytas marmoratus (Townsend)], predators (birds, rodents, beetles, earwigs) and pathogens [nuclear polyhedrosis virus (NPV), Baciluss thuringiensis (BT), Entomophaga aulicae, Nomuraea rileyi, and Erynia radicans] and botanicals (Assefa & Ayalew, 2019; FAO, 2020). Besides, Gebreziher (2020a) has reviewed the various FAW control methods such as monitoring (scouting, light traps, and pheromone traps), cultural methods (use clean seeds, avoiding late planting, increasing crop diversity or intercropping, optimizing planting depth, proper irrigation, destroying egg masses and handpicking and killing of larvae, push-pull technology, biological control, and chemical pesticides.

Push-Pull based integrated pest management, a multi-purpose use, climate-smart method, is considered one of the management methods recommended for control of FAW in East Africa (Kassie et al., 2018; Midega et al., 2018). The push-pull strategy is a novel tool for integrated pest management (IPM) programs which use a combination of behaviour-modifying stimuli to manipulate the distribution and abundance of insect pests and/or natural enemies (Holdrege, 2012; Khan et al., 2015; Midega et al., 2015b; Bhattacharyya, 2017; Midega et al., 2017; Gebreziher, 2020a, 2020b; Gebreziher & Gebreziher, 2020). In this strategy, the pests are repelled or deterred away from the main crop (push) by using stimuli that mask host apparency that releases repellent or deterrent semiochemicals. For example, the silver-leaf desmodium plant (Desmodium uncinatum Jacq.; Fabales: Fabaceae) is used as a repellent plant to various lepidopteran pests (Khan & Pickett, 2015; Midega et al., 2015a, 2015b). The pests are simultaneously attracted (pulled), using highly apparent and attractive stimuli to other areas such as trap crops like Napier grass (Pennisetum purpureum S.; Poaceae) or Sudan grass (Sorghum sudanense Piper; Cyperales: Poaceae), where the insect pests can be concentrated, facilitating their control (Khan & Pickett, 2015; Midega et al., 2015a, 2015b; Bhattacharyya, 2017; Midega et al., 2017; Gebreziher, 2020).

In the principle of push-pull systems the repellent plant, for instance, the silver leaf desmodium, produces volatile chemicals such as (E)-ß-ocimene and (E)-4,8-dimethyl-1,3,7-nonatriene (Midega et al., 2018), which repel the stemborer, FAW and other lepidopteran moths from the maize. The trap crops such as Napier- or Sudan grasses release volatile chemicals like octanal, nonanal, naphthalene, 4-allylanisole, eugenol and linalool, which attract female moths (pull-plant) to lay eggs on it (Midega et al., 2017). The volatiles released from the system also have an inhibiting effect on one devastating weed, the Striga (Midega et al., 2015a). Silver leaf desmodium roots produce chemicals that stimulate Striga seed germination, such as 4,5-dihydro-5,2,4-trihydroxy-5-isopropenylfurano-(2,3,7,6)-isoflavanone, and others which inhibit their attachment to maize roots, such as 4,5-dihydro-2-methoxy-5,4-dihydroxy-5-isopropenylfurano-(2,3,7,6)-isoflavanone (suicidal germination), thereby reducing Striga seed bank. The legume also improves soil fertility through nitrogen fixation (Midega et al., 2015a). In addition to its use in the system, the Napier- or Sudan grasses are good forage sources for livestock. Through the pushing and pulling effects of the companion plants, push-pull technology (PPT) has been reported to greatly reduce pest status in maize crops (Midega et al., 2017; Kassie et al., 2018; Midega et al., 2018; Gebreziher & Gebreziher, 2020).

PPT was first put into practice for the control of stem borer species and Striga in Eastern Africa such as Tanzania, Uganda, and Kenya (Midega et al., 2015a, 2015b; Midega et al., 2017). Recently, reports show that PPT has become a successful management tool for FAW in different East African countries such as Kenya, Uganda and Tanzania (Midega et al., 2017; Midega et al., 2018). Thus, adopting this technology to affected areas of Ethiopia is vital for the control of FAW in smallholder farmers involved in mixed farming.

