Maize–Legume Intercropping and Push–Pull for Management of Fall Armyworm, Stemborers, and Striga in Uganda

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ABSTRACT

Maize (*Zea mays* L.) production in Africa is constrained by several biotic and abiotic factors. The recent occurrence of fall armyworm (FAW), *Spodoptera frugiperda* (JE Smith) a new invasive pest in Africa, has escalated the problem. Push–pull technology (PPT), proven to be effective for stemborers (*Chilo partellus* Swinhoe and *Busseola fusca* Fuller) and the parasitic weed striga (*Striga hermontica* Delile) management in Africa has been shown to provide good control of FAW. This study investigated if intercropping maize with edible legumes can also reduce the abundance of FAW. Six treatments including (i) climate-smart PPT, (ii) conventional PPT, (iii) maize intercropped with bean (*Phaseolus vulgaris* L.), (iv) maize intercropped with soybean [*Glycine max* (L.) Merr.], (v) maize intercropped with groundnut [*Vigna unguiculata* (L.) Walp.] and, (vi) mono-cropped maize were evaluated on farm in six districts of Uganda in the 2017 short rains season. Data collected included FAW, stemborer, and striga infestation symptoms, and severity of infestation. Climate-smart PPT performed best in reducing stemborer, FAW, and striga infestation followed by conventional PPT over all the phenological stages of maize. Intercropping of maize with leguminous crops also provided significant reduction of stemborer and FAW compared to mono-cropped maize, especially in the early growth phases of the maize up to tasseling. However, intercropping of maize with edible legumes was not very effective for striga management as compared to PPT. Hence in addition to PPT, intercropping of maize with edible legumes could also be an alternative FAW management option when integrated with other sustainable management measures.

Core Ideas

- Recommending complex maize pest management options for small-scale African farmers.
- Determining effective and environmentally friendly fall armyworm management for smallholder farmers.
- Evaluating effects of edible legume and maize intercropping on fall armyworm.

Maize ranks first among cereal crops grown worldwide, and in Africa alone, the lives of more than 300 million people depend on it. Maize occupies 24% of the farmland (Okweche et al., 2013; Shiferaw et al., 2011; International Plant Biotechnology Outreach, 2017). Maize is one among the most important food crops produced in Uganda. According to the census report in 2008/2009, Uganda produced 1,108,554 t of maize (Ministry of Agriculture, Animal Industry and Fisheries, 2010). However, its low productivity coupled with a high population growth is a serious threat for food security (FAO, 2015). The production of maize is constrained by biotic and abiotic factors. Cereal stemborers and the parasitic striga weed are among the predominant pests (De Groote et al., 2004; Mugo et al., 2005). In East Africa, losses in cereal grain yields due to stemborers range from 44 to 50% (Robert et al., 2014). The combined effects of stemborer and striga could result in a complete crop failure. More recently, several African countries have faced outbreaks and the devastating effects of FAW on maize and other cereal crops. Fall armyworm is a polyphagous insect, with more than 80 host species, that causes severe damage to economically important crops (Goergen et al., 2016; Roger et al., 2017). It is a significant economic pest in the United States, causing substantial losses to maize, sorghum [*Sorghum bicolor* (L.) Moench], rice (*Oryza sativa* L.), cotton (*Gossypium hirsutum* L.), groundnut as well as forage and turf grasses production (Sparks, 1979). In the Americas, it is known to migrate from cooler to warmer climates, causing significant damage to agricultural crops (Sparks, 1979; Knipling, 1980). According to the biology of FAW, it does not diapause, and this implies that there will be a continuous population buildup and several generations can overlap within a single crop cycle when suitable conditions prevail. It was evident from observations in several African countries that FAW infestation was present throughout the growth stages of maize. Out of 54 African countries surveyed, FAW is found to be spreading very fast, having covered about 38 countries in Africa as of December 2017, since it was first reported in 2016 (FAO, 2017). Moreover, it does not need to migrate within Africa as the climate is suitable throughout the year with abundant presence of main and alternative host species. With vast geographical coverage and diverse host ranges, FAW could be extremely devastating, particularly for smallholder farmers who are already struggling with cereal stemborers and the parasitic striga weed. Preliminary assessments estimate

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Abbreviations: FAW, fall armyworm; PPT, push–pull technology.

Fig. 1. On-farm data collection sites in Uganda.

about US$2.5 to 6.2 billion losses to maize in 12 major maize growing countries in Africa due to FAW (CABI, 2017). CABI's Plantwise advises for small-scale farmers include handpicking, destroying egg masses and larvae, and putting sand mixed with lime or ash in the whorl of attacked maize to kill the larvae (CABI, 2017; Abrahams et al., 2017). Although efforts have been made by farmers to apply available insecticides, it was not effective and economical (Kumela et al., 2018). It is therefore crucial to identify environmentally friendly and cost-effective strategy for the management of this pest.

