Pheromone-based mating disruption to control *Spodoptera frugiperda* in Tanzania: Possibilites and Constraints for smallholders

Thomas O'Malley

Degree project • 30 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Landscape Architecture, Hortriculture and Crop Production Science
Agroecology
Alnarp, 2024

Pheromone-based mating disruption to control *Spodoptera frugipera*: Possibilities and Constraints for smallholders

Thomas O’Malley

Supervisor: **Teun Dekker, Swedish University of Agricultural Sciences, Department of Plant Protection Biology**
Assistant supervisor: Fikira Kimbokota, Mkwawa University College of Education, Department of Chemistry
Examiner: Raj Chongtham, Swedish University of Agricultural Sceiences, Department of Biosystems and Technology

Credits: 30
Level: Advanced, AE2
Course title: Independent Project in Agricultural Science
Course code: EX0848
Programme/education: Agroecology
Course coordinating dept: Department of Biosystems and Technology
Place of publication: Alnarp
Year of publication: 2024
Cover picture:
Copyright: All featured images are used with permission from the owner.
Keywords: pheromone, mating disruption, fall armyworm, Tanzania, smallholder, *Spodeptera frugiperda,* integrated pest management

Swedish University of Agricultural Sciences
Faculty of Landscape Architecture, Hortculture and Crop Production Science, Department of Biosystems and Technology

Abstract

Despite a growing interest in the use of pheromones as a more sustainable form of pest control, their use remains unstudied in the smallholder context. This paper is one of the first to study their use by small scale Tanzanian maize farmers to control the invasive pest *Spodoptera frugiperda* (known as fall armyworm). Given cost projections for pheromone production predict a drastic reduction in price, it is important to know how these products could be most effectively applied by highly resource constrained farmers. This paper therefore seeks to answer the questions: how effective is pheromone based mating disruption at controlling *spodoptera frugiperda* and how could it best be used by smallholder maize farmers? In answering this question this study will examine: 1) how well does pheromone based mating disruption work to control FAW 2) what role might pheromone-based mating disruption play in future pest management strategies for smallholders in Tanzania and 3) under what conditions might pheromones be most successfully used? This was done through a field study that tested the effects of a fall armyworm pheromone on maize production and interviewed trial participants about pest management strategies and perceptions of pheromone-based mating disruption. The results of the trial showed a significant reduction in pest numbers and leaf damage amongst plots that received the pheromone. Pheromones were seen as effective and well received by farmers, but affordability and coordination remain challenges for more widespread adoption of their use. In the future, pheromones could replace government subsidised pesticides, as they provide strong and efficient protection against fall armyworm and help to reduce the negative effects of excessive insecticide use in Tanzania.

Keywords: pheromone, mating disruption, fall armyworm, Tanzania, smallholder, *Spodoptera frugiperda,* integrated pest management

Table of Contents

List of tables

List of figures

Abbreviations

FAO – Food and Agriculture Organisation of the United Nations
FAW – Fall armyworm
IPM – Intgerated Pest Management
MOA – Mode of Action
MUCE – Mkwawa University College of Education
NGO – Non-Governmental Organisation
PBMD – Pheromone based mating disruption
SFW – Small Fresh Windowpane
SLU – Swedish University of Agricultural Sciences
TPHPA – Tanzania Plant Health and Pesticides Authority
USDA - United States Department of Agriculture

Introduction

Tanzanian farmers have struggled to control the invasive pest *spodeptera frugiperda* since its arrival in 2017 and it can devastate maize crops if left uncontrolled. Given the centrality of maize production in many regions of Tanzania, finding sustainable ways of controlling this pest is a national priority. Despite the growing interest in pheromones as a pest control method, the use of pheromones to control fall armyworm (FAW) has yet to be comprehensively studied amongst smallholder farmers. Although pheromones could play an important role in pest control for small-scale farmers, little is known about how they might be most effectively used in this context.

Pheromones (a subclass of chemicals that is used within intraspecies communication) are one potential way of reducing the negative impact FAW has on food production in Tanzania. Broadly speaking, pheromones are chemicals that are excreted by organisms in order to generate a response in members of the same species, including in sexual, trail and aggregation communication. These signals are sent and received in order to elicit behavioural responses, like alarm or as is common in agricultural settings, to convey sexual responses. These sex pheromones show 'the presence of potential mating partners and their reproductive status' (Rizvi et al. 2021). Given this, sex pheromones have been used in numerous ways, including to monitor pest populations, to detect the progress of invasive pests, to undertake mass trapping of insects, to invoke mating disruption and in 'push-pull' strategies. Pheromones can be used to monitor pest populations, whereby sticky traps are placed throughout fields with a rubber lure that contains a concentration of the species-specific pheromone. As male pests are caught in traps, they can be tallied in order to provide useful information about when pest pressure is highest. This information then allows for more optimum timing of spraying for pests. Mass trapping involves placing traps throughout fields and using sex pheromones to attract pests, which are then caught within the traps (Howse et al. 1998). Push-pull strategies utilise a repellent and an attractive stimuli, used in tandem, in order to reduce pest numbers. This method involves 'pushing' pests away with repellent plants or odours and 'pulling' them towards other stimuli, where they can be trapped or contained (Cook et al. 2007).

This research analysed mating disruption as means of controlling *S. frugiperda* through the use of a synthesised mating pheromone. Mating disruption works by placing high concentrations of mating signals throughout agricultural fields, thereby creating a 'cloud' of pheromone trails. High amounts of pheromones desensitise male mating receptors such that they cannot distinguish true signals. This inability to find a mate leads to a disruption in reproduction rates and in turn, lower pest numbers. Pheromones have many advantages when compared to conventional, synthetic pesticides. These include: having no toxicity to humans, targeting only specific pest species (leaving beneficial organisms unaffected) and causing no damage to surrounding ecosystems (waterways, soil and plants). The negative effects of pheromones on human health are much lower than conventional, synthetic pesticides, which can cause a range of negative health impacts, particularly when incorrectly applied or without proper protective clothing (as often happens in Tanzania) (Lekei et al. 2014). While chemical pesticides often kill non-target organisms, pheromone based mating disruption (PBMD) is species specific, meaning there is less negative impact on beneficial organisms and because they are non-toxic substances, they do not pollute soil and waterways like synthetic pesticides (Witzgall et al. 2010). For these reasons, there has been ongoing global growth in demand for pheromones as a sustainable method for pest control (Wang et al. 2022)

As of 2015, mating disruption products were used on more than 750,000 hectares of farmland worldwide and there was a 75% increase in areas commercially treated by pheromones from 2005 to 2015 (Miller & Gut. 2015). The overwhelming majority of the areas treated by pheromones are however in higher-income countries, primarily in the European Union and the USA. Richer farmers tend to have larger plot sizes, which make them better suited to PBMD, as well as access to greater monitoring tools (allowing for more accurate deployment of pheromones). Pheromones are currently used on cotton, rice and in forestry, but due to their relatively higher costs (compared to chemical pesticides), pheromones have been primarily used on higher value crops (particularly fruit) (Witzgall et al. 2010). Although pheromone use is a fairly well-established pest control strategy amongst large-scale, industrialised farms, smallholders have vastly different pest control priorities and strategies.

One of the major challenges associated with increasing the uptake of mating disruption in lower-income countries is its need for area-wide application. This is because ‘coordinated areawide efforts have been much more effective than patchworks of treated and untreated areas’ (Welter et al. 2005), due to the fact that ‘if the species is highly migratory and the area under management is near a source population, then the area under mating disruption may suffer crop damage due to the immigration of mated females’ or because ‘virgin females could leave an area under disruption, mate, and then reinvade the crop’ (Cardé. 2021). FAW is capable of travelling large distances, meaning that area wide control would appear necessary to limit the reproduction of this pest. This makes successful pheromone application more challenging amongst smallholder farmers, as they typically farm small plots. In order to be successful, PBMD would therefore need to be implemented across numerous plots simultaneously.

The cost of pheromones is another major challenge for increased uptake in pheromone use in lower income countries, given the limited capital smallholders have available for pest control. According to Stockstad (2022), pheromones can cost anywhere from $40-400 per hectare, which equates to between $16-260 per acre. However, these costs can vary depending on the pheromone used (how easy it is to produce), the crop on which it is applied, what level of pest damage is acceptable, the mode of application and the number of re-applications needed. While there are projections for the cost of pheromones to decrease, as new, more cost-effective production techniques become available (Petkevicius et al. 2020), as it stands however, the cost of pheromones remains a barrier for resource-constrained farmers. This is especially the case for a crop like maize, which tends to be lower value, meaning farmers may be less inclined to invest large amounts of capital into inputs.

The regulatory climate for pheromones in Tanzania is also a major consideration, as the registration process of biopesticides is ‘costly and bureaucratic’ and claims that ‘the registration procedure takes a minimum of three and half years’ (Moshi & Matoju, 2016). In assessing what role PBMD may play in Tanzania, it is vital to consider these administrative barriers, as well as the role of the Government in facilitating this transition. If this technology is to be rapidly adopted in lower-income countries, it needs to be supported by governments that are open to rapidly authorising and adopting novel forms of sustainable pest control and making these products available commercially.

Finally, smallholders have more limited access to capital, support and information, compared to farmers in higher-income countries. If pheromones are to be adopted by smallholder farmers, it is vital to consider how this new technology could best be applied and learned by farmers. Extension Officers play an important role in improving pest control in Tanzania, as they are the ‘gateway to information on new farming technologies developed outside their narrow environments’ (Msuya et al, 2017). Extension Officers would likely play an important role in disseminating information about any potential future use of pheromones. The means by which farmers learn and adopt new pest control techniques will as such, be an important part of this research.

As it currently stands, there are no published scientific articles that relate to PBMD for fall armyworm in Tanzania or East Africa. There are also no published studies that have tested PBMD against FAW in globally (given the recent development of the product SPLAT-FAW used in this trial). The research on pheromones for FAW control have so far only dealt with trapping (Cruz-Esteban et al. 2022) or the use of pheromones for population monitoring (Pair et al. 1989). This research therefore seeks to contribute to these knowledge gaps by analysing the efficacy of PDMD on control of *S. frugiperda* on maize plants. This study will also contribute to the use of PBMD in Tanzania and to the understanding of how pheromones may best be used by smallholder farmers in East Africa more broadly.

This study seeks to answer the question: how effective is pheromone based mating disruption at controlling *spodoptera frugiperda* and how could it best be used by smallholder maize farmers? In answering this question this study will examine: 1) how well does pheromone based mating disruption work to control FAW 2) what role might pheromone-based mating disruption play in future pest management strategies for smallholders in Tanzania and 3) under what conditions might pheromones be most successfully used? It will first assess the efficacy of pheromones to control FAW in smallholder farmer settings, based on the results of the field study that was established in early 2023. In addition, this study will examine the farming practices of those involved to understand the prevailing pest control techniques amongst participants and to investigate how pheromones were understood by the farmers (with reference to factors like effectiveness, safety and ease of use). Finally, these findings are discussed within the context of integrated pest management (IPM) strategies for smallholder farmers, to better understand how pheromones might best be utilised by small scale farmers and which conditions could facilitate the rollback of pesticides through adoption of this green technology. These findings can clarify potential advantages or disadvantages of pheromone use in small-scale farming, providing an overall assessment of possibilities, constraints and areas for further research. This paper therefore incorporates a field study that tests the effectiveness of PBMD, but also seeks to answer what behavioural, institutional or economic change may be required for pheromones to be more widely used by small-scale farmers.

1. Materials and Methods

1.1 Background

This research was conducted as part of a trial that was set-up in Iringa Region of Tanzania in January 2023 to test the efficacy of the Specialized Pheromone & Lure Application Technology (SPLAT, ISCA Technologies, Riverside, CA), loaded with 5% Z9—14O:Ac (a major pheromone component of FAW) in reducing FAW infestation amongst maize. It was a collaboration between researchers from Swedish University of Agricultural Sciences (SLU) and Mkwawa University College of Education (MUCE), in collaboration with ISCA Technologies. It was funded through an BBI-JU EU grant, Phera (H2020-BBI-JTI-2019), which aims at developing, scaling up and testing moth pheromone production in yeast cell cultures, thereby affording a significant reduction in future prices of pheromone production.

1.2 Trial Site and agroecological characterisation

The trial sites were located close to Mgera in Iringa, Tanzania (7° 41' 49.9"S 35° 37' 16.1"E). This region is one of the major food producing areas of Tanzania and is particularly important for maize farming. The soils in this area are arenosols, a loamy sand which is particularly well-suited for maize production. Cropping seasons are characterised by a wet season that runs between November to May and a dry season that starts in June and continues until October. The original experiment was established in January 2023 with the primary aim of testing the effect of the pheromone on mating disruption, and interviews began in April 2023 with the aim of providing more insight into farmers' perspectives on pheromone use and to gather more information on the management techniques that participants used throughout the trial.

Image 1. Map of Tanzania. Mgera is denoted by the red pin

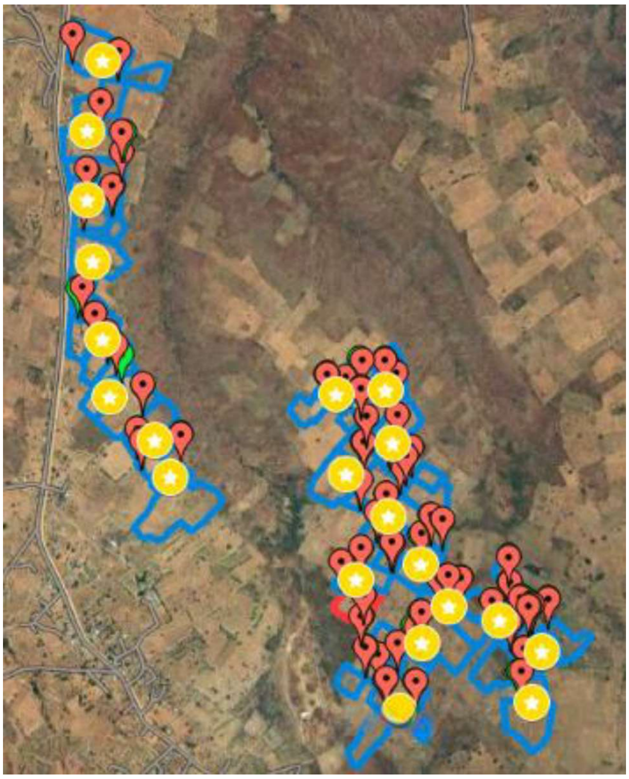


Image 2. Control (left) and treatment (right) plots. Insect traps are represented by the yellow circle. Fields are 400 metres apart at the closest point.