FAW which has become a severe insect pest in all states of Ethiopia (Gebreziher, 2020), is also a serious maize pest in Eastern Tigray Regional State, Ethiopia; especially around Hawzien and nearby Woredas (administration level below zone). This insect pest has already become a significant challenge for smallholder farmers in the regional state. Thus, making the adoption trial of PPT (which has been proven effective in controlling FAW in other East African countries) in the smallholder farming system of the regional state is vital. Push-pull is one of the climate-resilience strategies in managing many lepidopteran species. The plant species used for push-pull, involve silver-leaf desmodium (repellent), Napier grass and Sudan grass (trap crops) which are widely available in Ethiopia including in different parts of Eastern Tigray Regional State. Considering the success of PPT in controlling FAW in our region (East Africa), adopting the technology in the already affected parts of Eastern Tigray is expected to reduce these pests to below economic threshold. Therefore, the objective of this study is to determine pre- and post-training perceptions of smallholder farmers on FAW and PPT and evaluate the status of the pest and proportion of plant damage by FAW on PPT adopted maize fields relative to maize monocrop plots.

2. Methodology

2.1. Project Area

The project was carried out twice through rain-fed (from June to October 2018) and by irrigation (from February to May 2019) in Hawzien Woreda, Hatset Kebelle. The district is located at 1850 - 2200 meter above sea level and receives an annual rainfall of 350-500 mm per annum, and temperatures range between 16-29oC. The Kebelle (administration area below Woreda level) fully involves smallholder farmers who are known for their production of maize, wheat, barley, and sorghum. Besides, vegetables such as tomato, onion, pepper, and leafy vegetables, and fruits, though not widely distributed, are also produced in the districts mainly by irrigation. The smallholder farmers in the Kebelle produce maize twice a year through rain-fed (June to October) and irrigation (February to June). Similar to other Kebelles of the Woreda, the study area has been affected by the devastating FAW since 2017 and is predicted to be a problem in the irrigated and rain-fed crop production.

2.2. Materials and Methods

In the push-pull system, silver-leaf desmodium (Desmodium uncinatum Jacq.; Fabales: Fabaceae) as a repellent plant (push-plant) and Sudan grass (Sorghum sudanense Piper; Cyperales: Poaceae) as trap plant (or pull-plant) were used. The seeds of silver-leaf desmodium were obtained from Aksum Agriculture Research Center and Sudan grasses were obtained from Wukro Agriculture College. Maize (Zea mays L.; Variety: Melkassa-1Q) seeds were obtained from Hawzien Woreda Seed Distribution Office.

2.3. Description of the training and push-pull adoption

The study involved evaluating the perception of smallholder farmers on FAW and PPT before and after training, determining the status of FAW larvae and eggs on PPT adopted and monocrop maize plots and perception of farmers after the adoption of PPT. The smallholder farmers were asked about their awareness of FAW and PPT using a semi-structured interview. Interviews aimed to determine the awareness of farmers on the pest and the PPT technology. Then, training was given to nine smallholder farmers and two data collectors who were interested in adopting the technology (based on volunteerism) in June 2018 and covered topics on biology, identification and management of FAW, principles and practices of PPT, and application for FAW management. (Training topics are found in Tables 1 and 2).

After evaluating the response of farmers on the training (results show that farmers developed awareness about FAW and PPT; Table 4 and 6), a 10m by 5m maize plot was prepared with PPT on each farmer's field (description of PPT is found in 2.4 of this paper). Additionally, each farmer also had a 10m by 5 m plot of sole maize crops (monocrops), for a total of nine PPT maize plots and nine monocrop plots. The status of FAW at two stages (egg and larvae) and proportion of plant damage were compared between PPT maize plots and maize monocrop plots. The experiment regarding the infestation and damage of maize by FAW were carried out twice, that is, through rain-fed during 2018 (July to October) and by irrigation during 2019 (February to June).

2.4. Description of treatments

On each of the nine smallholder farmer's fields, a 10m x 5m field plot for PPT was prepared in addition to a 10m x 5m field plot for maize monocrops, both during the 2018 and 2019 experiment seasons. Thus, a total of nine plots for PPT adoption and nine plots for maize monocrop (as a control) were prepared. Each plot was considered as a replication. All farmers planted the maize simultaneously, mid-June for the 2018 experiment and at the beginning of February for the 2019 experiment. Maize crops were planted at 0.5m and 0.5m inter- and intra-row spacing, respectively. For the PPT plots, silver-leaf desmodium (push-plant) were intercropped at equidistance between maize plants in all rows. The maize field plots were surrounded by two rows of Sudan grass (pull-plant) at 0.5 m away from edges of the maize field plot with inter- and intra-row spacing of Sudan grass batch at 0.5m and 0.3m, respectively.