Crop diversification with various temporal and spatial arrangements reduces pest incidence while increasing the population of beneficial arthropods (Altieri and Liebman, 1986; Ogenga-Latigo et al., 1992; Girma et al., 2000; Girma, 2006; Seran and Brintha, 2010;) and this has been reported as one management option for FAW (Altieri, 1980a, 1980b). Maize planted closer to hedges of Crotalaria *Crotalaria grahamiana* Wight & Arn, Calliandra, Gliricidia *Gliricidia sepium* Jacq., and croton *Croton megalocarpus* Musine registered less stemborer infestation, compared with those planted away from these hedges (Girma et al., 2000). Agricultural crops bordered with other vegetation or weeds recorded more predators than did mono-crops or crops without border vegetation (Murdoch, 1975; Altieri and Todd, 1981). Susceptible host plants have been planted for use as trap crops to reduce the pest population buildup on target crops (Hokkanen, 1991; Parker et al., 2013). Furthermore, certain crops and their arrangements will help disrupt host location by pests, and act as repellents or deterrents reducing oviposition on host crops (Nayanya et al., 2000; Khan et al., 2010). One such novel technology that helps control striga and cereal stemborers is PPT that was developed by the International Center of Insect Physiology and Ecology (ICIPE) in collaboration with Rothamsted Research (Khan et al., 2008; Hassanali et al., 2008; Midega et al., 2010). There are two types of PPT: (i) conventional PPT, where maize is intercropped with Silverleaf desmodium, *Desmodium uncinatum* Jacq., to repel cereal stemborer moths and control striga and Napier grass, *Pennisetum purpureum* Schum, a susceptible attractant crop, is planted surrounding the plot to attract repelled moths; and (ii) climate-smart PPT, where maize is intercropped with drought-tolerant desmodium (*D. intortum* Mill. 'Greenleaf') and brachiaria (*Brachiaria ruziziensis ′ B. decumbens ′ B. brizantha* 'Mulato II'), is planted around the farm providing similar protection as the conventional PPT (Khan and Pickett, 2004). Apart from controlling striga and cereal stemborer and providing high-quality fodder, a recent study proved that the technology controlled the newly introduced invasive pest, FAW in east Africa (Midega et al., 2018). Several studies have proved that intercropping often reduces pest infestation including FAW in the United States and increases the incidence of beneficial arthropods (Baliddawa, 1985; Altieri, 1980a, 1980b; Altieri and Letourneau, 1982; Risch et al., 1983; Trenbath, 1993). In addition to the beneficial effects of PPT on FAW incidence, other suitable maize-edible legume intercropping strategies that could counter FAW could be amenable for smallholder maize production systems in Africa. Hence this study focused to compare the effects of selected maize-edible legume intercropping systems and PPT on the abundance and infestation severity of FAW, cereal stemborer and striga weed in Uganda.

Table 1. Number of farms surveyed for fall armyworm (FAW), maize stemborer ,and striga infestation in Uganda, 2017.

Number of farms	Treatment
1	Climate-smart PPT†
2	Conventional PPT
3	Maize+Bean
4	Maize+Groundnut
5	Maize+Soybean
6	Sole maize

† PPT = push–pull technology.

MATERIALS AND METHODS

Study Sites

The survey was conducted in six districts of Uganda where ICIPE is promoting PPT technology to control maize stemborer and the parasitic weed striga. The districts include: Bugiri, Bukedea, Busia, Iganga, Pallisa, and Tororo (Fig. 1). All the districts receive a bi-modal rainfall, with an average precipitation of 700 to 1200 mm. The first (long) rains extend from March to May, while the second (short) rains extend from August to November.

Treatments

The survey was conducted in October 2017 on 36 maize farms in Uganda to evaluate the abundance and severity of FAW, stemborer, and striga infestation. Six treatments comprising (i) climate-smart PPT, (ii) conventional PPT, (iii) maize intercropped with bean, (iv) maize intercropped with soybean, (v) maize intercropped with groundnut, and (vi) mono-cropped maize replicated in six villages (Table 1).

Table 2. Cumulative infestation and difference in fall armyworm (FAW) infestation on maize intercropped with edible legumes, push–pull technology (PPT) and mono-cropped maize in Uganda, 2017.

Treatment	Cumulative infestation of FAW on maize n (% ± SD)	Differences in FAW infestation between treatments Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	78 (65.0 ± 4.35)‡	–				
Maize+SB	89 (74.2 ± 3.99)	0.092ns§				
Maize+GN	77 (64.2 ± 4.38)	0.042ns	0.133ns			
PPT-A	43 (35.8 ± 4.38)	0.292***	0.383***	0.25**		
PPT-C	45 (37.5 ± 4.42)	0.275***	0.367***	0.233**	0.017ns	
Sole maize	114 (95.0 ± 1.99)	0.300***	0.208*	0.342***	0.592***	0.575***
Chi square	129.479***					
$F_{5,714}$				31.31***		

*P < 0.05.