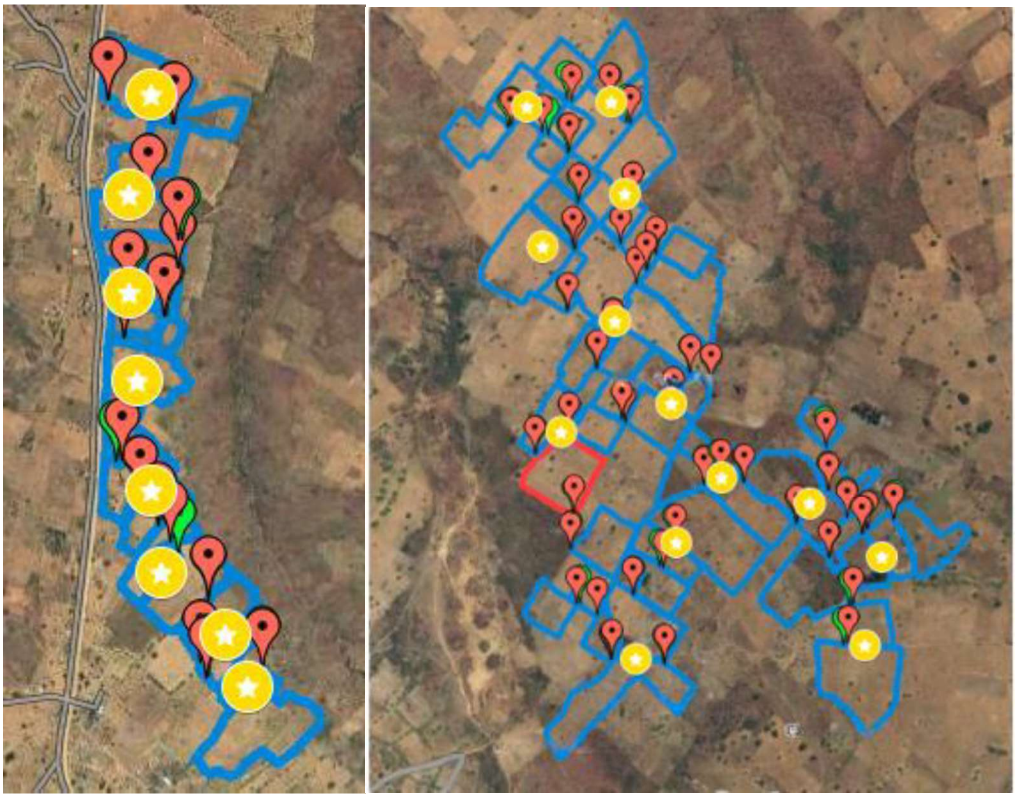


Image 3. Control plots (left) and Treatment plots (right). Insect traps are represented by the yellow circle.

1.3 Experimental setup of the mating disruption trials

The trial sites were established on a cluster of 71 farms, located near Iringa, in the southern highlands of Tanzania (displayed in image 2). The total area of the treatment was 50 and 35 hectares in the control. Plot sizes varied from 0.34 to 3.89 ha (0.84 to 9.61 acres) with an average plot size of 1.06 ha 2.61 acres (2.61 acres) in the treatment and an average plot size of 1.94ha (4.79 acres) in the control. The treatment plots were to the east of the control, as this intended to ensure that winds did not blow the pheromone in the direction of the control plots. While researchers initially assumed that wind blew predominantly east, meteorological data suggests that winds tend to blow west (Weather Spark, 2023). This was not seen to be a major issue however, as the trial's data would be more on the safe side (trap capture was still higher in the control, despite the slight possibility of pheromone crossover from the treatment). The control was located 400 metres away from the treatment at the nearest point.

All farmers included in the trial planted maize, with sowing taking place between November-January (with a majority of farmers planting in December). The cropping practices of farmers varied, with 50% of treatment monocropping and 60% of control farmers monocropping. Data for seeding density was not collected although hybrid seeds were most common (82% in treatment and 100% in control). All farmers in the control and treatment applied inorganic fertilisers, although pesticide use varied greatly (23% in treatment and 90% in control). Of the 71 farms, 53 were grouped into contiguous treatment plots, which received two applications of SPLAT -FAW. SPLAT-FAW contains only the major pheromone component of FAW, Z9-14O:Ac, which was produced in yeast biofermenters. A control group of 18 farms, received no pheromone application from researchers. For this experiment, using a randomised plot allocation within the same area was impossible, as the effect of airborne pheromones released from the SPLAT-FAW matrix exceeds the small plot sizes that were typical of farmers in the experiment, which is why two different sites had to be established in two separate contiguous areas.

Once the trials sites had been established, white delta traps baited with a pheromone lure (rubber septum that contained a commercially available FAW pheromone lure used for monitoring (ISCA Technologies, Riverside, USA), were placed in the treatment and control plots. Insect traps were placed every 5 acres, with 13 in the treatment and 8 in the control and are display in Image 3 as the yellow circle with a white star inside. A lure with the pheromone was placed inside the traps and replaced every month. SPLAT-FAW dollops of 1 gram were then applied by researchers every 25m^2 within the treatment plots on between 15/01/2023-19/01/2023 and a second application took place between 18/02/2023-21/02/2023. SPLAT-FAW was mistakenly not applied a third time at the end of April, as was originally planned Adult male FAW populations were then measured eight times between January and June by counting male *S. frugiperda* caught in insect traps that were placed throughout the control and treatment plots. No pheromones were applied to the control plots and farmers were encouraged to continue their usual management strategies (in both the treatment and control plots).

1.4 Leaf Damage Assessments

Leaf damage from *S. frugiperda* was also assessed in every plot on four occasions, between January and March, with plants being assessed for damage using the Davis scale (Davis et al, 1992). The Davis scale uses numbers between 1 and 9 in order to classify leaf damage, with 1-3 representing minor damage, 4-6 representing mild damage and 7-9 representing severe damage. The number of plants were then tallied, according to the number of plants with minor damage (1-3), mild damage

(4-6) and significant damage (7-9) (Davis & Williams, 1992). To assess leaf damage, researchers first walked in perpendicular lines through the centre of each plot, from one edge of each field to the other on both sides, assessing every plant along the way. Each plant was analysed and the level of damage in the top three leaves tallied. Researchers only tallied the top leaves during each inspection, to ensure that only new leaf damage was assessed.

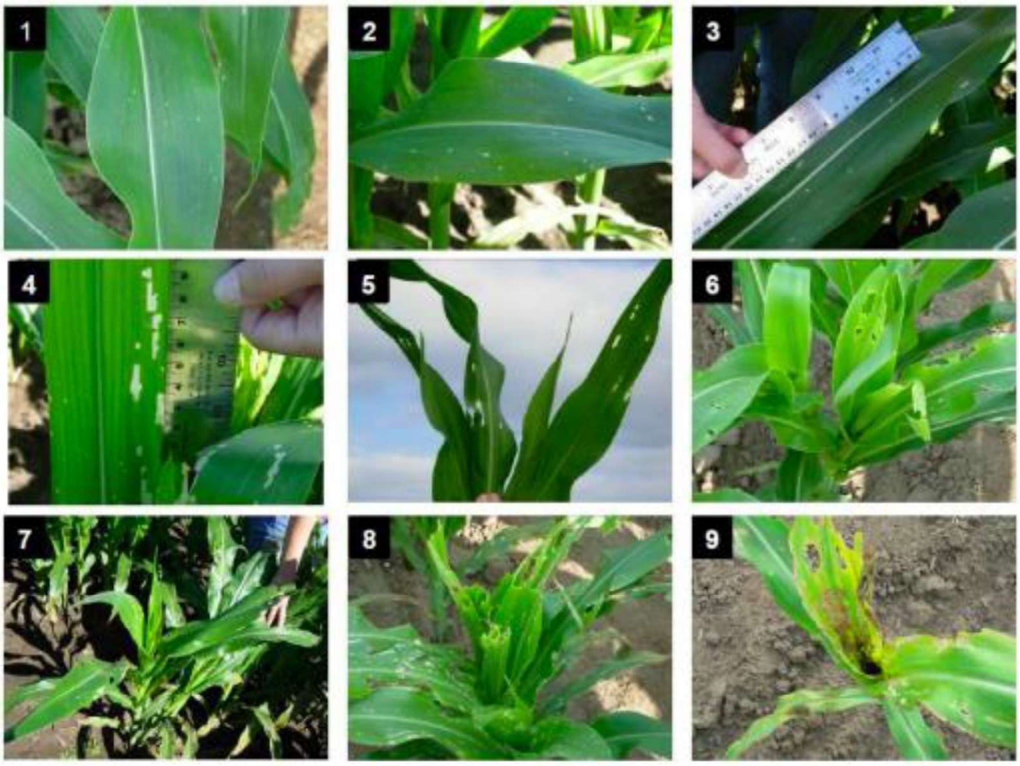


Figure 1. Visual guide of the Davis Scale. Source: Supartha et al (2019)

1.5 Cob Damage Assessments

In May, just prior to harvest, measurements were taken to assess cob damage, yield and FAW numbers in control and treatment plots. Cob damage was assessed according to a scale between 1-6, with 0 representing no visible FAW damage and 5 representing cob damage greater than 50%. The length and damage level of cobs from fifty plants were measured and assessed in each field, with researchers selecting 50 cobs from each plot in a manner where cobs were evenly sampled from four quadrants of the plot, by walking through the centre of the field starting from one boundary edge to the other, on both the long and short side of the field. Every cob length was measured and given a score between 0-5 (0 representing no damage and 5 representing damage of 50% or greater). Any FAW larvae found during the inspections were also tallied. This data was gathered in order to give an indication of relative yield, final damage to maize cob and number of FAW larvae present in the field. The average length and damage scores were then calculated and assessed.

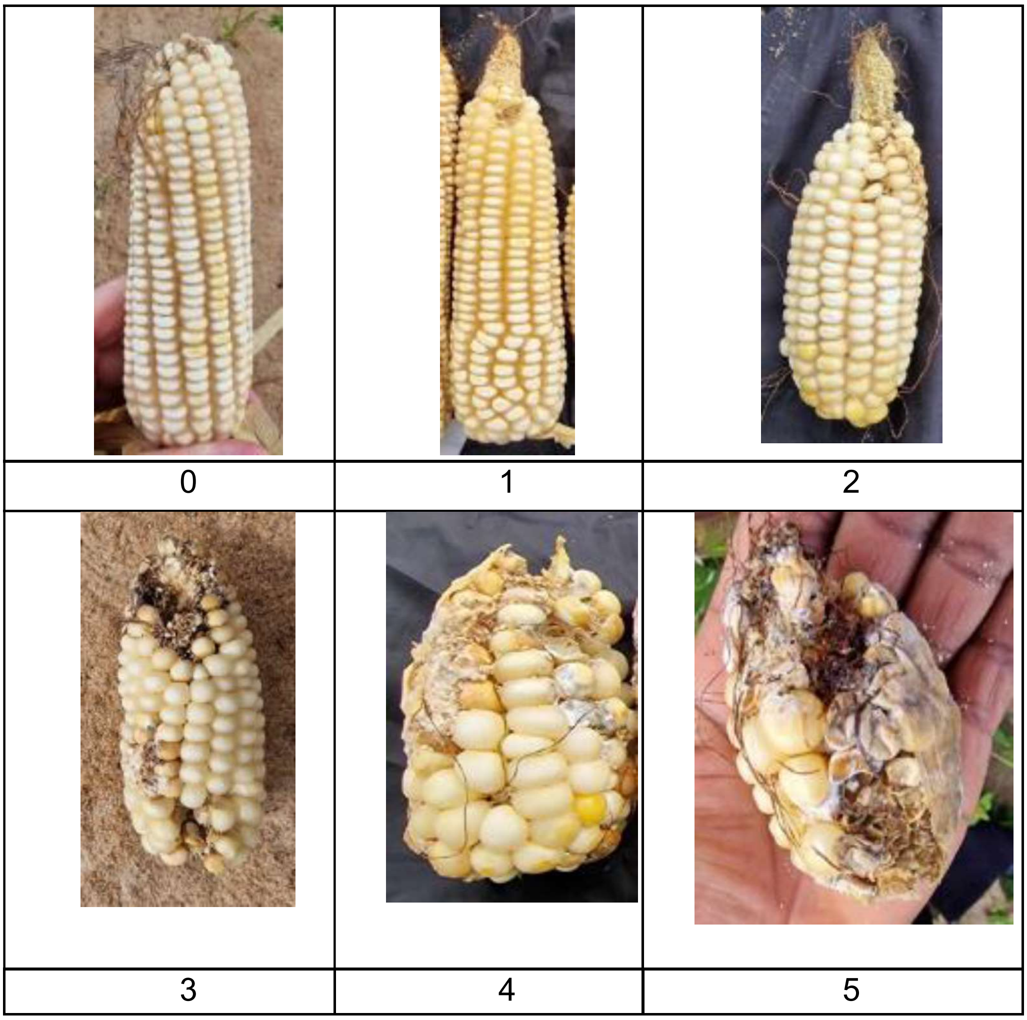


Figure 2. Images of maize scoring guidelines. 0 represents no visible FAW damage down to 5 which represents more than 50% damage by FAW

1.6 Evaluation of farming practices, opportunities and constraints for semiochemical interventions

Semi-structured interviews were undertaken with 50% of the participants in both the treatment and the control, 22 and 10 farmers respectively.[1] These interviews were conducted between April and June of 2023, with each semi-structured

---

[1] While 53 plots were originally outlined for the treatment, final damage scoring was only assessed for 44 (due to some plots being abandoned, not growing maize, or being unable to be located).

interview typically lasting 45-60 minutes.[2] This was done to assess management practices of farmers and to better understand pest management and perceptions of pheromone use more broadly. Although the original intention was to gather data and responses from a larger sample of farmers, there were significant logistical challenges in organising interviews with all participants. Nonetheless, a 50% sample was seen as sufficient to gauge the overall trends and perceptions of farmers in the treatment and control plots.

These interviews were divided into two sections. The first section covered agronomic management practices used by farmers during the course of the trial. These included questions about tillage, fertiliser use, seed type, planting date, cropping regime, insecticide use and weeding techniques. Following this, more qualitative questions were asked regarding perceptions of pheromones, in terms of their efficacy, safety and use, as well as questions relating to pest management, fall armyworm, and broader opinions on land use, economic considerations, climatic impacts and priorities for agriculture. These interviews were conducted to provide a socioeconomic perspective on pheromone use, and to better understand the priorities of smallholders with regards to pest control. All the interviews were conducted in Swahili, with answers being translated into English via an interpretor. These interviews were all recorded, transcribed, and then collated and converted into data points, whenever possible. Qualitative interviews were analysed through thematic analysis that consisted of ‘coding, theme identification and organisation and interpretation’, and the organisation of these themes paid attention to differences, similarity and frequency of views (Braun and Clarke, 2014).