2.5. Evaluation of the PPT Adoption

Proper agronomic practices (weeding, cultivation, fertilization, and irrigation) were applied for both PPT adopted and monocrop maize plots. Daily inspections were carried out by farmers and supported with data collectors as well as weekly inspections by researchers for FAW eggs and larvae and the proportion of plant damages. The impact of the adoption of PPT during the rain-fed (2018) and irrigated (2019) experiments were evaluated by comparing PPT adopted maize plots with maize monocrop plots using FAW infestation (numbers of eggs and larvae), and proportion of plant damaged by the pest (if any) as parameters. Numbers of FAW eggs and larvae, as well as the proportion of plant damage, were collected from 10 randomly selected plants from a 3m-wide transect line which was demarcated diagonally across the PPT maize plots and monocrop maize plots.

Depending on the growth stage of maize, fall army-

Table 1. Training topics and time allocation on biology of FAW and field practices

S.No	Topics	Description	Type of supporting materials used	Time allocated	Number of trainees involved
1	Biology of FAW	Life cycle of FAW; - adult stage and identification (male and female) - eggs and identification - larval stages (1st to 5th instars) and identification	Photos of different stages of FAW	One day	9 farmers and 2 data collectors
2	Field practice on identification of eggs and larvae of FAW	Based on the graphical presentation on biology of FAW from the previous training, each trainee collected eggs and larvae (different stages) of FAW	Field practice for identification	Two days	9 farmers and 2 data collectors
3	Insect collection methods, labeling, and reporting	Different jars (eggs and larvae, sweeping nets (adult), traps were demonstrated. Each trainee practiced the methods of specimen collection	Materials prepared at Adigrat university	One day	9 farmers and 2 data collectors

Table 2. Awareness creation topics on PPT and application for management of FAW and soil fertility

S.No	Topics	Description	Type of supporting materials used	Time allocated	Number of trainees involved
1	Awareness on PPT	- what is PPT - compositions of PPT - Economic functions of PPT	Photos and figures from internet sources	1 day	9 farmers and 2 data collectors
2	Companion plants for PPT	Types of plants to be used and their function	Photos and figures from internet sources	1 day	9 farmers and 2 data collectors
3	Agronomic practices	Planting time, spacing, fertilization, irrigation	On field training	1 day	9 farmers and 2 data collectors

worm larvae are found on young leaves, leaf whorls, tassel or cobs (Goergen et al., 2016). Therefore, infestation levels and damage of the pest on young leaves and leaf whorls during vegetative growth were assessed non-destructively. Each plant was then visually examined, and FAW eggs and larvae on the plant were counted, summed and then divided by the total number of plants and expressed as the number of eggs or larvae per plant. During the vegetative phase of the plants, feeding by the FAW larvae results in skeletonized leaves and heavily windowed whorls loaded with larval frass (Goergen et al., 2016). Therefore, damage caused by larvae was assessed by examining the vegetative parts of each of the 10 plants for visible larval damage and data were expressed as the percentage of plants damaged per plot.

2.6. Data analysis

Data on farmers' perceptions before and after training were summarized using cross-tabulations and processed descriptively using percentages. Data on fall armyworm infestation levels (eggs and larvae), and proportion of plant damage were averaged for each plot and farmer (each farmer being a replicate both for PPT maize plots and maize monocrops) and analysed using unpaired two-sample t-test to derive comparisons between the PPT adopted maize plots and maize monocrop plots. The analysis was made using MINITAP 17.

3. Results

3.1. Awareness of farmers on FAW management before and after training

As depicted in Table 4, the farmers had no or little knowledge of FAW before training. All of the farmers involved in the adoption of PPT to manage FAW had no knowledge (Table 4: 100%) on the basic biology of FAW such as the life cycle, feeding behaviour, spreading nature and other lifestyles of the pest. Before the training, 77.8% of the farmers had no knowledge and/or skills on how to identify the different stages (egg, larvae, pupae, and adult) of the pest and how to differentiate from other lepidopteran species. Only 22.2% responded that they have little knowledge and/or skills on the identification of the pest. 66.7% of the farmers had little knowledge and/or skills on management methods, of which most of them responded to cultural and chemical methods as control mechanisms. However, 33.3% of the farmers had no knowledge and/or skills on how to manage FAW (Table 4).