**P < 0.01.

***P < 0.001.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are percentages of infested maize. SD = standard deviation of proportions.

§ ns = not significant.

Farmers' fields from different selected districts were randomly sampled to compare farmer's practices of maize legume intercropping with the PPT practice in controlling the FAW, stemborer, and striga. At the time of the survey, Tororo district did not have any farm with maize+bean intercropping while Busia and Bukedea district did not have any farm with maize+groundnut intercropping. The sampled fields are those with an even distribution of population of maize and the legume intercrop.

Maize cultivar Longe 5 was the most predominant among the selected farmers in the region. The Red Beauty variety was used for groundnut, common bean variety Nambale, and soybean were used in this study as they are more predominantly cultivated among the selected farmers. Noteworthy the push–pull fields considered in this study were established in the previous seasons and both PPT and non PPT farmers planted their own maize seeds.

During the survey, maize was found at different growth stages, mainly attributable to the rainfall pattern where farmers continued planting. Therefore, sampling was done on maize fields at different growth stages, where maize samples from early stage to tasseling were assembled together as one group, and from silking to maturity as a second group, to evaluate infestation at different growth stages. All the maize fields sampled including the push–pull fields used the same maize variety (local open-pollinated maize Longe 5).

Plot Layout and Data Collection

Farm sizes of the surveyed sites differed considerably, ranging from 300 to 500 m^2, and for sampling purposes, an area of 15 by 20 m was demarcated in each farm. A systematic random sampling method was considered for selecting maize samples from the assigned plots. Within a row, one maize plant was chosen in every four plants, and then the next row chosen was considered, after skipping every three rows of maize. A total of 20 to 25 plants were sampled within a plot to score incidences of FAW, stemborer, and striga infestation, and to score the severity of infestation symptoms.

The total number of plants sampled and plants showing FAW, stemborer, and striga infestation were recorded. The severity of infestation was also scored on visual observation of the foliar damage attributed to each pest using a 1 to 5 scale, where 1 is clean with no visual infestation symptoms, 2 = very little damage, 3 = high level of damage where plants show the presence of FAW larvae feeding and most of the young leaves show infestation symptom, 4 = severe damage where almost 75% of the leaves are severly affected and excrement is visible on the infested areas and the maize whorls, and 5 = very severe damage where total plant damage due to FAW is visible. Similar scoring scales were applied if maize was infested by maize stemborer. Striga infestation was obtained by identifying plants that show typical striga infestation symptom such as stunted growth and maize plants that had visible striga within the maize stalk. Striga count was done from each maize sample through counting shoots of striga within the circumference of 94.2 cm.

Data Analysis

Data were analyzed using *STATA* (version 13) by generating proportions of infestation of the FAW. The severity of infestation of the FAW was averaged at the farm level. Data collected at different growth stages of maize were combined into early growth to tasseling stage, and silking to maturing stage, for analysis. One-way analysis of variance was used to test for differences in average severity of infestation, as well as an average number of striga count for the different maize intercrops, and Tukey post hoc multiple comparison tests were used to make a comparison between the different intercrops. All tests were measured at the 95% confidence interval.

RESULTS AND DISCUSSION

Fall Armyworm Infestation and Severity of Infestation

The observations on FAW infestation for the different treatments at different growth stages of maize are presented in Table 2. Across the six districts of Uganda that were surveyed, significant variations ($P < 0.001$) between mono-cropped and intercropped maize for infestation of FAW were observed. Infestation symptoms in climate-smart and conventional PPT technology systems were 36 and 38%, respectively, as compared with maize mono-crop, where 95% infestation was recorded. Infestation of maize by FAW in PPT fields was lower, compared with maize intercropped with bean, soybean, and groundnut, and differences were significant at $P < 0.05$ level (Table 2). Outcomes of this study further confirms the findings of Midega et al. (2018)

Table 3. Severity of fall armyworm (FAW) infestation on maize intercropped with leguminous crops, push–pull technology (PPT), and mono-cropped maize in Uganda, 2017.

		Difference in severity of infestation of FAW between treatments				
Treatment	Average severity	Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	1.97(± 0.479)‡					
Maize+SB	2.13 (± 0.440)	0.150ns§				
Maize+GN	1.98(± 0.479)	0.001ns	0.150ns			
PPT-A	1.41 (± 0.482)	0.567***	-0.717***	0.567***		
PPT-C	1.52(± 0.486)	0.458**	0.608***	0.458**	0.108ns	
Sole maize	3.16(± 0.219)	1.183***	1.033***	1.183***	1.750***	1.642***
$F_{5,714}$	59.314***					

**$P < 0.01$.

***$P < 0.001$.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are standard deviations.

§ ns = not significant.