1.7 Interviews with Government Staff and Extension Officer

In order to better understand the current regulatory and policy climate surrounding pheromones and biopesticides more broadly, a semi-structured interview was undertaken with a Laboratory Scientist from the Tanzania Plant Health and Pesticides Authority (TPHPA), whose answers were used to inform the legal status of pheromones in Tanzania and other biopesticide policy considerations. The recorded interview took place via phone call and was transcribed after the conversation. The topics of the interviewed included: federal policies relating pesticide reduction, the registration process for new pesticides in Tanzania, challenges in reduction of pesticide use in Tanzania, current legal status of

---

[2] Interview questions in appendix

pheromones in Tanzania, barriers to adoption of biopesticides, and overall Government strategies for the control of FAW.

A Government Extension Officer for the Iringa region was also interviewed in order to understand the challenges in improving pest management and how pheromones could be used with local IPM techniques. The semi-structured interview took place via phone call which was then recorded and transcribed. Questions were asked relating to: overall challenges in IPM implementation amongst farmers, the potential challenges of pheromone use in smallholder plots, how coordination could be effectively undertaken to use pheromone, how small scale farmers access pest control information, perceptions of pesticide use for farmers and overall recommended strategies for controlling FAW.

1.8 Linear Regression of farming practices

In order to better understand what agronomic factors might be influencing the final cob damage and length data, a linear regression was also run using a range of agronomic variables, matched against the cob damage and cob length data. Although information was gathered on a range of agronomic variables, not all were included in the final analysis. For the linear regression, the sample size was 34, (including the control and treatment plots). Due to the significant logistical challenges in accessing all farmers for data collection (as many were not known to the staff that implemented the trial), relevant agronomic data could not be obtained for all 57 plots. The main purpose of the regression was to see whether any particular agronomic variables were most strongly correlated with plots that had low levels of FAW damage and long cob measurements.

To analyse this, data for damage scores and average cob length were first inputted and checked to ensure that the data were normally distributed, that any statistical outliers were removed, that heteroscedasticity was not present and that data was linear. For both cob damage and cob length the above conditions were seen to be met. A linear regression was then run against a range of agronomic variables against both cob length and cob damage, in order to see which displayed some correlation. The variables included were: seed type (purchased vs saved), planting date, quantity of fertiliser, number of insecticide sprays, crop diversity (monocropping vs. intercropping), crop rotation (whether implemented or not), tillage type, land ownership status, weeding technique, market vs. subsistence production, and age of farmer. This data was analysed to observe the adjusted r-squared and to see which agronomic variables had a p-value below .05. All data analysis was conducted with Microsoft Excel.

2. Results

2.1 Pest Populations

The results of the trial showed that SPLAT-FAW was able to significantly lower the number of FAW found in the treatment plots. The number of FAW is displayed in Figure 3, displaying the cumulative number of adult male FAW collected in 21 insect traps placed in the control and treatment plots. As is shown, all traps in the treatment caught less FAW compared to the control traps, with the treatment catching an average of 3.6 adult FAW per trap (across the eight inspections) and the control catching an average of 11.5 adult FAW per trap (across the growing season). This corresponds to an average per trap across the entire season of 30.08 adult male FAW captured in the treatment and 92.75 in the control. As shown in Figures 3 and 4 trap capture was higher in February and March, as it has been noted in previous studies that FAW activity peaks one to two months after planting.

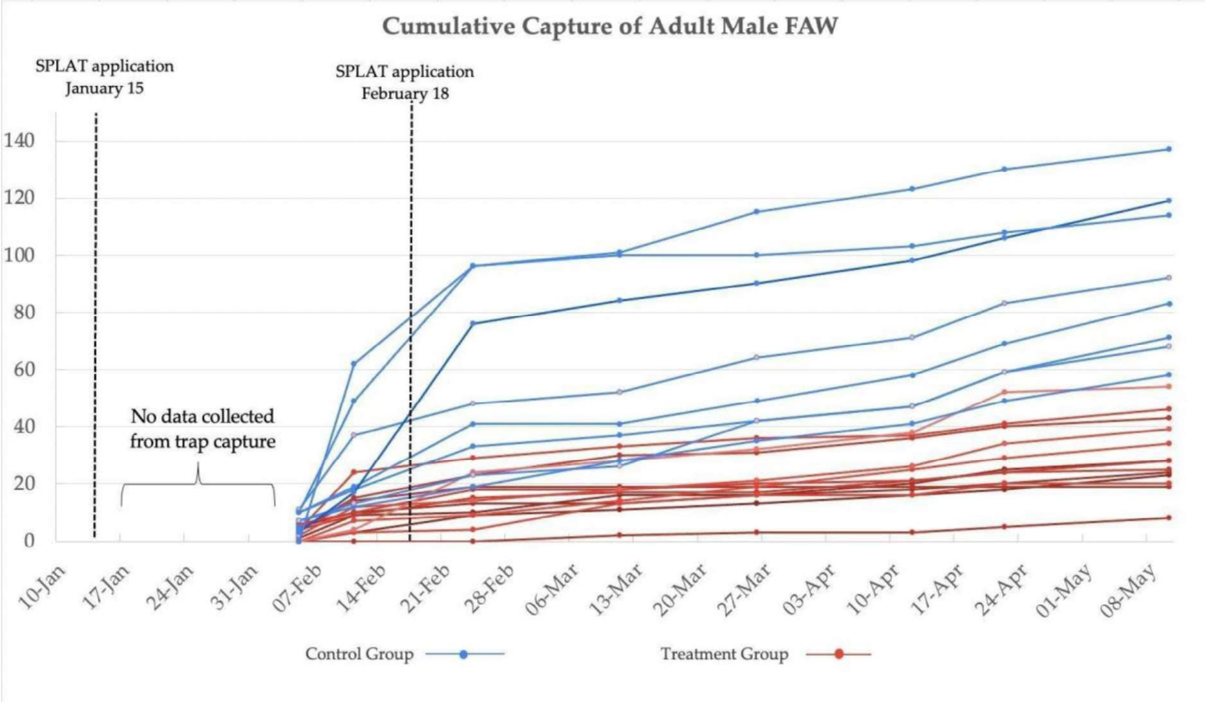


Figure 3. Cumulative number of FAW caught per trap between the control and treatment

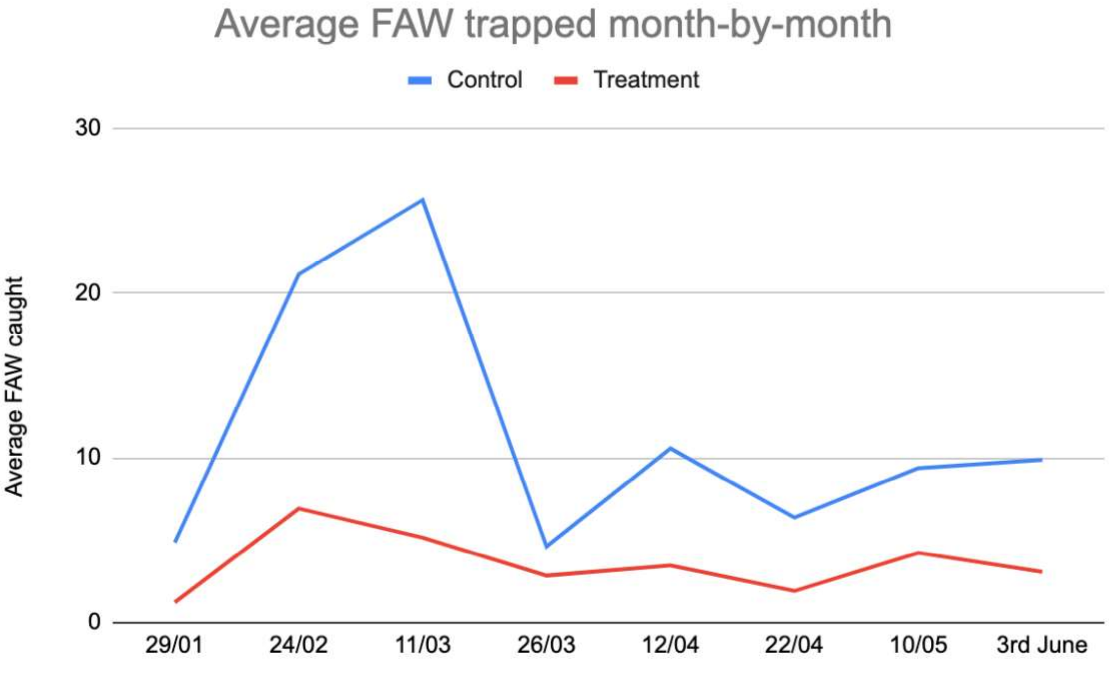


Figure 4. Month-by-month average capture of male S. frugiperda caught per trap

2.2 Leaf Damage

Directly prior to the start of application of SPLAT-FAW (12-14/01/2023), the percentage of plants with signs of *S. frugiperda* damage was tallied. Damage did not differ between the control (12.42% of the plants with some leaf damage) and the treatment (12.06% of plants with some leaf damage). After this initial inspection, the Davis scale score was used to assess damage on three dates - 2 weeks after application, 4 weeks after application and 9 weeks after application. In all instances, the control showed an overall significantly higher level of damaged plants (Figure 5). The first inspection showed that the control had an average of 18.73% plants showing some sign of damage (between 1-9 on Davis scale) compared to 7.48% in the treatment. The second inspection in February had an average of 13.77% plants in the control with signs of leaf damage, compared to 5.86% in the treatment. The final inspection in March showed that 15.85% of plants in the control showed some signs of damage, with the treatment plot having 6.94% of plants with some signs of leaf damage. There was also a noticeable reduction in severely damaged plants (7-9 on Davis Scale), as in the control plots 4.93%, 7.77%, and 3.19% of plants were badly damaged in each respective inspection. This compares to just 2.34%, 2.81 and 1.56% of plants in the treatment control.

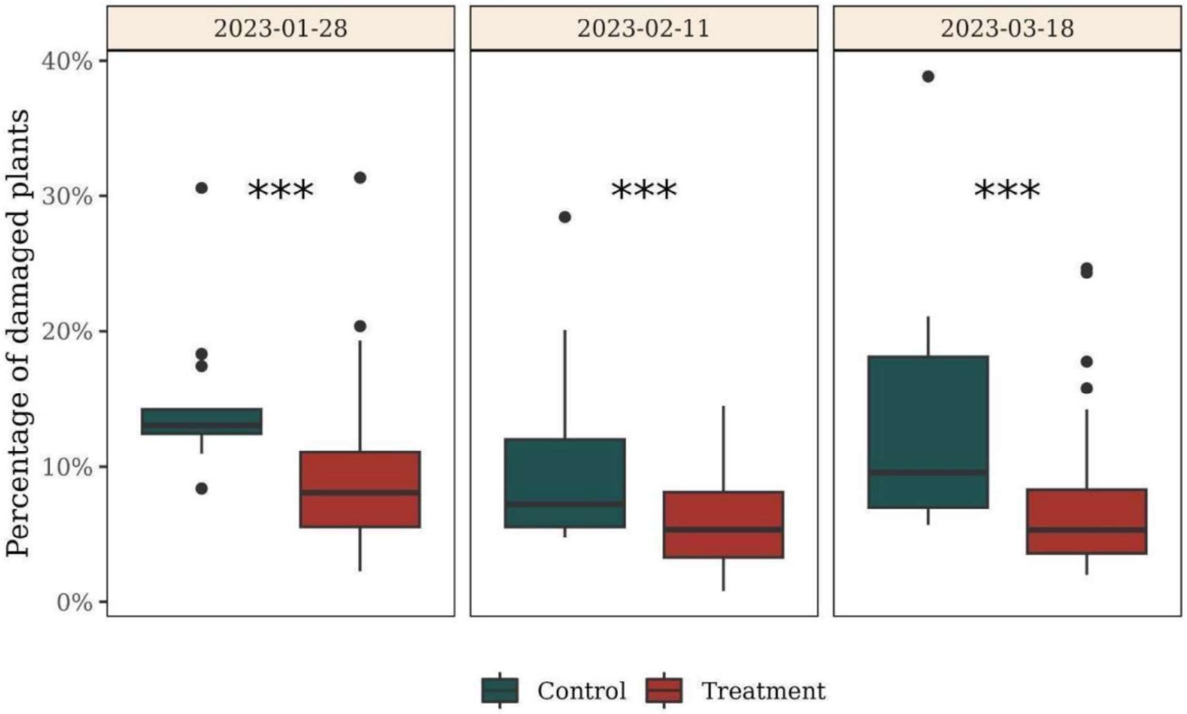


Figure 5. Percentage of plants showing some leaf damage from FAW across the three inspections. The three asterisk display statistical significance and the dots represent outliers.

2.3 Final Damage Scoring

Just prior to harvest, the length of the maize cobs and the severity of damage from FAW were assessed. The results from this scoring showed the average level of damage in the control was not statistically different as can be seen in Figure 6. The average cob length was 11.58cms in the treatment and 11.82cm in the control. Surprisingly, more FAW larvae per acre were found in the treatment plots, with an average of 11.45 FAW found per acre in the treatment and an average of 4.6 FAW per acre in the control.

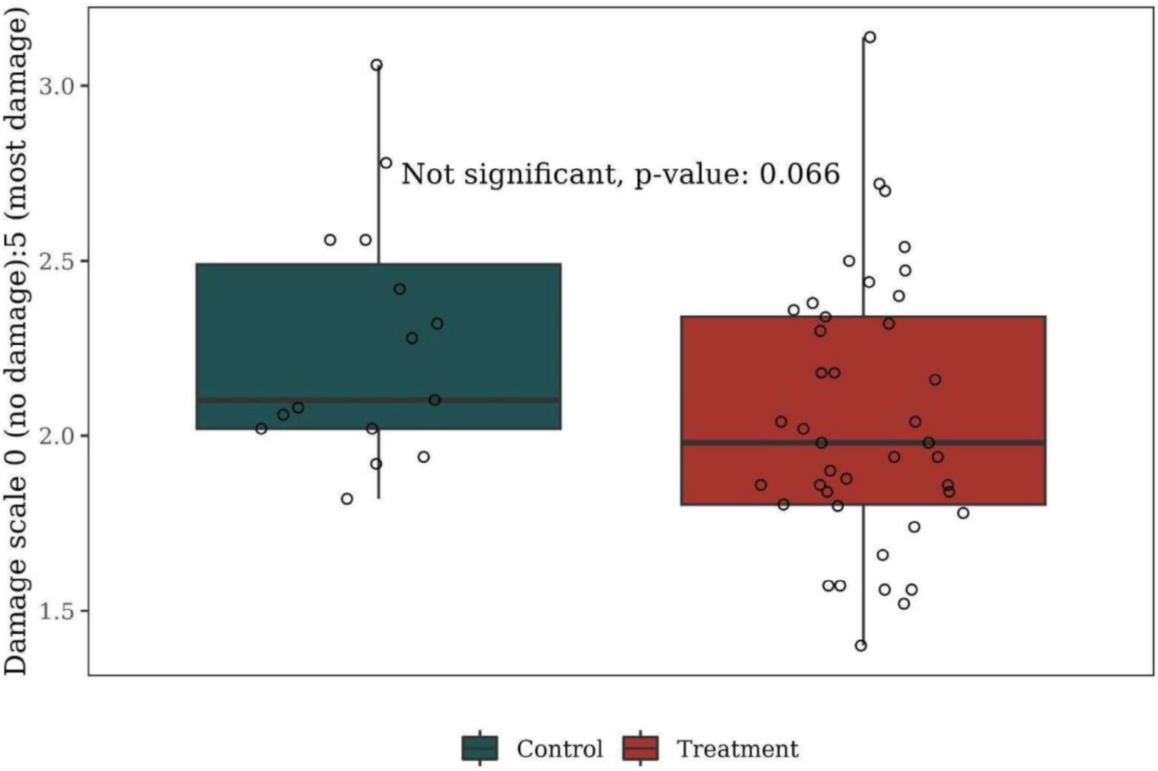


Figure 6. Cob damage scores in control and treatment plots. Bars display the median, the quartiles and outliers. Higher numbers represent cobs that had higher FAW damage along a scale of 6 discrete damage levels.