Table 3. Demographic profiles of targeted groups (smallholder farmers)

Item		Frequency	Percent
Sex	Male	5	55.6
	Female	4	44.4
Age	18-40	6	66.7
	41-65	3	33.3
Educational level	Illiterate	2	22.2
	Grade 1-8	5	55.6
	Completed highschool	2	22.2
	College or university	0	0.0
Marital status	Single	0	0.0
	Married	9	100.0
	Divorced	0	0.0

Table 4. Responses of farmers about FAW before training

Topics	Numbers of farmers	Responses (%)			
		Enough knowledge/skills	Moderate knowledge/skills	Little knowledge/ skills	No knowledge/ skill
1. Basic biology of FAW	9	0.0	0.0	0.0	100.0
2. Identification	9	0.0	0.0	22.2	77.8
3. Collection methods	9	0.0	0.0	0.0	100.0
4. Management methods	9	0.0	0.0	66.7	33.3

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After training was offered, 33% of farmers responded having acquired enough knowledge or skills to understand the basic biology and 66.7% responded to having acquired moderate knowledge or skills (Table 5). The farmers developed knowledge and skills on identification and collection methods as well as the different techniques of FAW management, including PPT. Farmers who responded to acquiring enough knowledge or skills and moderate knowledge or skills on the identification of FAW were 22.2, 66.7 and 11.1%, respectively (Table 5). The farmers who responded to having acquired enough knowledge or skills and moderate knowledge or skills on collection methods were found 44.4 and 55.6%, respectively. Of the farmers, 66.7, 22.2, and 11.1% responded that they acquired enough, moderate or little knowledge/skills on management methods of FAW, respectively (Table 5).

3.2. Awareness of Farmers about PPT before and after training

As depicted in Table 6, all farmers who were selected for the adoption of PPT had no knowledge of PPT and the companion plants used for push-pull (silver-leaf desmodium and Sudan grass) though they are locally available. Similarly, the farmers had no knowledge on the role of the companion plants for the suppression of the invasive Striga weed (suppression by the silver-leaf desmodium), improvement of soil fertility through nitrogen fixation (in this case the silver-leaf desmodium) and as a source of forage (both silver-leaf desmodium and Sudan grass) (Table 6: response = 100% for no knowledge).

However, after training on the role of PPT for pest management and other extra-benefits obtained from the companion plants, the farmers developed the basic knowledge on the principles of PPT (Table 7: 44.4 and 55.6% of the farmers responded for enough and moderate knowledge acquired, respectively). Similarly, 33.3%, 55.6%, 11.1% of the farmers responded for enough, moderate and little knowledge acquisition, respectively through the training about the function of silver-leaf desmodium and Sudan grass for FAW management (Table 7). Besides, 66.7 and 33.3% of the farmers responded to having gained enough and moderate knowledge, respectively both on the role of the companion plants for improvement of soil fertility and suppression of Striga weed. Results also showed that 66.7, 22.2 and 11.1% of the farmers responded to having enough, moderate, and little knowledge (respectively) after the training regarding the role of the companion plants as a source of forage for livestock (Table 7).

Table 5. Responses of farmers about FAW after training

Topics	Numbers of farmers	Responses (%)			
		Enough knowledge/ skills	Moderate knowledge/ skills	Little knowledge/ skills	No knowledge/ skill
1. Biology of FAW	9	33.3	66.7	0.0	0.0
2. Identification	9	22.2	66.7	11.1	0.0
3. Collection methods	9	44.4	55.6	0.0	0.0
4. Management methods	9	66.7	22.2	11.1	0.0

Table 6. Responses of farmers about PPT before training

Topics	Numbers of farmers	Responses (%)			
		Enough knowledge	Moderate knowledge	Little knowledge	No knowledge gained
PPT for pest management					
1. Principles of PPT	9	0.0	0.0	0.0	100.0
2. Awareness on silver-leaf desmodium for pest management	9	0.0	0.0	0.0	100.0
3. Awareness on Sudan grass for pest management	9	0.0	0.0	0.0	100.0
Other functions of companion plants used in PPT					
4. Improvement of soil fertility	9	0.0	0.0	0.0	100.0
5. Source of forage for livestock	9	0.0	0.0	0.0	100.0
6. Suppress Striga weed	9	0.0	0.0	0.0	100.0