Table 4. Cumulative infestation of fall armyworm (FAW) at early to tasseling stages of maize intercropped with leguminous crops, push–pull technology (PPT), and mono-cropped maize in Uganda, 2017.

		Difference between treatments				
Treatment	Cumulative infestation of FAW	Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	39(65.0 ± 6.16)‡					
Maize+SB	31(77.5 ± 6.60)	0.125ns§				
Maize+GN	15(71.4 ± 9.86)	0.064ns	0.061ns			
PPT-A	19(31.7 ± 6.01)	0.333**	0.458***	0.398*		
PPT-C	19(31.7 ± 6.01)	0.333***	0.458***	0.398***	0.001ns	
Sole maize	74(92.5 ± 2.94)	0.275***	0.150^{ns}	0.211*	0.608***	0.608***
$F_{5,714}$	21.96***					

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are percentages of infested maize.

§ ns = not significant.

and provides field-based evidence for benefits of PPT technology for mitigating FAW in Africa. This also supports the findings of Altieri (1980a, 1980b) in Colombia, who observed corn–bean polycultures with natural weeds complex, significantly decreased FAW incidence and enhanced parasitism and yield.

It is well established that populations of insect pests are smaller in diverse ecosystems or intercrops (Perrin and Phillips, 1978; Risch, 1979; Degri et al., 2014). The current study concurs with the stated findings where intercropped maize with leguminous crops resulted in a significantly lower FAW infestation, compared with mono-cropped maize. Within leguminous crops intercropped with maize, levels of FAW infestation were relatively similar (65% bean, 74% soybean, and 64% groundnut) and differences were not significant (Table 2).

There was no significant difference in FAW infestation between climate-smart and conventional PPT. However, severity of infestation was lowest in climate-smart PPT, and the differences were highly significant ($P < 0.001$) compared with maize intercropped with leguminous crops and mono-cropped maize (Table 3). Similar to the climate-smart PPT, conventional PPT also showed lower level of severity and the differences were highly significant ($P < 0.001$) when compared with maize–soybean and mono-cropped maize. Differences were significant ($P < 0.05$) compared with maize–bean and maize–groundnut (Table 3). Maize intercropped with leguminous crop also recorded less severity of infestation compared with mono-cropped maize and differences were highly significant at $P < 0.001$ level (Table 3).

Scoring of FAW infestation conducted at early to tasseling growth stages of maize showed differences between treatments. For example, highly significant ($P < 0.001$) differences were observed between PPTs and mono-cropped maize (Table 4). Climate-smart PPT showed highly significant difference ($P < 0.001$), when compared with maize–soybean followed by maize–bean ($P < 0.01$) and maize–groundnut ($P < 0.05$). There was no significant difference between conventional and climate-smart PPT (Table 4). There was slight variation in the level of FAW infestation on maize intercropped with leguminous crops; nevertheless, differences were not significant (Table 4). In conservation agriculture, where minimum tillage is practiced, infestation of maize by the FAW was reduced at seedling (three leaves) stage. However, as the plant height increased, the infestation was similar to that in plots where tillage was practiced (All, 1988). This indicates that PPT technology, practiced under conservation agriculture, is an added advantage, particularly at the first establishment phase of PPT where desmodium is just planted. When desmodium is established, the desmodium that grows will provide protection, complementing the benefit gained from conservation agriculture.

The severity of infestation was highest on mono-cropped maize compared with all the treatments (Table 5). On the

Table 5. Severity of fall armyworm (FAW) on maize scored from early to tasseling growth stages.

Treatment	Average severity (1–5 scale)	Difference in severity of infestation between treatments Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	1.97(± 0.901)‡					
Maize+SB	2.17(± 0.874)	0.208nS§				
Maize+GN	2.14(± 0.910)	0.176ns	0.032ns			
PPT-A	1.37(± 0.581)	0.600***	0.808***	0.776***		
PPT-C	1.49(± 0.747)	0.500**	0.708***	0.676**	0.100ns	
Sole maize	2.91(± 1.224)	0.946***	0.738***	0.770***	1.546***	1.446***
$F_{5,714}$	25.882***					

**P < 0.01.

***P < 0.001.

† B = Bean, SB = soybean, GN = Ggroundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are standard deviations.

§ ns = not significant.

Table 6. Fall armyworm (FAW) incidence at silking to maturity stages of maize intercropped with leguminous crops, push–pull technology (PPT), and mono-cropped maize in Uganda, 2017.