2.4 Agronomic Data Analysis

The results of the linear regression run on the cob length and damage figures proved unable to find any clear indication of which variables were most closely correlated with cob health.

Summary Output - Damage - Treatment and Control

The results of the linear regression are displayed in Table 1. The adjusted r-squared value for damage scores was .22, meaning only 22% of the variation in damage scores could be explained by the selected variables. There was similarly only one variable that displayed a p-value lower than .05, which was seed type, with farmers that used purchased seeds typically having lower cob damage than those who used saved seeds. However, this relationship is only correlational and could be more closely connected to other factors. For example, farmers that used 'saved' seeds may be in general less likely to invest heavily into any external farming inputs. Whereas those who used purchased seeds may be more inclined to spend more money on inputs, which may indicate a farmer that spends more time and energy in maize production. Beyond seed type, the remainder of the agronomic variables were unable to display any strong correlation with data from cob damage. However, given that there were very few strong relationships observed between dob damage socres and agronomic variables, it was difficult to draw any other conclusions from this data.

R Square	0.433
Adjusted r-squared	0.220
Observations	34
p-value	0.079

Variable	**P Value**
Insecticide Sprays	0.543
Monocropping vs. Intercropping	0.382
Crop Rotation	0.185
Fertiliser	0.323
Renting vs. Owning	0.431
Subsistence vs. Market Production	0.997
Age	0.902

Table 1. Results from multiple linear regression on cob damage scores

Summary Output - Length - Treatment and Control

A multiple linear regression analysis was done matching average cob length against the variables pictured in Table 2. For this regression the adjusted r-square value was negative, meaning that these variables showed no predictive value. The only variable that showed a p-value that was close to statistical significance was whether the farmer produced maize for the market or for their own consumption, with the numbers suggesting that farmers who aimed production for subsistence had on average shorter cob lengths. The remaining agronomic variables indicated no strong correlation with average cob length.

R Square	0.206
Adjusted R-Squared	-0.07
Observations	34
P-Value	0.68

Variable	**P Value**
Seed Type	0.841
Date Planted	0.745
Fertiliser	0.615
Insecticide Sprays	0.707
Monocropping vs. Intercropping	0.464
Crop Rotation	0.677
Renting vs. Owning	0.737
Subsistence vs. Market Production	0.081
Age	0.857

Table 2. Results from linear regression on cob length

2.5 Qualitative Interviews

The interviews conducted helped provide more information on farmer demographics, difference in management practices between the control the treatment, prevailing pest control methods and broader farmer priorities.

2.6 Farmer Demographics

Figure 7 provides an overview of the farmer demographics from the trial. Demographically, the treatment plots had a higher percentage of younger, male farmers that were more likely to be renting than in the control plots. The average plot size in the control was also higher (although it was not uncommon for one plot to be sub-divided and farmed by more than one person). The higher percentage of ownership in the control is due to the proximity of the control plots to the farmers dwellings, while treatment plots were generally further away from the closest village. Finally, a significant proportion of production on these plots was purely for the farmers own consumption, although the majority of farmers expressed that they would likely keep whatever maize was required to feed their household and sell the surplus at the market (or conversely, sell enough maize to cover the costs of production and keep the remainder for home consumption).

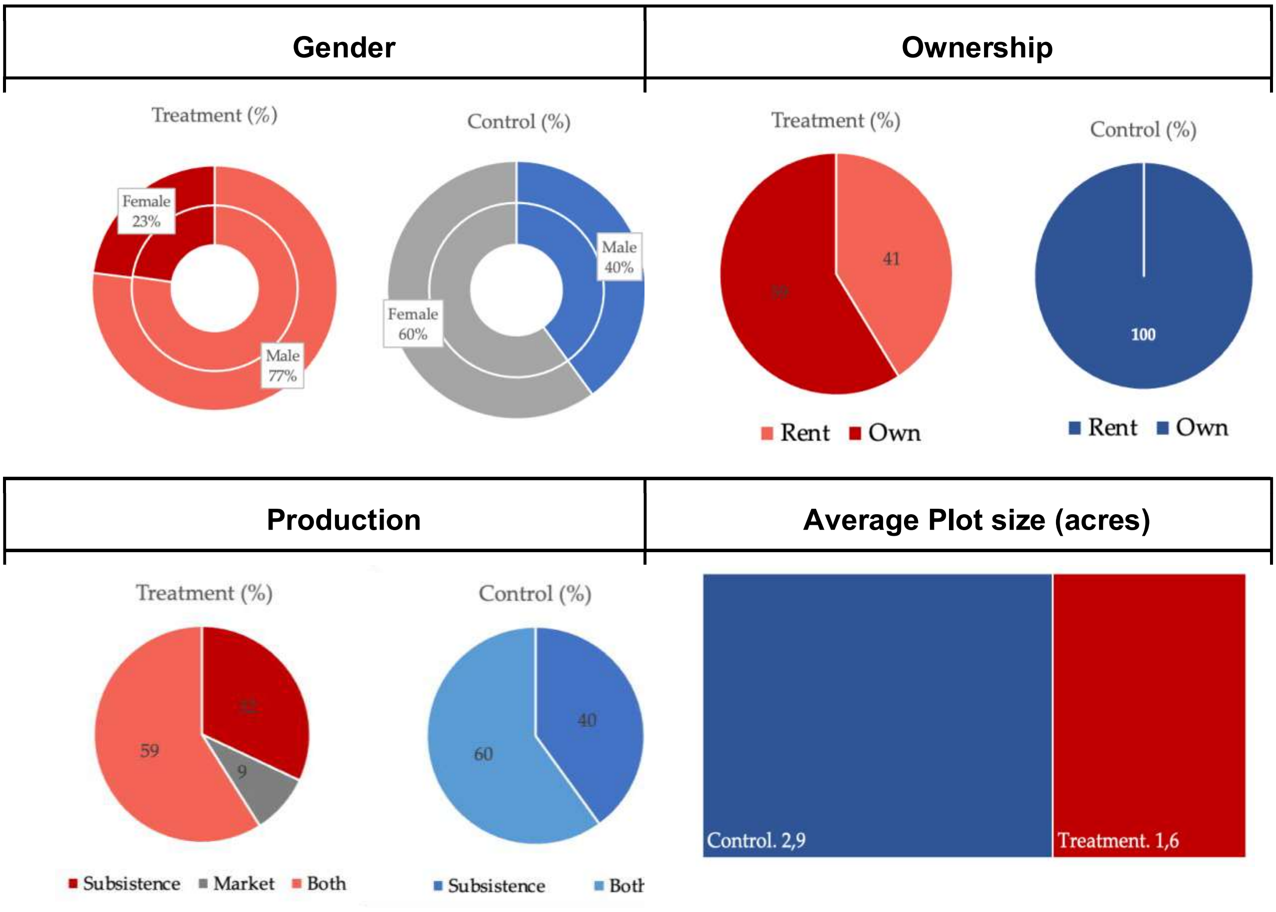


Figure 7. Overview of farmer demographics in the control and treatment

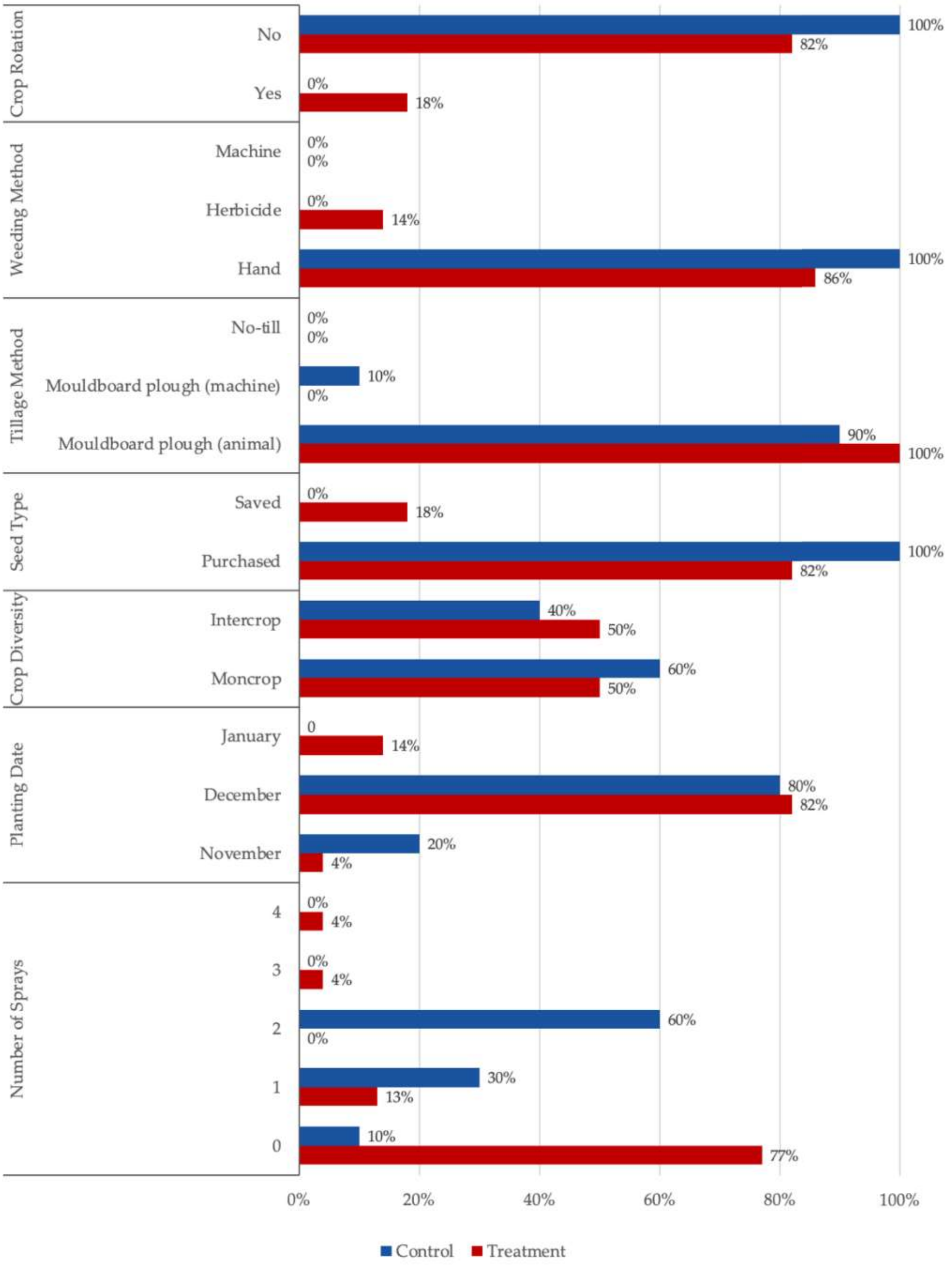
2.7 Management Practices - Treatment

Surveys of farmers who used pheromone treatment on the maize plots showed that most of themadopted fairly uniform practices to maize production. In the treatment plots, a vast majority (82%) planted in December, used purchased seeds (82%), tilled using an ox-driven mouldboard plough (100%), weeded by hand (86%) and did not utilise a year-by-year crop rotation (82%). The use of crop rotation was defined as any farmer that did not plant maize on that land in any of the previous five seasons (meaning 82% of farmers had planted maize for the previous five seasons). Monocropping was practiced by 50% of respondents, with the other 50% practicing intercropping (for various reasons such as…).[3] The most common intercrops were green beans (36%), sunflower (36%) or green beans and sunflower

---

[3] These included: to diversify production in case of crop failure or price fluctuations of maize, to diversify food available for consumption, because seeds of other crops were cheaper, to have access to cooking oil from sunflower

(27%) Average per acre fertiliser[4] inputs showed considerable variation, with an average of 102kg/ac, ranging from 25kg-150kg/ac (with a median of 100kg/ac). 77% of respondents did not spray their crop with insecticide at all, while 13% sprayed just once. Two (9%) farmers interviewed sprayed multiple times (three and four times respectively).



---

[4] This includes all fertiliser types, including UREA, DAP, CAN and NPK and is the gross weight of the bag, not the amount of N, P or K that is made available to the soil

Figure 8. A comparison of farming practices in the control and treatment plots

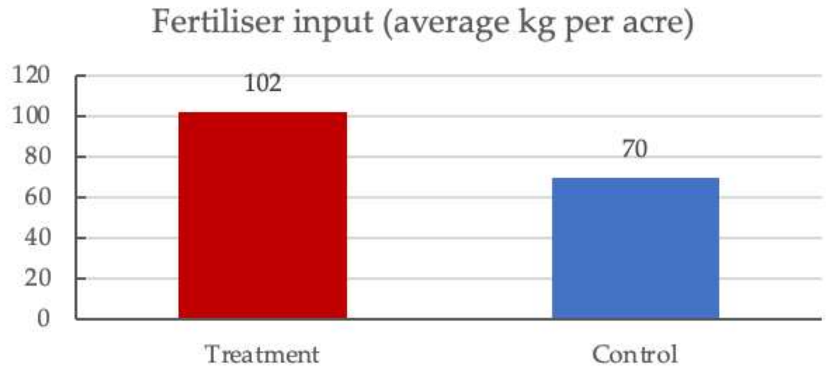


Figure 9. Fertiliser use in the treatment vs. control plots

2.8 Management Practices - Control

Data for the control plots showed many similarities with that of the treatment (displayed in Figure 8). All (100%) of farmers used purchased seeds, 90% tilled with an ox-driven moldboard plough, 100% weeded manually, 100% did not utilise a crop rotation, 80% planted in December and 60% did not intercrop. The main differences between the control and treatment plots were the use of insecticide and average quantities of fertiliser. In the control, 90% of farmers sprayed their field with insecticide against FAW, an average of two times during the season. The average input of fertiliser was lower in the control (70kg per acre), however there is some uncertainty about the accuracy of this figure. This is due to the fact that in the control, many plots of land were subdivided into several smaller parcels and it was sometimes unclear whether in the interview the farmer specified their total land size as the section that they were farming, or the total land area (according to the legal boundaries of the plot). Some farmers may have named the entire land as the acreage, despite the fact that they were only farming a portion of that space. For example, one respondent named their farm size as four acres, using just 100kg of fertiliser, although in reality she was likely only farming one section of a four acre plot. This, alongside the smaller sample in the control, has possibly distorted the fertiliser input data to make it look like the control was using significantly less per acre.