Table 7. Responses of farmers about PPT after training

Topics	Numbers of farmers	Response (%)			
		Enough knowledge	Moderate knowledge	Little knowledge	No knowledge
PPT for pest management					
1. Principles of PPT	9	44.4	55.6	0.0	0.0
2. Awareness on silver-leaf desmodium for pest management	9	33.3	55.6	11.1	0.0
3. Awareness on Sudan grass for pest management	9	33.3	55.6	11.1	0.0
Other functions of companion plants used in PPT					
4. Improvement of soil fertility	9	66.7	33.3	0.0	0.0
5. Source of forage for livestock	9	66.7	22.2	11.1	0.0
6. Suppress Striga weed	9	66.7	33.3	0.0	0.0

3.3. Adoption of PPT by farmers and infestation of FAW

After the training, PPT was implemented on each farmer's field to compare the status of the FAW population on the novel system with maize monocrop plots. As depicted on Figures 1a and b, the adoption of PPT resulted in a significant reduction of numbers of FAW eggs on maize plants compared to maize monocrop plots both during the 2018 (Fig 1a; t-test: P < 0.001) and 2019 (Fig 1b; t-test: P < 0.001) experiment seasons. The average numbers of FAW eggs during the 2018 experiment season ranged from 0.14 to 0.89 per plant in the PPT maize plots whereas 0.68 to 4.37 eggs per plant were recorded in the monocrop maize plots (Fig 1a). Similarly, the average numbers of FAW eggs during the 2019 experiment season ranged from 0.14 to 0.65 eggs per plant in the PPT maize plots whereas 2.16 to 3.81 eggs per plant in the monocrop maize plots were observed (Fig. 1b). After mid-September, as the maize plants were approaching the harvesting stage, they might have become less attractive to the adult FAW and consequently resulted in the reduction of eggs and larvae of FAW infestation per plants in the monocrop.

The FAW larvae infestation on the PPT maize plots were significantly lower compared to monocrop maize plots in 2018 (Fig 2a; t-test: P < 0.001) and 2019 (Fig 2b; t-test: P < 0.001) experiment seasons. During the 2018 experiment season, the FAW larvae infestation ranged from 0.1 to 0.13 per plant in the PPT maize plots compared to 0.18 to 1.09 per plant in the monocrop maize plots (Fig 2a). The FAW larvae infestation in the PPT maize plots ranged from 0.06 to 0.14 larvae per plant relative to 0.77 to 1.09 larvae per plant in the monocrop maize plots during the 2019 experiment season (Fig 2a).

3.4. Proportion of plants damaged by FAW larvae

As depicted in Figure 3, the proportions of plant damage by FAW larvae were significantly higher in the monocrop maize plots with per cent damage ranging from 64.5 to 68.9% and 62.4 to 70.3% during the 2018 and 2019 experiment seasons, respectively. In comparison, PPT maize plots per cent damage ranged from 4.9 to 7.5% and 3.5 to 7.1% during 2018 (t-test = 69.4; P < 0.0001) and 2019 (t-test = 66.0; P < 0.0001), respectively. The adoption of PPT resulted in a highly significant reduction in proportions of plants damaged by FAW larvae (average proportion of damage reduction = 91.4% and 92.1% in the 2018 and 2019 experiment seasons, respectively) (Fig 3).