Treatment	Cumulative infestation of FAW)	Difference in infestation between treatments Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	39(65.0 ± 6.16)‡					
Maize+SB	58(72.5 ± 4.99)	0.075ns§				
Maize+GN	63(63.6 ± 4.84)	0.014ns	-.0886ns			
PPT-A	24(40.0 ± 6.32)	0.250**	0.325***	0.236**		
PPT-C	26(43.3 ± 6.40)	0.217**	0.292***	0.203**	0.033ns	
Sole maize	40(100.0 ± -)	0.350***	0.275**	0.364***	0.600***	0.567***
$F_{5,714}$	11.28***					

**P < 0.01.

***P < 0.001.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are percentages of infested maize.

§ ns = not significant.

contrary, the lowest level ($P < 0.001$) of severity was recorded from the climate-smart PPT compared with all the treatments except conventional PPT where no significant difference was recorded. Although there was no significant difference between the two PPT technologies, climate-smart PPT performed best. One may speculate that since FAW belongs to the same family Noctuidae as *B. fusca* the same control mechanism of PPT might prevail. Although the technology has been reported effective against FAW (Midega et al., 2018), the mechanism underlying the process requires further investigations. There was no significant difference in the level of severity of infestation within maize intercropped with leguminous crops (Table 5).

The infestation symptoms scored in the maize from silking to maturity stages, also showed significant differences among treatments. Both PPTs performed in a similar way but differed with mono-cropped maize and maize–soybean with high level of significance ($P < 0.001$) (Table 6). Significant differences ($P < 0.05$) were also observed between both PPT and maize–bean and maize–groundnut systems. Differences between maize intercropped with leguminous crops were not significant however; all the maize–leguminous crops performed better than mono-cropped maize (Table 6).

Although 40% of the maize plants showed infestation symptom in the climate-smart PPT, severity of infestation was the lowest compared to all the treatments and differences were highly significant ($P < 0.001$) except conventional PPT (Table 7). Conventional PPT also showed highly significant difference ($P < 0.001$) compared with maize–soybean followed by maize–bean ($P < 0.01$) and maize–groundnut ($P < 0.01$). There was no significant difference between conventional and climate-smart PPT, and similarly, no significant differences were observed between all the maize–grain legume intercrop (Table 7).

The study further evaluated how the infestation was spread by looking into severity of infestation among the plants surveyed. Thus, in both conventional and climate-smart PPT technologies, none of the plants were severely affected due to FAW infestation. Moreover, severely infested maize plants were also less in maize intercropped with leguminous crops (6.6% in bean, 7.5% soybean, and 8.3% groundnut) compared with 42% observed in mono-cropped maize (Fig. 2).

Maize Stemborer Infestation and Severity of Infestation

Previous studies have already demonstrated that PPT technology is efficient in controlling striga and stemborer (Midega et al., 2015; Khan et al., 2010). This study also showed significantly lower infestation of maize with stemborer in climate-smart (2.5%) and conventional (7.5%) PPT technologies, as compared with maize intercropped with leguminous crops ($P < 0.05$). Moreover, differences between PPT technology and mono-cropped maize were highly significant at $P < 0.001$ level (Table 8).

Table 7. Severity of infestation and difference in severity of fall armyworm (FAW) infestation of maize scored from silking to maturity growth stages.

Treatment	Average severity of FAW infestation (1–5 scale)	Difference in severity of infestation between treatments				
		Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	1.98(± 0.948)‡					
Maize+SB	2.10(± 0.894)	0.117ns§				
Maize+GN	1.94(± 0.924)	0.044ns	0.161ns			
PPT-A	1.45(± 0.595)	0.533***	0.650***	0.489***		
PPT-C	1.57(± 0.772)	0.417**	0.533***	0.373**	0.117ns	
Sole maize	3.65(± 0.834)	1.667***	1.550***	1.711***	2.200***	2.083***
$F_{5,714}$	39.324***					

**P < 0.01.

***P < 0.001.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are standard deviations of average severity of FAW infestation on maize.

§ ns = not significant.