2.9 Existing Pest Management Strategies - Treatment Plots

To properly understand how pheromones might be most effectively used as part of a smallholder IPM plan, questions were asked about prevailing pest management strategies and fall armyworm control methods. While no explicit advice was given to farmers in the treatment to stop spraying insecticide, only five (22%) of the interviewed farmers sprayed during the season, with three (13%) of these farmers only spraying once at the beginning of the growth season and ceasing spraying once they learned of the application of pheromones. This compares to the 68% of farmers in the treatment plots that said they applied pesticides in the previous season. Seven (32%) of the surveyed treatment farmers applied no pesticide in the previous season, five (23%) of which said they had never used insecticide, citing a lack of capital as the reason.

All participants knew of insecticide as a way to control FAW, and five (22%) interviewees also mentioned other control methods, primarily a 'local' method, which involved putting ash on crops. Despite knowledge of this local method, none of the farmers applied it during the season, citing a lack of effectiveness to this approach. Beyond this local method and insecticide, farmers did not explicitly mention any other form of pest control that they were implementing. For farmers who sprayed insecticide, the results were often seen as mixed, with many expressing frustration at the need to re-apply insecticides several times a year. A large majority (86%) of those interviewed also said that they had not received any specific training on how to control FAW, while the remaining 14% said that they had received some training from the government.

Other potential methods for pest control, like crop rotations, intercropping and weeding were sometimes utilised, though rarely with the explicit aim of controlling invasive species. Although two (9%) of the surveyed farmers mentioned the use of crop rotations with the intention of ensuring soil fertility, the use of crop rotations was rare amongst those interviewed (only 18% of the participants in the treatment did not plant maize in the previous season). Intercropping was fairly widely practised, with 50% planting another crop within their maize plot, however the reasons for doing so were generally to diversify production (avoiding risk of crop failure), to have a wider variety of crops for consumption or because seeds of other crops are cheaper (particularly sunflower), rather than for the explicit purposes of pest control. The use of herbicide was uncommon (16% of respondents used herbicide), and weeding was often neglected (personal observation) - although data regarding the number of times the plot was weeded within the season was not gathered. All this together suggests that a holistic IPM strategy was lacking from most of those surveyed in the treatment.

2.10 Perceptions of Pesticide Use and Safety - Control and Treatment Plots

Farmers having control and treatment plots were also surveyed regarding their perception of pesticide use and safety. Most (66%) respondents reported some kind of negative health impact from pesticide use, with only 17% not reporting any health impacts, while 17% did not comment, having never used insecticide. Amongst the most commonly mentioned side effects were the flu (40%) and skin irritation (28%). Chest pain and coughing were identified by 9%, as well as cancer and a loss of appetite by 3% of farmers. One farmer said that they had to 'accept the risk' of pesticide use, seeing no other viable alternative to pesticide use. The use of protective clothing was also not widespread, with 23% of farmers who used insecticide saying they did not use any protective clothing, with the most common forms of protection being masks[5] (45%), boots (36%), overalls (32%) and gloves (27%). Of farmers spoken to, 23% said that they paid someone else to spray, citing a lack of knowledge or equipment as the reasons. Only 36% of those surveyed were able to recall the name of the most recently used product.

Some other issues with insecticides mentioned by farmers included not having the knowledge of how to properly apply the product (dosage or timing of applications), not having the correct equipment to spray (with one farmer expressing that they had to use a broom to spread insecticide amongst their crops), the burden of carrying a heavy can on one's back, the need to constantly re-apply pesticides and purchasing pesticides that were expired. Many (45%) farmers surveyed expressed some dissatisfaction with insecticides, with the most common complaint being that crops required constant spraying (up to five times a year in the previous cropping season). Some farmers (18%) felt overall satisfaction with insecticide use, saying that while it did not eliminate the problem, it lowered pests to an acceptable level. These suggest that while pesticides were seen by most farmers as necessary to control FAW, there was not necessarily a high level of satisfaction amongst farmers regarding their safety and efficacy as well as sometimes poor knowledge of their use.

---

[5] Masks were often just bandannas wrapped around the mouth, which are ineffective at preventing negative side-effects of insecticide inhalation

2.11 Perceptions of pheromone-based mating disruption - Treatment Plots

Farmers in the treatment were also asked about their opinion on pheromone use in relation to its performance in controlling pests, safety, ease of use, mode of action (MOA), trust in product, and overall benefits of the pheromone. Farmers viewed the pheromone as effective at reducing FAW populations, with 95% of respondents claiming that they viewed the pheromone as effective at controlling FAW (the respondent who did not answer in the affirmative was unsure of its effects, having spent very little time on their plot during that season). The most common response relating to the benefit of the pheromone concerned its good performance at controlling pests (77%), with 18% of farmers also citing very quick results in pest control after its application. Another advantage cited by farmers was that it is easy to apply, with a dollop of pheromone only required every 25m^2, compared to insecticide, which requires every crop to be sprayed (18% of respondents). This perception of ease of use was however only based on observing researchers applying pheromone, as farmers were not actively involved in placing it throughout field. Of those spoken to, 9% also mentioned the health benefits of pheromones, citing that one can roam within the field without using protective clothing, even immediately after application of the pheromone.

A large majority of farmers (95%), felt that the pheromone was safe for human health, while the remaining 5% did not comment due to a lack of time spent in the field during the maize season. This perception of safety was due to direct observation of its effects, rather than from an understanding of its MOA. The conclusion on its safety was reached after spending time in the field after its application and not feeling any negative effects (despite not wearing protective clothing). Despite this high level of trust, 95% of respondents were unsure of how specifically the pheromone functioned to control FAW, with just one farmer mentioning that the pheromone operated through smell. The low level of understanding is unsurprising, given that the farmers did not take part in any workshop about the pheromone prior to its application. It is, however, notable that most farmers felt the product to be safe and effective without requiring any specific information as to how it functions. This suggests a preference for farming technologies that can be directly observed without necessarily needing a precise understanding of the scientific mechanisms by which it works.

The pheromone was generally viewed as easy to use by 59% of those interviewed, with the remaining 41% being unsure (having not seen the pheromone being applied). Among the reasons cited for the ease of use were: not needing to carry a heavy insecticide tank on one's back and only needing to apply it every five metres (as opposed to insecticides which are sprayed on a plant) (23%), that it can be applied without expensive equipment (15%), and 7% mentioned that it works well after only needing one application (although this is not entirely correct, as the pheromone should be reapplied every four to six weeks for optimal results). Finally, none of the respondents identified any downsides to the pheromone, although it is unclear what exact information they had about its MOA (beyond its ability to control pests).

Finally, within the treatment plots, pesticide use was significantly reduced after the application of the pheromone. While 68% of farmers in the treatment plots stated that they applied pesticide in the previous season (with a median of three sprays per year), only 22% of farmers in the treatment used any pesticide during the trial (with a median of one spray). Additionally, only 9% of those in the treatment plots sprayed for pests on more than one occasion. This reduction in insectide application was a direct result of the pheromone, as farmers observed lower pest numbers and decided that insecticide sprays were unnecessary.

2.12 Other Considerations

Mating disruption, like most other pest management plans, should be viewed within the context of an IPM system rather than as a stand-alone strategy. Its ability to be incorporated successfully into a pest management plan must therefore also factor in the relevant economic, cultural, regulatory and environmental conditions of the farmers. As such, surveys included questions that would help provide more of this context.

2.13 Pest Management Information - Treatment and Control

As mentioned previously, few farmers appeared to be practising an IPM plan, with many lacking the support, training or capital to do so. A large majority (84%) of farmers stated that they had not received training about FAW control from the government. The most common source of information about pest control was other farmers (56%), followed by learning from experience (25%), government officers (22%),[6] non-governmental organisation (NGO) or radio (9%), farm shops (6%) and

---

[6] There is some discrepancy between the figure of 84% claiming to have not received training on FAW control and 22% claiming that they learn about pest control from the Government

TV (3%). Farmers often cited that extension officers rarely came to the more remote villages, meaning that farmers generally observed and learned from larger and richer farmers that were based in the nearby town. Many farmers also mentioned that most farmers had to ‘struggle alone’, ‘be independent’ and ‘learn from each other’.

2.14 Farmer priorities - Treatment and Control

In order to assess the relevance of pheromones for smallholders, the overall priorities of participants were also gauged.[7] By far the most common challenges cited by participants were a lack of capital to invest in agricultural activities and unpredictable or insufficient rainfall, with 59% mentioning these both as issues. These were followed by difficulties controlling pests (41%), challenges accessing inputs (31%), price fluctuations (13%), poor farmer health[8] (6%) and lacking market power (3%). This implies that pest management is one of the main considerations for farmers involved in the trial, but that it may be less of a priority than climatic conditions and financial issues. When asked specifically about weather changes in the previous 10 years, 75% of farmers mentioned problems relating to rainfall, while a rise in pest numbers and a decline in soil fertility were mentioned by 9% of respondents.

Broader questions relating to environmental changes and soil health were also aksed, in order to gauge farmer’s views on long-term patterns of potential land degredation or uncertainty in weather. When asked about soil fertility, most farmers (81%) felt that they were using more inputs now than five years ago, with 31% saying they use more fertiliser due to technical advice from extension officers and 34% saying explicitly that soil fertility has been declining.[9] When asked about why farmers did not invest more money into restoring soil fertility, those that were renting were generally unwilling to add manure in order to improve soil health, due to fears that the landowner would not rent out the land next year. This lack of ownership therefore created no incentives for farmers to improve soil health. Those that owned the land they farmed said that they would like to use manure to improve fertility, but that manure was expensive (most did not own livestock). These responses show that although proper soil management was seen as important, there were limitations on farmers that meant few had long term plans for fertility management.

---

[7] Farmers were allowed to name more than one challenge for maize production

[8] Iringa has one of the highest rates of HIV in Tanzania and some farmers saw these infections as inhibiting many farmers

[9] Farmers also mentioned the need to use more insecticide and other inputs

2.15 Economic Costings - Treatment and Control

Given that semiochemicals like pheromones are more expensive than conventional chemical pesticides, it was seen as important to consider the overall expenditure of participants in the trial (which are displayed in Table 3). The average sum spent on insecticide in the previous year (across the control and treatment) was 41,600 Tanzanian shillings (TSH) or approximately 15.10€ (for an average of 2.5 sprays per acre, per year). The biggest expense for most farmers was fertiliser, with an average input of 102 kg per acre in the treatment (costing roughly 140,000TSH (53€)). Based on an average figure of 9 bags of maize harvested per acre (based on self-reported figures), overall revenue from a one acre plot would be roughly 526,500- 652500TSH (225-261€), with one bag of maize selling for between 70,000-80,000TSH (25-29€). It is also worth noting that 84% of farmers in the control and treatment spoken to also farmed other pieces of land, so it is unlikely that the field used during the trial was their only source of agricultural revenue.

Table 3 - Average farmer expenditures

Inputs	**Value (TSH)**	**Value (€)**
Fertiliser (50kg bag)	70,000	26
Insecticide (1 spray)	15-20,000	6-8
Seeds (1 bag)[10]	15,000	6
Herbicide (1 spray)	15-20,000	6-8
Plough (rent)	10,000	4
Costs		
Rent (1 acre/per year)	30,000	11
Labour hire (one day)	10,000	4
Revenue		
Income (1 maize bag)	70,000-80,000	25-29
Average bags per acre (9)	526,500-652,500	225-261

2.16 Coordination

---

[10] 5 bags of seed was seen as typical for a one acre plot

The need for area wide application of pheromones was identified as a potential barrier for adoption amongst smallholders. Based on the responses from the interviews, there appeared to be little formal organisation between farmers in both the treatment and control plots. No farmers mentioned that formal meetings ever took place between farmers who cultivated land in the target areas and although some respondents did mention discussing issues with other farmers, this was only in informal settings. Additionally, many farmers were also only renting land in that area and did not appear to have existing relationships with many of the neighbouring plots. Although 61% of those interviewed were members of One Acre Fund (an NGO that provides farmers with credit for agricultural inputs), none (0%) of the surveyed farmers were a part of any agricultural cooperative or any local agricultural organisation that coordinated or organised farmers in the local area.

2.17 Regulatory Climate

The interview conducted with a staff member from TPHPA showed that while there was interest in the potential benefits of pheromone use for pest control, they have so far only been used in trials. As it currently stands, pheromones are not commercially certified for use in Tanzania, but rather only for use in scientific trials. Although the process of registration is often reported as being slow and cumbersome, the interviewee stated that the registration process for new pesticides only takes three to six months, which may suggest that the TPHPA has responded to some of these inefficiencies in the certification of biopesticides. The TPHPA representative also suggested that disseminating information and training farmers on the use of pheromones may be a barrier to its widespread use, as well as an unwillingness on the farmers side to invest large amounts of capital into pest control. This staff member also said that there was no official government target on the reduction of pesticide use and although the Tanzanian government encourages the use of non-chemical pesticides, the supply and cost of bio-pesticides were identified as two major hurdles, alongside farmer awareness of new products.

2.18 The role of Government Extension Officers in IPM strategies

The Government Extension Officer’s responses regarding his perception of farmer priorities for pest control largely aligned with what farmers had mentioned in the surveys. Namely, that farmers are primarily interested in seeing quick and effective results in pest control and that they will assess the performance of the product through direct observation (rather than through a theoretical understanding of its MOA). He also felt that, although most farmers knew that pesticides carry some risk, their immediate concern was to find a product that was effective at reducing pest pressure. He also said that most farmers will learn pest control methods by observing which farmers have been successful and copying the products and methods that they use. A lack of easy access to biopesticides was also cited, as he noted that farm shops generally have a much smaller range of environmentally friendly pest control products.

The Government Extension Officer interviewed cited the main challenge for implementation of sustainable pest control on the Government side as a lack of resources to implement and monitor programs. Effective delivery of pest management programs was felt to require more funding, in order to collect the necessary data, supervise farmers and continually monitor progress. Due to these constraints, they felt that government employees often had to give quite general recommendations about pest control. He also said that many farmers lacked the capital required to use several control methods simultaneously (as is recommended for IPM). Finally, pheromones were viewed by this staff member as a promising way to slow insecticide resistance, which they viewed to be a major problem in the Iringa region. He said this was because farmers would typically find one product that they felt works well and continually use this insecticide, meaning that different MOAs were not being used (and hence resistance was more likely to develop in pests).