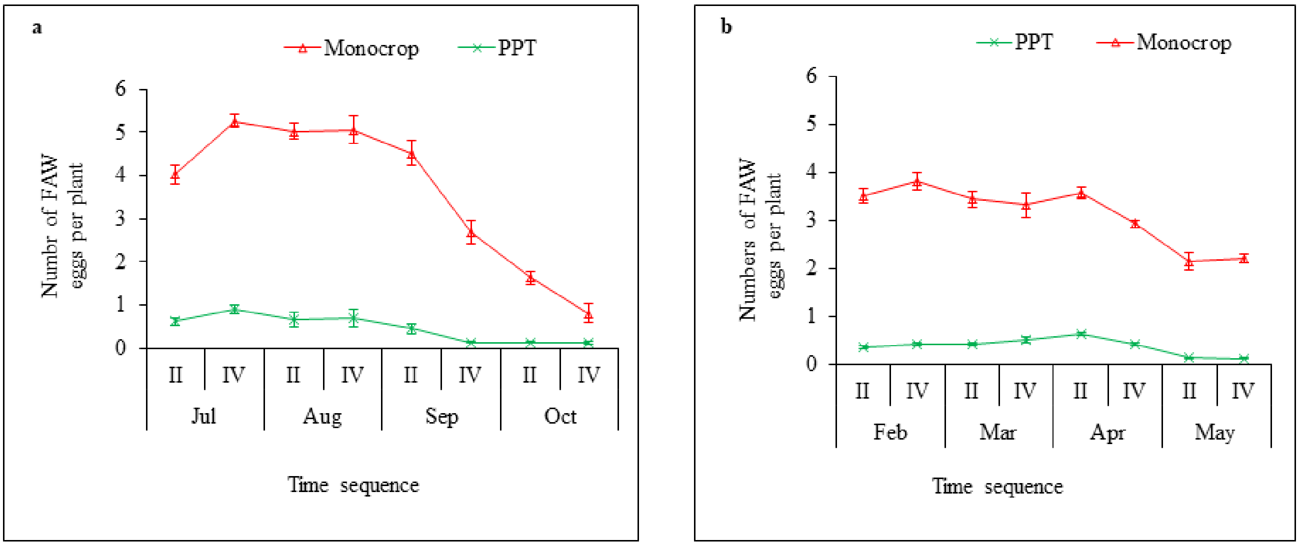

Figure 1. Level of infestation by FAW eggs (number of eggs per plant) on PPT adopted maize field plots and monocrop maize field plots (t-test; n = 9; P < 0.001; bars indicate standard errors) (a: 2018 experiment season; b: 2019 experiment season)

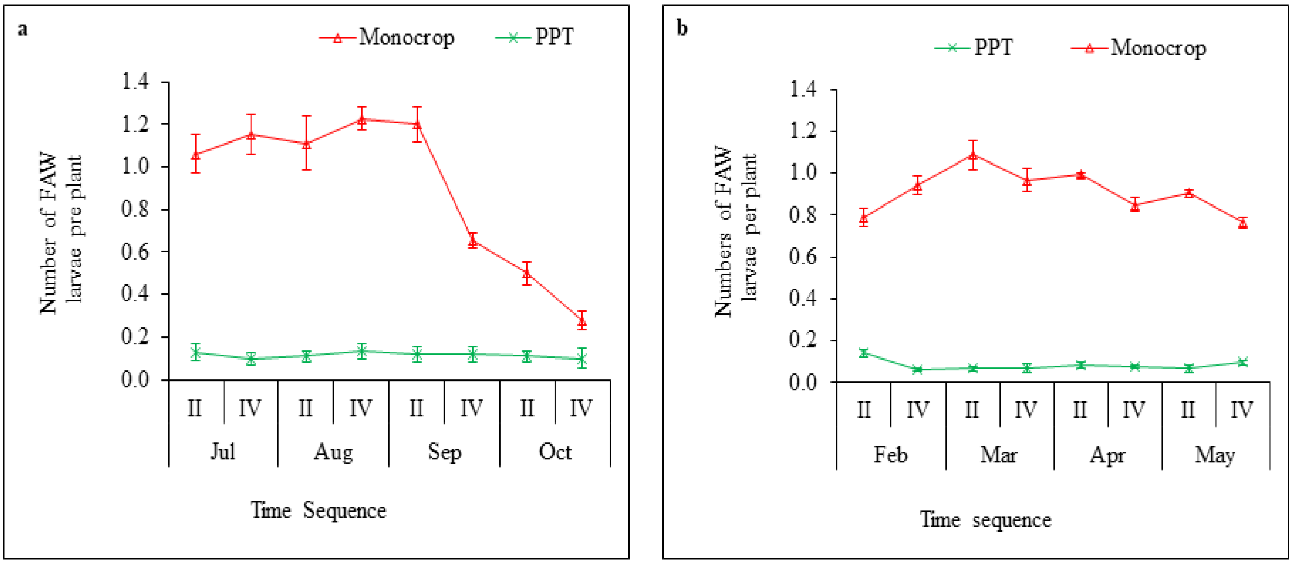

Figure 2. Level of infestation by FAW larvae (number of larvae per plant) on PPT adopted maize field plots and monocrop maize field plots (t-test; n = 9; P < 0.001; bars indicate standard errors) (a: 2018 experiment season; b: 2019 experiment season)