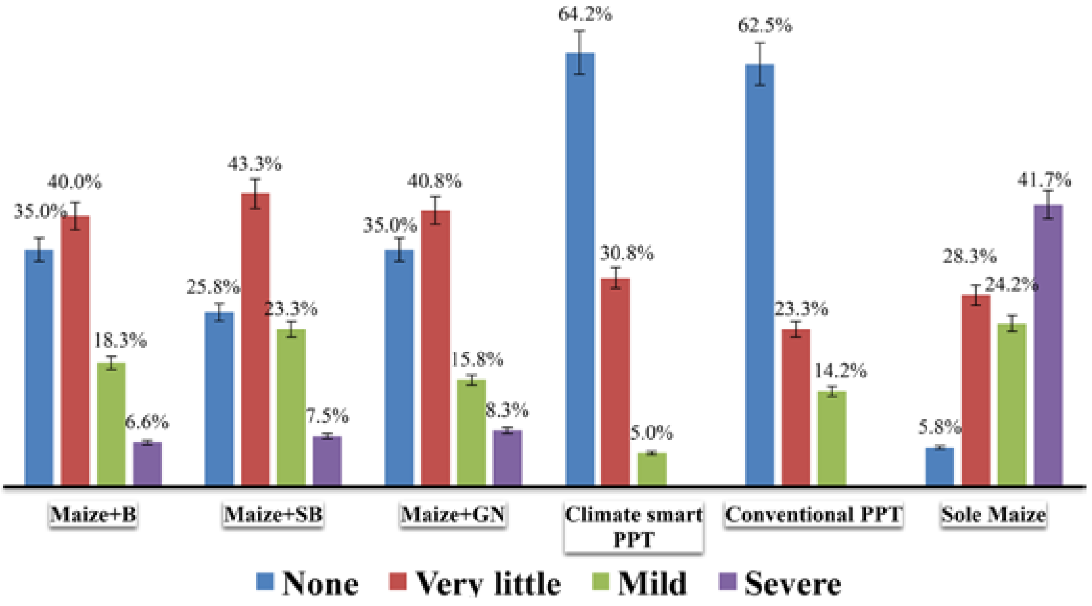

Fig. 2. Proportions of plant sampled with different levels of severity of fall armyworm (FAW) infestation.

Maize intercropped with leguminous crops also showed significantly lower stemborer infestation, compared with sole maize where 38% of the plants showed infestation symptoms (Table 8). According to our field observation, where FAW infestation is higher stemborer infestation seems to decrease. This could be associated with the feeding behavior of FAW where the larvae feed in the whorl of maize that could prevent the stemborer larvae to bore inside. Further FAW are cannibalistic in nature. Infestation is expected to happen if the stemborer larvae hatches before the FAW as larvae tend to bore into the stem thereby avoiding the competition with FAW which feeds in the whorl. Similar to FAW infestation, the three sets of legume intercropping also influenced the stemborer population but to a lesser extent. Differences among the legume intercropping strategies were not significant. The infestation level between conventional and climate-smart PPT was not significantly different. However, both climate-smart and conventional PPT had a better control of stemborer which showed highly (P < 0.001) significant differences compared with all the legume intercropping treatments (Table 8). Significant differences at P < 0.01 and P < 0.05 levels were recorded with maize–bean and maize–groundnut systems, respectively (Table 8).

The severity of maize stem borer infestation was also least in both PPT technologies, compared with the rest and differences were highly significant at P < 0.001 level (Table 9). Maize intercropped with leguminous crops also showed the lower level of severity of infestation, compared with mono-cropped maize (Table 9). No significant difference was recorded among the treatments with the three leguminous crops.

Monitoring the severity of stemborer damage through the foliar symptoms and availability of exit holes showed very little damage in the PPT field, followed by maize intercropped with leguminous crops (Fig. 2). Field observations revealed that in the presence of FAW infestation, the damage due to stem borers is reduced considerably as indicated by only 3% of infested plants showing severe damage in mono-cropped maize (Fig. 3).

Striga Infestation and Severity of Infestation

Maize infested by striga included maize plants with visible striga and maize that exhibited infestation symptoms even when striga was not visible. Striga infestation was highest in mono-cropped maize, compared with most other treatments except maize–groundnut intercrops (Table 10). Climate-smart PPT

Table 8. Cumulative infestation and difference in infestation of Stemborer on maize intercropped with leguminous crops, push–pull technology (PPT), and mono-cropped maize in Uganda, 2017.

Treatment	Cumulative infestation of maize stemborer	Differences in infestation of MSB between treatments Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	27 (22.5 ± 3.81)‡					
Maize+SB	29 (24.2 ± 3.91)	0.017ns§				
Maize+GN	23 (19.2 ± 3.60)	0.033ns	0.050ns			
PPT-A	03 (2.5 ± 1.43)	0.200***	0.217***	0.167***		
PPT-C	09 (7.5 ± 2.40)	0.150**	0.167***	0.117*	0.050ns	
Sole maize	46 (38.3 ± 4.44)	0.158***	0.142**	0.192***	0.358***	0.308***
$F_{5,714}$	13.85					

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart, push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are percentages of infested maize.

§ ns = not significant.

Table 9. Severity of maize stemborer infestation in maize intercropped with leguminous crops, push–pull technology (PPT), and mono-cropped maize in Uganda, 2017.

Treatment	Average severity of maize stemborer infestation (1–5 scale)	Differences in severity of maize stemborer infestation between treatments Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	1.27 (± 0.530)‡					
Maize+SB	1.28(± 0.518)	0.008ns§				
Maize+GN	1.25(± 0.554)	0.017ns	0.025ns			
PPT-A	1.03(± 0.222)	0.233**	0.242**	0.217*		
PPT-C	1.08(± 0.306)	0.183^{ns}	0.192^{ns}	0.167^{ns}	0.050ns	
Sole maize	1.54(± 0.819)	0.275***	0.267***	0.297***	0.508***	0.458***
$F_{5,714}$	13.821					

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are standard deviations of average severity of maize stem borer infestation.

§ ns = not significant.