3. Discussion

In this study we sought to assess the potential of PBMD both in controlling fall army worm in smallholder settings and in offering a sustainable alternative for the local socio-economic and political context of Tanzania. While PBMD effectively suppresses FAW populations and aligns with many government and farmer priorities, it will only be successfully adopted by small scale farmers if certain agronomic, cultural, economic and institutional conditions are met. These will be outlined in the following section, after which an overall assessment and recommendations can be made.

3.1 Pest Populations

The results of the trial showed significant reductions in the number of adult male FAW captured with monitoring traps in the treatment. This reduction was particularly strong between January and March, with the difference between the control and treatment diminishing in the second half of the trial. This is likely due to the effects of SPLAT-FAW waning, as it was not re-applied a third time (as had been originally planned). It is likely that a third application of SPLAT-FAW in the second half of the trial would have further reduced captured FAW in the treatment. Although the SPLAT-FAW was not applied as frequently as was initially recommended, it is encouraging that in spite of this, there was still a 67.55% less FAW captured per trap in the treatment. This decrease in pest numbers can be strongly attributed to the effect of the pheromone, given that a large majority of farmers in the treatment did not spray after the pheromone had been applied, while 90% of farmers in the control used insecticide.

The ability of the pheromone to suppress FAW populations seems particularly important, given that the existence of irrigation in the cropping system has been shown to increase the likelihood of a given area to support year round FAW populations. While irrigation means that farmers can lengthen the period that crops can be grown, this will ‘shorten the period during which adverse climatic conditions will suppress FAW’ (Wightman. 2018). This is because FAW is able to migrate from the rain-fed farms to the irrigation-based farms at the beginning of each new season, when maize plants are particularly vulnerable to attack. The existence of the Kiwere irrigation scheme just a few kilometres from the trial site suggests that the area of the field study would appear to support continuous FAW populations, as the conditions at this irrigation scheme are identical to those noted by Wightman (2019) - namely, commercially focused, irrigation-based agriculture with high insecticide use. This seasonal influx was also mentioned as an issue by the Director of the irrigation scheme, during conversations. Area wide PBMD could therefore have a good impact on controlling FAW, given its prevalence in both the dry and wet season cropping season in the Iringa area.

3.2 Leaf Damage and Economic Injury Level

Results from the trial showed that leaf damage was lower in the treatment plots, though it is important to try to put these figures into perspective and determine what level of leaf damage is considered severe enough to cross the 'action threshold' for intervention, and 'economic injury level' for FAW on maize. These two concepts are connected, but the concept is that farmers need to balance the costs of any given pest control intervention against the potential benefits it will afford them, in terms of reducing losses from pests. Unfortunately, it was difficult to find an action threshold for leaf damage, based on the Davis Scale from similar ecosystems to Iringa. As noted by Overton (2021) there is a 'lack of consistency in which management interventions have been established for this pest', as many studies use different metrics for measuring when intervention should take place[11].

The 2021 guide 'Fall armyworm in Asia: A Guide for Integrated Pest Management' however puts the intervention thresholds at different levels, depending on the growth stage of the plant. According to Prasana et al. (2021), action should be taken if 20% of leaves at the early growth stage of the plant (V1-V6) show some small fresh windowpane (SFW) signs of damage. V1-V6 corresponds roughly to the first four to six weeks after planting and the plant will be between 20-30cm tall by stage V5. SFW damage is described as 'an area of the leaf that the FAW fed upon but was unable to penetrate fully' and is typical of early instar FAW larval mandibles that are not capable of fully penetrating the leaf surface (Prasana et al. 2021). The Davis Scale refers to these as 'pin holes' and they correspond to a score between 1-3 on that scale. Prasana et al's (2021) guidelines also suggest that between V7-V12, the action threshold increases to when more than 50% of plants show SFW damage. This underscores the fact that plants are better able to withstand damage from FAW

---

[11] For example, some studies use larvae per plant, some larvae/part of plant, some percentage infestation, percentage of defoliation, etc.

in later growth stages. It also suggests that early stage damage may give rise to new generations that increase the pest pressure later on in the growth season, reinforcing the importance of implementing PBMD at early growth stages for maximum benefit.

It is difficult to make a confident assessment as to whether the pheromone was able to limit leaf damage below the action threshold, due to the slightly different leaf assessment techniques. The figures from the baseline assessment on leaf damage showed that 12.06% of plants in the treatment showed signs of damage from FAW, but this was only from assessing the top three leaves of the crop, rather than the entire plant. Each of the three inspections thereafter showed leaf damage never went higher than 7.48%. Given that the threshold climbs to 50% at the V7 growth stage, it seems likely that the pheromone alone was able to provide control sufficient to limit damage below this level. It is also worth noting however that the baseline damage in the treatment was 12.42% and that the average damage never went above 18.73% (in the first inspection). It is therefore possible that the insecticide applications in the control were also sufficient to limit severe pest infestation and yield loss.

Future research should seek to adopt more uniform measurements of measuring FAW damage and should try to link more clearly the relationship between pest populations, leaf damage and yield loss. This is made difficult however by the complexities of each local situation, with each ecosystem having differences in natural enemies of FAW, different maize growth rates, and climatic factors. This makes it hard to design uniform rules, which in turn makes it harder for farmers to make informed and rational pest control decisions (with often changing guidelines).

3.3 Discrepancies between foliar damage, cob length and cob damage levels

One noteworthy finding from the research was that there appeared to be a disparity between the amount of leaf damage and the final damage to the maize cob and average cob length. Even though the leaf damage was higher in the control, the final cob length and damage was the same. This also seems counterintuitive, given that there were higher numbers of adult male FAW found in the control plot traps throughout the entire experiment. One explanation may be sampling error. For the damage assessment, 50 cobs were randomly inspected in each plot with maize being given a score between one and six (zero being perfect and five being more than 50% damage from FAW). One possibility is that there were discrepancies in scoring between different researchers or similarly with the tallying of FAW larvae, some researchers may have been more attentive of *S. frugiperda* in the field. Additionally, taking a perfectly random sample was challenging, due to many plots being subdivided amongst two or more farmers. This meant that one plot (for the purpose of the trial), may have had different inputs or management on one side, compared to the other. Although samples were always taken in a manner that included four different quadrants, one must consider that this could have affected the average scores.

Finally, it is also worth noting again that the pheromone was only applied twice during the growing season (once in January and once in March), rather than the three times that was initially intended (due to a misunderstanding in the field). It is possible that FAW re-established itself in the treatment plots, as the effects of the pheromone began to wane in April and May[12]. Given this, the population of FAW could have been on the rise, but these FAW may have been smaller and less developed, hence the lower levels of damage that were found in the treatment plots. This increase in population likely happened at a time when maize plants were well established and hence, less vulnerable to attack. These factors together may have contributed to the end result that despite having far higher numbers of FAW caught in pest traps, the control plots had similar levels of cob damage.

Another factor worth noting is that the relationship between foliar damage and yield reduction is not perfectly understood. This is something that has been observed by researchers including Hruska (2019) and Wightman (2018) and is noted in the FAO's 2018 document 'Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa' (FAO, 2018). According to these guidelines 'the quick response to sight of significant-looking damage is to assume that it will cause dramatic yield reduction. But that's not necessarily true' (FAO, 2018). Hruska (2019) and Wightman (2018) observe similar findings from the Americas and Africa. They note that while severe leaf damage can initially be alarming to many farmers, under conditions of adequate moisture and nutrition, maize plants are capable of compensating for this damage and that it does not always lead to significant yield reductions. According to statistics from the US Department of Agriculture (USDA), at the 12 leaf stage 'a 25% defoliation never causes more than 9% yield reduction'. It is therefore possible that in the control plots, there was considerable foliar damage, but that the plants were able to endure FAW larvae without major damage and yield loss. This of course depends on the 'genetics, nutrition, water availability… and other agronomic practices' (Hruska, 2019). This would suggest that any pest control program should place importance on ensuring crop health so as to withstand attacks from FAW. A 2023 study done

---

[12] Despite this, there was no major spike in adult male FAW captured in traps during these months.

by Chisonga et al. (2023) on the effect of leaf damage on maize yield also found that the relationship between leaf damage and yield loss was only observed when plants were at an early stage of maturation, but that once plants had reached maturity, leaf damage did not impact yield .

3.4 Regulatory and Commercialisation Challenges

The novelty of pheromones in the Tanzanian context was identified as another potential barrier to their further adoption. Although Moshi and Matoju (2016) do not provide an exact number, these authors affirm that 'hardly any' biopesticides have been registered and commercialised in Tanzania. While they outline numerous laboratory and field trials that have been conducted with bio-pesticides, they identify three major barriers to the further adoption of these products: 1) that research is conducted 'without concrete plans for sustainability and technology commercialization' 2) that the trials are often done without focus on specialization and development of the biopesticides industry and 3) there is no 'clear, straightforward legal framework for biopesticides development, registration and application'. These are some major barriers to more widespread pheromone use in Tanzania and based on this research, it is unclear that major improvements have been made in improving these regulatory processes.

While the TPHPA staff member stated that pheromones are already certified for use within Tanzania, this was only for use in trials - while their use in commercial agriculture is still non-existent. There was also conflicting information regarding the length of the registration process - while Moshi & Matoju (2016) state that the registration procedure takes a minimum of three and a half years, the TPHPA staff member said that the process for new pesticides only takes three to six months. It is possible that theoretically, it should take three to six months but that in practice, the registration process is much longer (due to other bureaucratic inefficiencies). Despite Moshi & Matoju's (2016) claim that 'regulation does not specify between chemical and non-chemical pesticides', this appears to have been changed in the updated Tanzanian Plant Health Act 2020 (Section 36). This may suggest that the TPHPA has responded to some of these inefficiencies in the certification of biopesticides (although this would need to be researched further in order to certify its validity).

Although the Tanzanian Government encourages the use of non-chemical pesticides, there is no official target for the reduction of synthetic pesticide use. The elimination of highly hazardous pesticides (HHPs) does appear to be a policy priority for the Government, as it recently banned 44 of these substances (Mbashiru

& Mhagma, 2021), and there are likewise numerous references to the need to reduce chemical insecticides in the Tanzanian Government's 2014 Integrated Pest Management Plan (IPMP) (The United Republic of Tanzania Prime Minister's Office. 2014). It is unclear, however, whether this push towards removing HHPs will translate directly into more widespread use of biopesticides or whether the previously used HHPs will simply be supplanted by comparatively safer chemical insecticides. It appears therefore that while there is a desire to move towards more sustainable pest control measures, there remain challenges in improving the regulatory climate for bio-pesticides and pheromones, which in turn would speed up the commercial viability of these products.

3.5 Effect of pheromone on pest control methods

The reduction in pesticide use in the plots with pheromone traps in this study suggests a willingness for farmers to try new approaches to pest management and little attachment to pesticides as the only viable method of pest control. It is likely that farmers observed lower FAW populations in the field and decided that further insecticides were not warranted, especially, given that maize is a relatively low value crop and additional investment in inputs would likely provide little economic benefit. This is encouraging for the goal of reducing pesticide use, as the number of insecticide sprays dramatically fell, despite no instructions from researchers to cease spraying.

3.6 Prevailing IPM strategies and the potential role of agroecology

While there are explicit references to IPM in the Tanzanian Government's 2014 document 'Integrated Pest Management Plan', it has not yet been updated since the arrival of FAW in Tanzania in 2016. However, few of the practices recommended by the FAO for FAW control were being widely practiced. Some of these FAO recommend techniques include not spraying multiple times with insecticide that has the same MOA, the use of 'push-pull' crops[13] or using biopesticides. In practice however, farmers in the control relied very heavily on insecticides for pest control while the farmers in the treatment depended primarily on the pheromone to limit FAW numbers. The sharp reduction in pesticide use in the treatment plots suggest that pheromones could be incorporated into an IPM plan, as farmers appeared to

---

[13] Napier grass and desmodium has been used with some success in trials sub-Saharan Africa

have no particular attachment to the existing pesticides and were willing to trust a different product without an in-depth explanation of its workings. However, it is worth noting that, because the pheromone was applied by researchers at no cost to the farmers, they were perhaps more willing to trial a new product (given the financial buy-in from them was none).

While pheromones did lower pest numbers and were well received by farmers, one should note that there may be other unutilised, cost-effective pest control measures that could also achieve positive results. There are a range of cultural, mechanical, and biological solutions to manage FAW that have been tested in East Africa (Harrison. 2019), although few of these were deployed by farmers in the control or treatment plots. Among those mentioned by Harrison (2019) include sustainable soil fertility management through the use of organic fertiliser, manure applications, nitrogen fixing cover cropping, crop rotations and intercropping. These practices are seen to 'improve crop health and pest resistance', allowing for maize plants that can better withstand infestation from FAW. Only 6% of farmers in the control and treatment used manure and only 12% of total farmers used a crop rotation - although 47% did practice intercropping. The precise reasons given for intercropping varied, but it was generally more of a bet hedging strategy, used by farmers to increase the variety of food sources or to protect against investing entirely into one crop (whose price may fall or may fail entirely). Data was not gathered on the use of cover crops, although based on observations, this practice was uncommon.

The reasons for this poor uptake of proper soil management are multifaceted. For one, although farmers were often conscious that soil was losing fertility, there was often a lack of long-term investment in improving soil health in the plot. For those who rented plots, they were unwilling to add manure due to fears that the landowner would refuse to rent out the plot the following year, with the assumption that the landowner would instead desire to farm the land and exploit its improved fertility. Most landowners stated that the application of organic fertiliser would improve soil health, but that they did not have access to sufficient quantities of manure (due to not owning livestock or being unable to afford the purchase of manure). This is noted by Harrison (2019) who states that uptake of soil management practices 'among farmers is low, which can be attributed in part to the time it takes for soils to accumulate carbon and for the benefits to be realised'.

Finally, there are also limitations in knowledge and/or labour capacity to implement many of these soil management and pest control techniques. For example, planting cover crops can be challenging after harvest, given that during this time labour and money may also be needed to prepare irrigation-fed crops for the upcoming season. The use of mulching is also seen by Harrison (2019) as a promising way of enhancing soil biological activity, but crop residues sometimes harbour pests and diseases, meaning farmers may be unlikely to risk using them without proper supervision and training. Mulch is also often used instead to feed livestock, as animals ‘contribute to the food security of the household, provide for system diversification, generate cash, spread risk, recycle nutrients, provide draft power and transportation, and are important assets for investment and/or savings’ (Wall. 2007). Implementing these strategies correctly also requires training and ongoing government support, which was seen by most farmers as lacking. So, while these agroecological approaches are promising in that they are often less dependent on capital, they will not be adopted if they do align with the realities of smallholder production, in terms of access to resources, support and knowledge. These techniques are also highly dependent on the specifics of the ecosystem in which they are applied, and must be tailored to the local environmental context (further complicating their adoption).