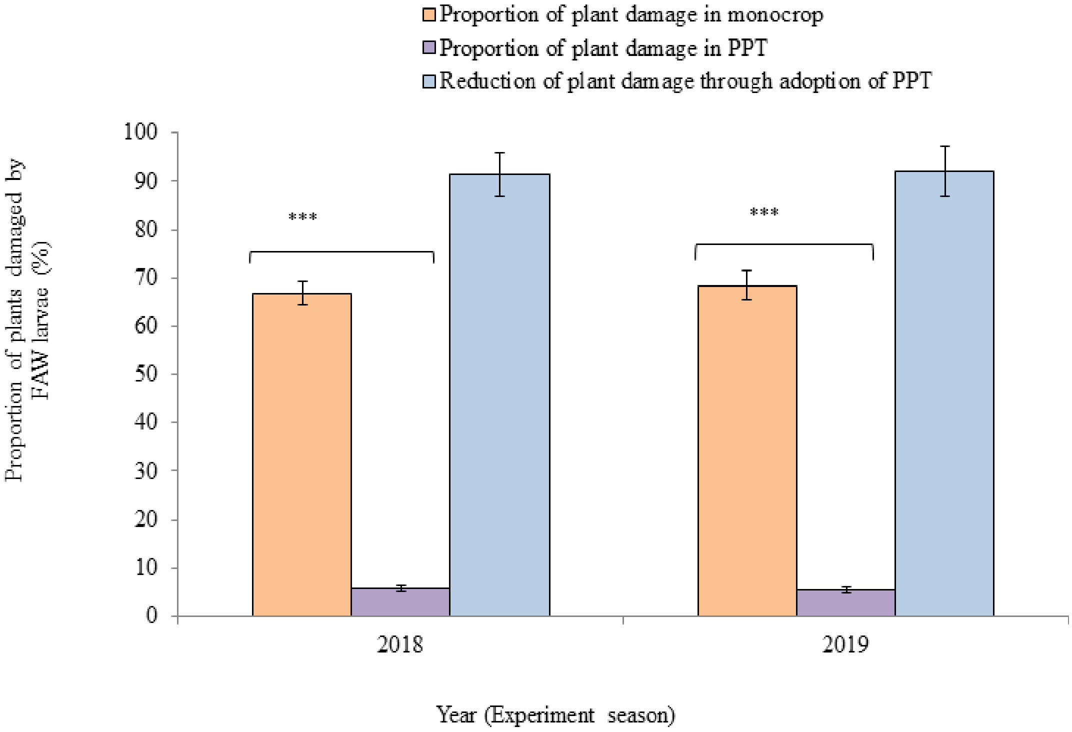

Figure 3. Comparison of proportion of plants damaged by FAW larvae on PPT adopted and monocrop maize plots and proportion of reduction in plant damage through adoption of PPT

4. Discussion

Since the first detection of FAW in Africa in 2016 (Goergen et al., 2016; Day et al., 2017; FAO 2017; Baudron et al., 2019; FAO, 2019; Harrison et al., 2019; FAO, 2020), a plethora of reports and findings have shown its impact on the maize productivity of smallholder farmers mainly in sub-Saharan Africa (Midega et al., 2018; Harrison et al., 2019; Hruska, 2019; Murray et al., 2019; Gebreziher, 2020a). Recently, many reports indicated that PPT is suitable, affordable, and friendly for the smallholder farmers for the management of FAW in the region (Midega et al., 2015a, 2015b; Kassie et al., 2018; Midega et al., 2018; Hruska, 2019). For instance, Kassie et al. (2018) reported that the adoption of PPT on smallholder farmer's field led to a significant increase in maize yield and net maize income. In other studies, Midega et al. (2015a, 2015b) found highly significant reductions in Striga (Striga hermonthica) (18 times lower) and stemborer (Busseola fusca Fuller; Lepidoptera: Noctuidae) (6 times lower) damage to maize plants in climate-adapted push-pull plots compared to the maize monocrop plots. In addition, Midega et al. (2018) found that maize plant height and grain yields were significantly higher in PPT maize plots than maize monocrop plots. Similarly, a reduction of 82.7% in an average number of FAW larvae per plant and 86.7% in plant damage per plot were observed in climate-adapted push-pull adopted maize crops compared to maize monocrop plots in Kenya, Tanzania, and Uganda (Midega et al., 2017).