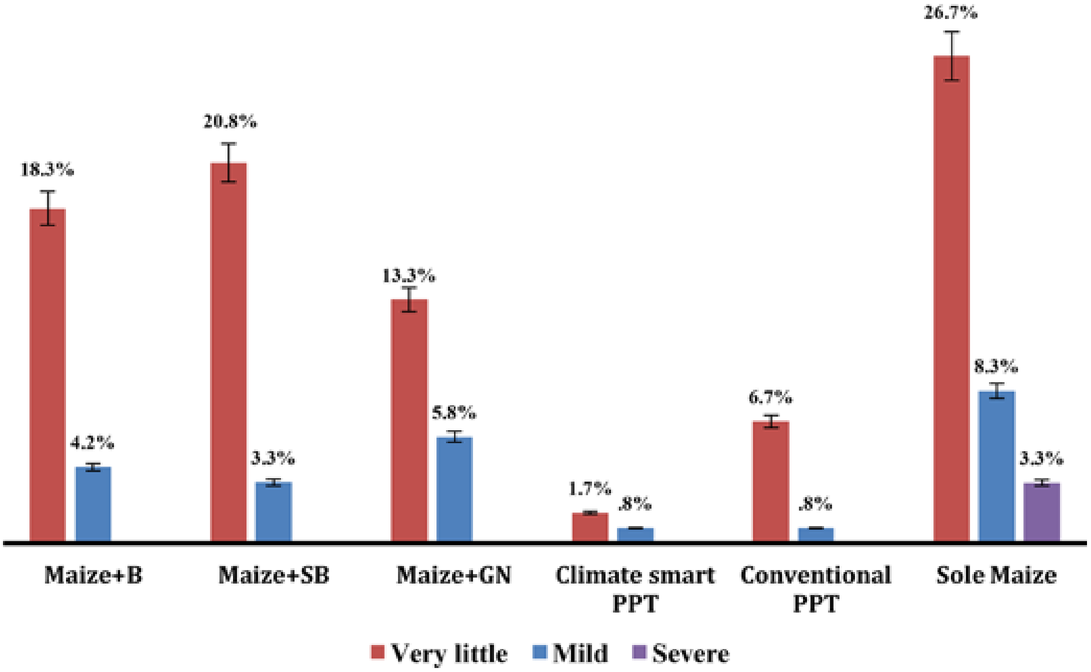

Fig. 3. Proportions of plant sampled with different levels of severity of stem borer infestation. B = Bean, SB = Soybean, GN = Groundnut.

Table 10. Striga infestation symptoms and severity of infestation in maize intercropped with leguminous crops, push–pull technology (PPT), and mono-cropped maize in Uganda, 2017.

		Differences in severity of maize stemborer infestation between treatments				
Treatment	Cumulative striga infestation	Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	39 (32.5 ± 4.28)‡					
Maize+SB	27 (22.5 ± 3.81)	0.100ns§				
Maize+GN	45 (37.5 ± 4.42)	0.050ns	0.150**			
PPT-A	12 (10.0 ± 2.74)	0.225***	0.125*	0.275***		
PPT-C	23 (19.2 ± 3.60)	0.133*	0.033ns	0.183***	0.092ns	
Sole maize	57 (47.5 ± 4.56)	0.150**	0.250***	0.100^{ns}	0.375***	0.283***
$F_{5,714}$	11.740***					

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are percentages of infested maize.

§ ns = not significant.

Table 11. Average number of striga counted on maize intercropped with leguminous crops, push–pull technology (PPT), and mono-cropped maize in Uganda, 2017.

		Difference in average number of striga between treatments				
Treatment	Average number of striga	Maize+B†	Maize+SB	Maize+GN	PPT-A	PPT-C
Maize+B	1.56(± 3.348)‡					
Maize+SB	0.43(± 1.708)	1.133***				
Maize+GN	0.35(± 1.113)	1.208***	0.075ns§			
PPT-A	0.33(± 1.189)	1.233***	0.100ns	0.025ns		
PPT-C	0.32(± 0.889)	1.242***	0.108ns	0.033ns	–0.008ns	
Sole maize	0.90(± 1.779)	0.658**	0.475*	0.550*	0.575*	0.583*
$F_{5,714}$	8.646					

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

† B = Bean, SB = soybean, GN = groundnut, PPT-A = climate smart push–pull technology, PPT-C = conventional push–pull technology.

‡ Numbers in parenthesis are standard deviations of the average number of striga.

§ ns = not significant.

technology showed significantly lower striga infestation, compared with all the treatments ($P < 0.05$), while conventional PPT technology did not show significant difference with maize–bean and maize–soybean intercrops (Table 10). No significant difference in striga infestation between maize intercropped with bean, soybean, or groundnut. Similarly, no significant differences between climate-smart and conventional PPT were observed.