3.7 Coordination

One considerable challenge for the more widespread use of pheromones by smallholders is the need to coordinate interventions on a large scale(REF). Because PBMD is most effective when done at an area wide scale and over 98% of maize farmers in Africa grow maize on less than 2 ha of land (FAO, 2018), pheromones would need to be applied to numerous farms simultaneously in order to be most effective. This raises issues around how farmers could effectively coordinate to purchase, apply and monitor the pheromone over a large area. The interviews’ results suggested that there was very minimal formal coordination and cooperation between farmers, with participants saying that they did not have regular meetings with other farmers in the area and none of the respondents stated that they were members of an agricultural organisation (except for One Acre Fund, which provides credit for inputs). It would have therefore been challenging to organise the application of the pheromone, given the lack of a formal group to make decisions.

Use of pheromones would perhaps be more likely to succeed amongst smallholders that have a clear organisational structure to manage collective decisions and that ideally manage the same plot each year. A relevant example was of the Kiwere irrigation scheme that was operating close to the trial plots, where farmers had to register, pay fees and meet regularly with farmers, government agricultural officers and board members of the scheme. This formal structure means that pheromones could be hypothetically paid for and applied at a group level more easily than in plots that lack formal organisation. Distribution could also be facilitated through direct government subsidies for pheromones or through other NGOs that could provide inputs and credit for pest control products. This of course would require efficient distribution and management of resources at a governmental level, which has been noted as a major challenge in improving African agriculture. Odhiambo (2007) states the importance of 'getting institutions right', stating that with weak or missing institutions, effective delivery of farming technologies will remain a major challenge.

Finally, production at Kiwere was also geared more for market consumption, meaning that farmers were more likely to spray maize with insecticide and be more willing to invest money into inputs. As such, pheromones may also be more impactful in these settings, as they would slow insecticide resistance and reduce insecticide consumption more drastically. The need for alternative pesticides as a way to slow insecticide resistance was something identified by both the TPHPA staff and the Government Extension officer as a priority. They said that because farmers tended to re-use products that they observed as being effective, they were rarely using different insecticide MOAs, leading to increased resistance amongst pests. Given these factors, an irrigation scheme like this would be a more likely candidate for adoption of pheromones, compared to the farms involved in the trial.

3.8 Lack of long-term investment

Incorporating pheromones into a pest control strategy may also be more successful amongst farmers that have a more permanent investment in their plot. Nearly half of farmers in the treatment did not own the land that they farmed and there was generally a low level of long-term investment in ensuring the quality of the land beyond that season. Farmers are more likely to make investments into more expensive pest control, if they can be sure there will be long-term benefits of adopting this new approach. Without the ability to plan long-term, pheromone adoption will be made all the more difficult.

3.9 Determining link between leaf damage and yield loss

There is a high degree of uncertainty surrounding 'the relationship between infestation levels, plant damage and yield loss' (Harrison et al, 2019). According to Hruska (2019) only one study has actually directly measured maize yield loss due to FAW in Africa[14] (reporting a 12% reduction). In Baudron et al's 2019 study, they

---

[14] All other studies on yield loss were based on farmer's perceptions of loss, which is seen as less accurate than a direct study

found that FAW yield loss was mainly caused by factors like frequency of weeding, tillage type, seed variety and intercropping, rather than from frequency of insecticide applications. If it is the case that with proper management, healthy maize crops can withstand FAW infestations, then the rational amount of money to spend on insecticide or biopesticides will fall. This however will need to be researched further, given there are few direct studies of yield loss from FAW in Africa and that there are still contradictory findings regarding the ideal management practices to suppress FAW. The regression analysis conducted for this research also proved inadequate at explaining what factors led to low yield, meaning future pheromone studies should place a priority on better understanding this relationship. Until these have been established with certainty, it is difficult to precisely measure the cost-effectiveness of pheromones as an intervention.

3.10 Cost of pheromones

The cost of pheromones will be a major factor in determining what role PBMD might play for smallholder farmers in Tanzania. Although ISCA Technologies was contacted to give information about the price of SPLAT-FAW, the exact pricing of this FAW specific pheromone could not be obtained. The costs used are therefore general figures and may differ somewhat from the actual cost of SPLAT-FAW. As noted in Section 2.15, farmers were spending around 17,000TSH (6.3€) per acre on one insecticide spray, with the median number of sprays in the treatment and control plots being three times a year, this would imply 18.9€ per year, per acre on the purchase of insecticide (this does not include the cost of equipment or labour hire). Several in the treatment said that they had never used insecticide, due to a lack of money.

Given the estimations in current costs of between $16-260 per acre (Stockstad, 2022), most pheromones are currently likely to be unaffordable for small-scale farmers. However, new developments in the production of pheromones mean that in the future pheromones could be ‘less than half the cost of current synthesizing methods’ (Stokstad, 2022). If the reduction in costs can be applied to pheromones that are currently already cheap to produce, they could potentially become affordable for smallholders. However, for pheromones that are currently expensive to manufacture, even a 50% reduction in cost would not make them affordable for lower-income farmers. The price of SPLAT-FAW also needs to be considered alongside the relatively low value of maize as a crop (meaning a hesitancy from farmers to invest money into inputs). Stoktstad (2022) notes that ‘a lower price might make the pheromones accessible to farmers in the developing world’ - although he too notes coordination issues would need to be overcome (Section 3.7)

It is also possible that if pheromones remain unaffordable for purchase by smallholders, governments or NGOs could instead buy and apply them directly for lower-income farmers, instead of supplying pesticides. African governments often subsidise or freely distribute pest control products, particularly if the pest is seen as posing a food security risk (as was the case with FAW). Proper training on safe and efficient use of these pesticides is often lacking, meaning that farmers often apply these pesticides in indiscriminate ways that harm human and ecosystem health. If pheromones are provided directly to farmers, this would overcome the cost issue while also preventing the haphazard spraying of pesticides, without proper regard for the negative environmental and health impacts they cause. Alternatively, the pheromone application could be handled directly by trained government workers or NGO staff. It is possible that this method is more cost-effective and would bypass some of the potential coordination issues relating to the proper area-wide application of pheromones.

3.11 Limitations in research

For the purposes of this paper, there were a few limitations in the experiment conducted. While a strong effect was observed in lowering FAW numbers and leaf damage, this trial was conducted without the farmers themselves applying the pheromone (this was done primarily by researchers at Mkwawa University). To better answer the research question, it may have been useful to observe how farmers understood the product to work and how successfully they were able to apply it within their plots. Unfortunately, farmers were not given any training on how the pheromone operates, so the interviews were unable to unearth any doubts or queries farmers may have had concerning its use. Similarly, while many farmers observed that the pheromone appeared easy to apply, it would have been useful to see farmers coordinate to apply the pheromone on a large scale and to observe whether this led to any issues (with dosage, timing, and organisation). Mwangi and Kariuki (2015) note that the ability to 'trial' a product before committing further to its use, has been linked to positive uptake in the adoption of new technologies, which may be the dynamic that was observed in the trial as although most farmers were very satisfied with the product, they were able to trial it before the need to commit to its purchase. Regardless, the pheromone is not registered yet for commercial use, so this barrier would need to first be overcome before more hands-on trials can take place.

There were also some challenges in obtaining a large and accurate sample of data regarding management of plots from farmers. This meant that statistical analysis was unable to find conclusive links between cob damage and other variables, like fertiliser input, pesticide use, and planting date. Likewise, some variables like frequency of weeding or exact date of fertiliser inputs were not collected or proved impossible to get accurate figures on. A more complete dataset might have been able to better explain the results of the trial, particularly the effect these farming techniques had on the final cob damage and cob length. Additionally, the subdivision of plots made data analysis challenging, as data (relating to leaf damage, cob length and cob damage) was taken according to the boundaries established at the beginning of the trial. However, as the research began it was revealed that many of these plots were subdivided and farmed by two or more farmers. This meant that agronomic analysis was imperfect, as two farmers that shared one piece of land might have used different farming practices, but that the final damage data would be identical (as it was taken as an average of the entire plot).

3.12 Initial Recommendations

Having outlined the findings from the study, some recommendations regarding pheromone use amongst smallholders can be given.

3.13 Establish relationship between foliar damage and yield loss

More certainty is needed regarding the effect of foliar damage on yield loss, otherwise making rational pest management decisions is difficult. Based on this research and other relevant studies, it seems that leaf damage 'is alarming to many farmers who have never seen this type of damage before' (Hruska, 2019) which leads many farmers to spray according to the 'detection threshold' - that is, whenever the presence of a pest is noted in the field, rather than the economic threshold. It is possible that this lack of clarity is leading to unnecessary spraying of crops and adequate pest control could be achieved in more cost-effective and less harmful ways. This can only be done once more clear thresholds are known and the relationship between foliar damage and yield is more clearly understood.

3.14 Trial different quantities of pheromones throughout the season

It would also be useful to conduct trials in which dollop density, the frequency and timing of application on infestation rates is assessed during different times of the year. Based on this research, the pheromone appeared to give the clearest benefit at the beginning of the cropping season, when FAW is particularly numerous. After the seasonal peak in FAW numbers, trap capture began to decrease and stayed fairly constant until the end of the trial. Although the pheromone was not applied during the final third of the cropping season, there still was not a massive spike in pest numbers. It is possible that pheromones may have the best cost-benefit if applied primarily in the peak FAW months (at the beginning of the maize season in December and again for irrigation-based agriculture in July).

3.15 Implement trials with farmer use of pheromone

As mentioned by Moshi & Matoju (2016) biopesticide research is often conducted 'without concrete plans for sustainability and technology commercialization' and PBMD should be aware of this risk. For the research, farmers were not explained the function of the technology nor asked to apply it, meaning not all potential barriers to adoption were not necessarily uncovered. In the future, it would be useful to implement trials in which farmers are given training in the pheromone and asked to apply it themselves. This would develop a better idea of how farmers understand and interact with the technology. Njiraini (2022) notes that 'distributors reckon that small-scale farmers are somehow hard to convince to adopt new technologies that they least understand' and that pheromones face barriers due to 'limited knowledge, perceived high cost, and also the fact that there is no huge demand for pesticide-free produce by local consumers'. This research showed that there was no hesitancy amongst farmers to try new pest control products, but this may differ in a more real-world setting, whereby farmers are required to implement PBMD themselves.

4. Conclusion

The conclusions from this research have been summarised in Table 4, which groups the likelihood of adoption according to the findings of this research. In assessing the suitability of pheromone use for farmers, Table 4 includes the most prominent factors as outlined in online research and face-to-face interviews. Based on these factors, many of the farms spoken to for the research may not be ideal candidates for pheromone use, given the numerous constraints mentioned by farmers. Much of the production was done for subsistence needs and there was often a reluctance to invest large amounts of money into inputs (particularly with the perceived uncertainty of rainfall). There was also a lack of training identified by farmers, meaning that a novel technology like pheromones would need to be initially supervised by extension officers, to ensure proper application. Finally, there was little coordination in treatment plots, with many farmers renting out land on short-term leases (suggesting a lack of connection to neighbouring plots). As mentioned earlier, pheromone use in lower income countries might best be trialled on farms that are investing more inputs into production, like the irrigation scheme mentioned in Section 3.7.

Table 4. Likelihood of adoption of pheromone-based mating disruption

Most likely
• High-value crops • High pest pressure • High levels of coordination with nearby plots • Large farm size • Strong access to extension services • Irrigation access • High access to capital

PBMD could play an important role in smallholder farming in Tanzania if certain conditions are met. The results of the study showed that two applications of pheromones were able to reduce pest populations significantly, lower leaf damage and led to a clear reduction in pesticide use by farmers. This reduction in trapped pests caused a reduction in foliar damage to crops, despite very little insecticide being applied in treatment plots. Pheromones were therefore successful in lowering FAW densities, but in also causing clear behaviour change in pest control amongst farmers. While the damage to maize cobs was not demonstrated to be lower in this experiment, this does not seem highly unusual given previous studies have also not always seen a clear link with foliar damage and yield loss. In this regard, the study was highly promising.

For the farmers interviewed for this research, the main barriers to future use of pheromone were a lack of access to capital for the purchase of pest control inputs and challenges in coordinating area wide application of pheromones. Those involved in the trial were typically producing a large portion of maize for subsistence and were often wary of investing large amounts of money into inputs (particularly with the uncertainty of rainfall). There were also low levels of coordination between farmers, meaning area wide application may be challenging to implement. However, for such farmers, it may be more cost-effective and efficient if the government directly subsidies and applies the pheromone on behalf of the farmers. Many African 'governments released millions of dollars in emergency funding to procure and distribute chemical insecticides for its control' (Chisonga et al. 2023) but that these were sometimes highly-hazardous and often had negligible impacts. This does however show a willingness for governments to directly support low-income farmers. The application of the pheromone itself could therefore be managed directly through existing government institutions. Once the externalities from excessive pesticide use have been calculated, government-controlled pheromone application may be a more cost-effective solution than the prevailing approach. A full cost-benefit analysis of this will be an important part of future research.

Pheromones are therefore a promising area in the future of pest control for smallholder farmers. As the Tanzanian government grapples with how best to protect its natural environment and simultaneously improve grain yields, it should be open to adopting new green technologies. While these are currently unaffordable and unavailable commercially, the projections for cost decreases mean that they may become available within the coming years. Assuming African governments are open to speedily regulating and actively promoting these products through government channels, NGOs and extension workers, they represent a big opportunity in the ongoing challenge of controlling FAW.