Concurrent to previous findings, the adoption of PPT by smallholder farmers in the current study effectively reduced infestation by FAW both on the rain-fed and irrigated experiments which in turn resulted in a highly significant reduction of damage levels on maize plants. As previous findings indicated, the reduction of pests such as stemborer by a push-pull method is mediated by semiochemicals released from the push- and pull-plants (Pickett et al., 2014; Midega et al., 2015a, 2015b; Midega et al., 2018).

Further, Midega et al. (2011) reported that there was increased abundance, diversity, and activity of predatory arthropods in the push-pull system, further contributing to pest populations reductions. The reduction of FAW eggs and larvae in the current adoption trial might also be due to these mechanisms, as FAW is a noctuidae like the stemborer. However, further investigation is necessary to fully elucidate the mechanisms for the reduction of FAW infestation in the PPT maize plots.

Regardless of the effectiveness of PPT for pest and soil fertility management, the current results depicted that the smallholder farmers where the adoption of PPT was applied in their field had no or little knowledge about FAW and PPT. As a result, the smallholder farmers had been challenged by this severe pest affecting mainly the maize production. The current adoption trial shows awareness creation for smallholder farmers involved in maize production as vital for effective adoption and extension of PPT as a means of integrated pest and soil fertility management and source of forage. After training, the smallholder farmer's perception towards FAW and PPT has significantly improved. In agreement with this, Midega et al. (2018) reported that farmers' perception towards PPT for pest control was improved in an adoption experiment to control stemborer and Striga. They found that farmers rated the PPT significantly superior in reducing Striga infestation and stemborer damage rates, and in improving soil fertility and maize grain yields. As the resistance of FAW to different insecticides (Yu, 1992; Al-Sarar et al., 2016) and Bacillus thuringiensis (BT) has been documented (Storer et al., 2010), adoption and extension of PPT to smallholder farmers are said to be affordable and effective to control FAW. Besides, future projections indicate that FAW might persist and become a lasting threat to smallholder farmers in sub-Saharan Africa. Therefore, adoption and extension of the multi-purpose PPT that suits well with the mixed farming system of the smallholder farmers are vital to manage the pest sustainably.

5. Conclusion

Most smallholder farmers have no or little knowledge about FAW as well as the PPT for pest management. After awareness creation, farmer's perception about the insect pest and PPT were greatly improved and helped for easy adoption of the technology in their fields. The adoption of PPT has reduced infestation and damage to maize by FAW. The current results demonstrate that for the adoption of new technologies such as PPT at the smallholder farmer's level, awareness creation about the pest and PPT is vital for success and extension so that the economic impact of the pests can be reduced to an acceptable level. Therefore, from the current study, it can be inferred that the adoption of PPT along with the awareness creation package significantly reduces the infestation of FAW at smallholder farmer's field levels. This finding highlights the need for expansion of PPT among smallholder farmers (which are financially constrained to purchase expensive insecticides) for the control of FAW and other pests. The potential of the system in controlling pests such as FAW together with a positive perception of farmers is an opportunity to adopt and expand this ecologically suitable technology in pest-prone regions. However, further study needs to elucidate the details of economic benefits that can be gained from the adoption of PPT.

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Author contributions

Conceptualization, Haftay Gebreyesus Gebreziher, Fissiha Gebreyesus Gebreazgaabher and Yemane Kahsay Berhe; Data curation, Yemane Kahsay Berhe; Formal analysis, Haftay Gebreyesus Gebreziher; Funding acquisition, Haftay Gebreyesus Gebreziher; Investigation, Haftay Gebreyesus Gebreziher; Methodology, Haftay Gebreyesus Gebreziher; Project administration, Haftay Gebreyesus Gebreziher; Resources, Fissiha Gebreyesus Gebreazgaabher; Software, Yemane Kahsay Berhe; Supervision, Haftay Gebreyesus Gebreziher; Validation, Haftay Gebreyesus Gebreziher, Fissiha Gebreyesus Gebreazgaabher and Yemane Kahsay Berhe; Writing – original draft, Haftay Gebreyesus Gebreziher, Fissiha Gebreyesus Gebreazgaabher and Yemane Kahsay Berhe; Writing–review and editing, Haftay Gebreyesus Gebreziher, Fissiha Gebreyesus Gebreazgaabher and Yemane Kahsay Berhe.

Conflict of interest

The authors declare no conflict of interest. Besides, the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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