Striga count was significantly higher in maize intercropped with bean compared with all the treatments (Table 11). For example, significant ($P < 0.01$) differences were observed compared with mono-cropped maize and highly significant ($P < 0.00$) differences with the other treatments (Table 11). Striga counted from the two PPTs as well as maize, soybean, and groundnut did not show significant differences. The number of striga counted from mono-cropped maize was higher than maize–soybean; maize–groundnut, and PPT where the difference was significant at $P < 0.05$.

From this study it was possible to filter three sets of comparisons, the PPT, maize intercropped with leguminous crops, and mono-cropped maize; and highlight distinct differences among them for management of pest complex of maize (Fig. 4). While both conventional and climate-smart PPTs were effective in the management of major pest complexes of maize including FAW, maize intercropped with leguminous crops also performed considerably better than the mono-cropped maize in most cases. This might be a second line defense mechanism against FAW in areas where PPT is not yet integrated into the farming system. Therefore, intercropping maize with other leguminous crops could be considered as integrated pest management option. The findings of this study concur with the previous reports by Altieri and Todd (1981) and Murdoch (1975). Further refinement of the intercropping technology in terms of choice of companion crop, ration of intercropping, and time of sowing could aid in enhancing the FAW control. For instance, Altieri (1980a, 1980b) observed that pre-planting of bean by 20 to 30 days before maize resulted in more than 80% decline in FAW incidence. However, if striga and cereal stem borers are among the limiting factors, PPT technology provides the best protection. A positive component interaction was observed between maize, Desmodium, and Bracharia as well as Napier in managing the complex pests of maize (Fig. 4).

CONCLUSION AND RECOMMENDATION

The current study provides tangible proofs that PPT technology can significantly reduce the FAW infestation in maize. Moreover, it is already established that PPT technology can provide good control of complex pests, including cereal stemborer and striga, while improving soil fertility and providing high-quality fodder. Climate-smart PPT performed the best across ranges of pests followed by conventional PPT suggesting that the technology will benefit farmers better than maize–edible grain legume

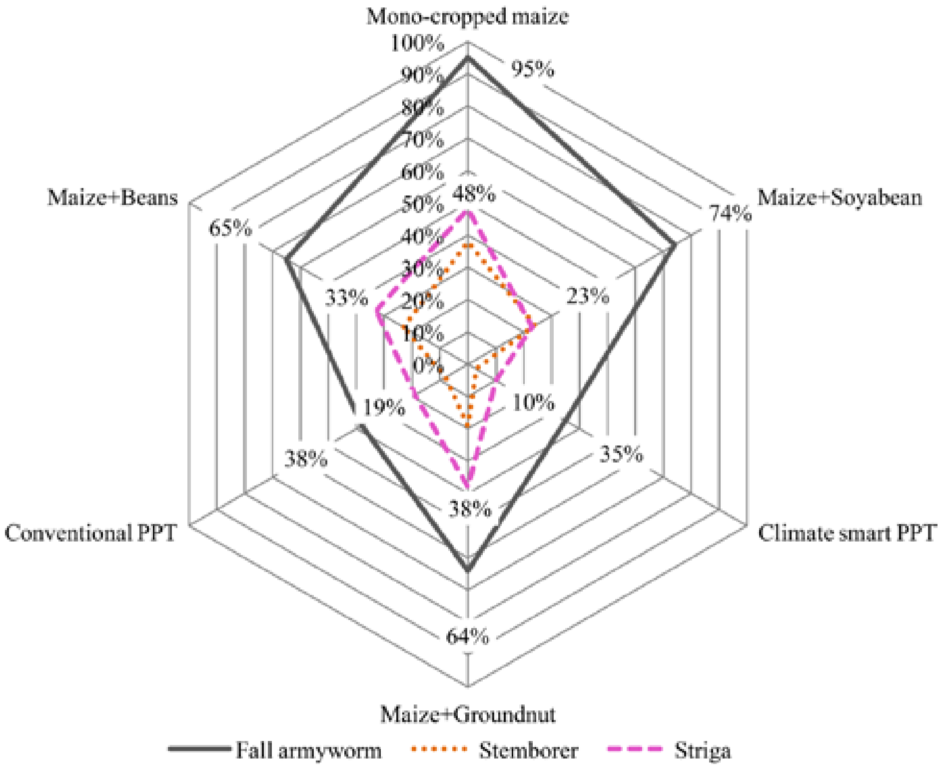

Fig. 4. Cumulative benefits of push–pull technology (PPT) in controlling pest complex of maize in Uganda.

intercropping. The intercropping of maize with leguminous crops also provides better protection of maize compared to mono-cropped maize. This study did not compare yield differences and hence further research is needed to determine the impact. Similar to the repellent effect of desmodium in PPT for stemborer could as well be attributed to decline in FAW incidence as well masking host recognition by FAW or affecting the movement of larvae. Such effects need to be further investigated and confirmed. This study also provides for intercropping of maize with edible legumes as an alternative FAW management approach, if augmented with one or more integrated management strategies.

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