References

Ahissou, B. R., Sawadogo, W. M., Sankara, F., Broustaux, Y., Bokonon-Ganta, A. H., Somda, I. & Verheggen F. J. (2022) Annual dynamics of fall armyworm populations in West Africa and biology in different host plants, *Scientific African,* Vol. 16

Baudron, F., Zaman-Allah, M. A., Chaipa, I., Chari, N., & Chinwada, P. (2019) Understanding the factors influencing fall armyworm (*Spodoptera frugiperda* J.E. Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabawe, *Crop Protection,* Vol. 120

Braun V & Clarke V (2014) What can thematic analysis offer health and wellbeing researchers? International Journal of Qualitative Studies on Health and Well-being, Vol. 9

Cardé, R. T. (2021) Mating Disruption with Pheromones for Control of Moth Pests in Area-wide Management Programmes *in* Hendrichs, J. Pereira, R., Vreysen, M. J. B. (2021) Area-wide Pest Management: Development and Field Application, CRC Press, Boca Raton, USA

Chisonga, C., Chipabika, G., Sohati, P. H., Harrison, R. D. (2023) Understanding the impact of fall armyworm (*Spodoptera frugiperda* J.E. Smith) leaf damage on maize yields, PLoS ONE, Vol. 18, No. 6

Cruz-Esteban, S., Rojas, J. C., Malo, E. A. (2020) A pheromone lure for catching fall armyworm males (Lepidoptera: Noctuidae) in Mexico, *Acta zoológica Mexicana*, Vol. 36

Davis, F. M., Ng. S.S. & Williams, W. P. (1992) Visual rating scales for screening whorl-stage corn for resistance to fall armyworm (No. Technical Bulletin 186), Mississippi State University, MS39762, USA

Food and Agriculture Organization of the United Nations (2018) Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa, FAO, Rome

Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., van de Berg, J. (2019) Agro-ecological options for fall armyworm (*Spodoptera frugipera* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest, *Journal of Environmental Management,* Vol. 243

Hruska, A. (2019) Fall armyworm (*Spodoptera frugiperda*) management by smallholders, *CAB Reviews Perspectives in Agriculture Veterinary Science and Natural Resources*, Vol. 14, No. 43

Howse, P. E., Stevens, I. D. R., Jones, O. T. (1998) Insect Pheromones and their Use in Pest Management, Springer Dordrecht

Kruger Seeds (2020) Determining Corn Growth Stages, <https://www.krugerseed.com/en-us/agronomy-library/corn-growth-stages-and-gdu-requirements.html>

Lekei, E. E., Ngowi, A. V., London, L. (2014) Farmers' knowledge, practices and injuries associated with pesticide exposure in rural farming villages in Tanzania, *BCM Public Health,* Vol. 14

Mbashiru, K. & Mhagama, H. (2021) TPHPA bans use of 44 highly hazardous pesticides, Daily News, Dodoma, Tanzania <https://dailynews.co.tz/tphpa-bans-use-of-44-highly-hazardous-pesticides/>

Miller, J. R. & Gut, L. J. (2015) Mating Disruption for the 21st Century: Matching Technology With Mechanism, *Environmental Entomology*, Vol. 44, No. 3

Moshi, A. P. & Matoju, I. (2016) The status of research on and application of biopesticides in Tanzania. Review, *Crop Protection*, Vol. 92

Msuya, C. P., Annor-Frempong, F. K., Magheni, M. N., Agunga, R., Igodan, C. O., Ladele, A. A., Huhela, K., Tselaesele, N. M., Msatilomo, H., Chowa, C., Zwane, E., Miiro, R., Bukeyn, C., Kima, L. A., Meliko, M., Ndiaye, A. (2017) Agricultural Extension in Africa's Development, The Importance of Agricultural of Extension Workers and the Need for Change, *International Journal of Agricultural Extension,* Vol. 5, No. 1

Mwangi, M. & Kariuki, S. (2015) Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries, *Journal of Economics and Sustainable Development,* Vol. 6, No. 5

Njiraini, J. (2022) Pheromones Are Making Inroads in Africa, Albeit Slowly, *Agribusiness Global,* <https://www.agribusinessglobal.com/biologicals/pheromones-are-making-inroads-in-africa-albeit-slowly/>

Odhiambo, W. (2007) Financing African Agriculture: Issues and Challenges, Draft Paper, Second African Economic Conference at the United Nations, Addis Ababa, 15-17 November

Pair, S. D., Raulston, J. R., Sparks, A. N., Sims, S. R., Sprenkel, R. K., Douce, G. K., Carpenter, J. E. (1989) Pheromone traps for monitoring fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) populations, *Journal of Entonomological Science,* Vol. 24, No. 1

Petkevicius, K., Löfstedt, C., Borodina, I. (2020) Insect sex pheromone production in yeasts and plants, *Current Opinion in Biotechnology,* Vol. 65

Rivzi, S, A, H., George, J., Reddy, G, V. P., Zeng, X., Guerrero, A. (2021) Latest Developments in Insect Sex Pheromone Research and Its Application in Agricultural Pest Management, *Insects,* Vol. 12, No. 6

Stockstad E. (2022) Researchers just made it easier – and cheaper – to confuse crop pests, *Science,* < https://www.science.org/content/article/researchers-just-made-it-easier-and-cheaper-confuse-crop-pests>

Supartha, I. W., Susila, I. W., Sunari, A. A. A. A. S., Febri Mahaputra, I. G., Kadek Wisma Yudha, I., Putu Anggu Wiradana. (2021) Damage characteristics of distribution patterns of invasive pest, Spodoptera frugiperda (J.E Smith) Lepidoptera: Noctuidae) on maize crop in Bali, Indonesia, *Biodiversitas Journal of Biological Diversity*, Vol. 22, No. 6

The United Republic of Tanzania Prime Minister's Office (2014) Integrated Pest Management Plan (IPMP)

Wall, P., 2007. Tailoring Conservation Agriculture to the Needs of Small Farmers in Developing Countries. *Journal of Crop Improvement*, Vol. 19, No. 1-2

Wang, H. L., Ding, B. J., Dai, J. Q., Nazarenus, T. J., Borges, R., Mafra-Neto, A., Cahoon, E. B., Hofvander, P., Stymme, S., Löfstedt, C. (2022) Insect pest management with sex pheromone precursors from engineered oilseed plants, *Nature Sustainability,* Vol. 5

Weather Spark, Summer Weather in Iringa, 2023, https://weatherspark.com/s/98686/1/Average-Summer-Weather-in-Iringa-Tanzania

Wightman, J. A. (2018) Can lessons learned 30 years ago contribute to reducing the impact of the fall army wom *Spodoptera frugiperda* in Africa and India? *Outlook on Agriculture*, Vol. 47, No. 4

Acknowledgements

First and foremost, a big thank you to Teun for helping me along the way and making this all possible. And the same to my Tanzanian colleagues, Fikira, Joyce, Benjamin, and Ruta – without you all none of this work would have been possible. And thanks to Claire for supporting me throughout the long process!

Appendix 1

Sample of farmer survey – Quantitative Section

Section A – Basic Information

Name:	
Plot number:	
Age	
Sex	
Plot size	
Household size (family members):	
Current land lease status:	
Phone number	
Date	

Section B - Agronomic Practices

i) Planting History

1. What crops have been grown on this field previously?	
2023:	
2022:	
2021:	
2020:	
2019:	

Comments:

ii) Field Preparation

2. Was your field tilled before sowing?	
a) Regular tillage	
b) No-till	
c) Minimal tillage	

3. What instrument was used?	
a) Hand	
b) Animal plough	
c) No-tillage	

4. How many times was field ploughed prior to sowing?	
a) Once	
b) Twice	
c) More than twice	

iii) Seeds

5. What seeds were planted?	
6. Were they purchased or saved?	
7. If purchased, from where were they obtained?	
8. How many seeds per hole/m^2	
9. What is the strain used?	
10. Why was this strain chosen?	

iv) Planting Date

11. When did you plant the maize (date)?	

v) Irrigation:

12. Did you irrigate your crops?	a) Yes (manual irrigation) b) no (rainfall only)
13. If yes, how frequently did you irrigate your crops?	

vi) **Fertilisation**

14. Did you fertilise your crops?	a) Yes b) No
15. If yes, what type of fertiliser? More than one answer is possible	a) Synthetic/chemical b) Manure/organic c) Other (legume) d) Both Specify product name:(UREA,DAP,CAN,SA)
16. How much fertiliser was applied (total)?	Kg:
17. When was fertiliser applied?	
18. How many separate applications and when?	
19. If you did not fertilise you crops, why not?	

vii) **Weed Management**

20. How were weeds controlled? (several answers are possible)	a) Manually (hand) b) Mechanically (machine) c) Chemically (herbicide) d) No weed control
21. If yes to **c**, how much was applied?	
22. How many applications of herbicide?	
23. When were applications made?	
24. What product was used to control weeds?	Product name:

viii) Plant Diversity

25. Were any other crops grown apart from maize?	a) Yes b) No
26. What other crops were grown?	
27. Why were these crops chosen?	

ix) Insecticide Use

28. Did you use insecticide?	a) Yes b) No (if no, skip to question 32)
29. If yes, how much did you use?	Kg:
30. If yes, how frequently did you apply it?	
31. If yes, what product did you use?	
32. If yes, how much did you spend on insecticide?	Tsh:
33. If you did not use insecticide, why not? Reason:	a) Save money b) Trust pheromone technology c) Other

Qualitative Section

Name(jina):	
Plot number(Idadi ya mashamba)	
Age (umri):	
Sex (Jinsia):	
Plot size (ukubwa wa shamba):	
Household size (family members):	
Current land lease status: mmiliki	
Phone number (namba ya simu):	
Date (tarehe):	

Section A – General

1. Is this the only land that you farm, or do you also cultivate other land?
2. Do you also farm during the dry season (irrigation-based agriculture)?
3. Do you use this land to produce for your own consumption, or to sell in the market?
4. What was the yield here last year (how many bags)?
5. How many bags do you expect to yield this year?

Section B - Economic

6. How much does it cost to rent the land for one year? (if renting)
7. Do you have to pay rent at the beginning of the season, or can you pay in smaller amounts throughout the year?
8. How much money do you invest in inputs each year?
9. Do you have to pay inputs at the beginning of the year, or can you access them on credit?
10. How much revenue did you make per acre last year?

Section C – Fall Armyworm

11. When did you first learn about or observe about FAW?
12. How do you identify fall armyworm (what does it look like) and where did you learn this information?
13. What percentage of crops were affected by FAW last season?
14. What percentage of crops have been affected by FAW this season?
15. What methods do you know about how to control FAW? (
16. What control methods for FAW have you tried previously?

Section D – Pest Management

17. How effective were pesticides at controlling FAW? Were they able to manage the problem?
18. Have you received any training on how to control FAW (from government, NGOs, etc)?
19. Where do you get your information about pest control?

Section E – Previous Control Methods

20. Were there any positive aspects of pesticide use?
21. Were there any negative aspects of pesticide use?
22. How much money did you use on insecticides last year?
23. What type of pesticide did you use last year?
24. How many times did you spray your crop last year?
25. Why didn’t you spray your crop this year?
26. Do you use protective clothing when spraying your crop? Why or why not?

Section F – Pheromone Use

27. Can you explain how it works?
28. Do you trust the technology?
29. Why or why not?
30. Do you perceive it as easy to use

31. For you, what is the main benefit (the main positive aspects) of using pheromones?
32. Do you know of any disadvantages of using pheromones, instead of insecticides?
33. Do you think that the pheromone is safe to use (not bad for your health)?
34. Do you perceive pesticides as safe for human health and the environment?

Section G - Other

35. What is your biggest challenge for growing maize?
36. Have you noticed any problems with pheromone treatment relating to pests?
37. Have you noticed any difference in the weather in the past 10 years? How has it changed? What do you do differently to adapt to it?
38. Do you coordinate with other farmers who work in this area? Are you part of any farming organisations with them?
39. Do you meet regularly with other farmers who work in this area?
40. Are you a member of any agricultural cooperatives?
41. Do you feel that you are using more inputs than five years ago? (are you using more fertiliser and pesticide than five years ago?)

Appendix 2

Fact Sheet

Pheromone-based mating disruption to control *Spodoptera frugiperda* in Tanzania:

Possibilities and Constraints for smallholders

Introduction to the Study

Despite a growing interest in the use of pheromones as a more sustainable form of pest control, their use remains unstudied in the smallholder context. This research is the first that has studied pheromone use by small scale Tanzanian maize farmers to control the invasive pest *Spodoptera frugiperda* (known as fall armyworm). Given cost projections for pheromone production predict drastic reductions in price, it is important to know how effective these products are and how they could be most effectively applied by resource constrained farmers .

Research Questions

1) How effective is PBMD at controlling spodoptera frugipera for smallholder maize farmers?

a) how well does PBMD work to control fall armyworm

b) what role might pheromone-based mating disruption (PBMD) play in future pest management strategies for smallholders in Tanzania

c) under what conditions might pheromones be most successfully used?

Materials and Methods

- The trial sites were established on a cluster of 71 farms, located near Iringa, in the southern highlands of Tanzania.
- The total area of the treatment was 50 hectares and 35 hectares in the control. Of the 71 farms, 53 were grouped into contiguous treatment plots and 18 grouped into the control plots
- Insect traps were placed every 5 acres, with 13 in the treatment and 8 in the control
- Pheromone dollops of 1 gram were then applied by researchers every 25m² within the treatment plots on two occasions throughout the season
- Control plots received no pheromone application
- Adult male FAW populations were then measured eight times between January and June
- Assessments of leaf damage from FAW were taken on three occasions between February and March and assessments of maize cob damage and length were made in May, just prior to harvest.

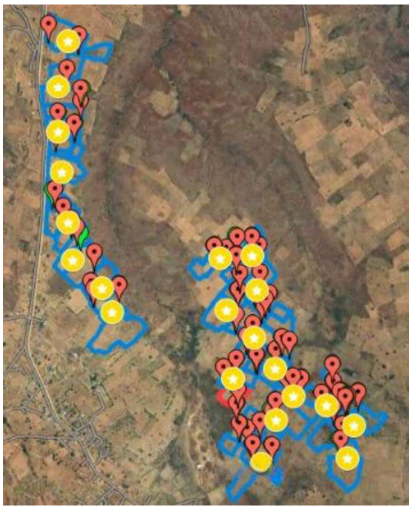


Image 2. Control plots (left) and treatment plots (right). Insects traps are represented by the yellow circles. Fields are 400 metres apart at the closest point.

WHAT IS PHEROMONE-BASED MATING DISRUPTION?

Mating disruption works by placing high concentrations of mating signals throughout agricultural fields, thereby creating a 'cloud' of pheromone trails. High amounts of pheromones desensitise male mating receptors such that they cannot distinguish true signals. This inability to find a mate leads to a disruption in reproduction rates and in turn, lower pest numbers. Pheromones have many advantages when compared to conventional, synthetic pesticides. These include: having no toxicity to humans, targeting only specific pest species and causing no damage to surrounding ecosystems. PBMD is most effective when applied at an area-wide scale.

Materials and Methods

- Semi-structured interviews were undertaken with 50% of the participants in both the treatment and control, 22 and 10 farmers respectively.
- Interviews typically lasted 45-60 minutes and were done to assess management practices and to better understand pest management practices and perceptions of pheromone use more broadly.
- These interviews were conducted to provide a socioeconomic perspective on pheromone use, to better understand the priorities of smallholders with regards to pest control and to inform some of the recommendations for future pheromone use by smallholder farmers in Tanzania.

Image 3. Two farmers whose fields were used as part of the pheromone based mating disruption trial.

Image 1. Mature larva of *spodoptera frugiperda*. Source: Capinera (1999)

Name: *Spodoptera frugiperda*

Distribution: native to the Americas but is now present across all of Africa, Asia and Australia.

Description: fall armyworm larvae vary in colour from dark-greenish-brown to black. On each side, there are long, pale white, orange and dark brown stripes along the length of the abdomen. Mature larvae are approximately 4cm long.

Lifecycle: ranges from between 30 days in summer to 90 days during winter. Contains an egg stage, then larval stage, a pupal stage and then an adult phase. Damage to maize crops is done during the larval stage.

Diet: fall armyworm larvae can feed on a variety of crops like wheat, rice, cotton, sugarcane and soybean although invasive species particularly target maize

References

Capinera, J. L. (1999) Featured Creatures: Fall armyworm, *University of Florida*

Pheromone-based mating disruption to control *Spodoptera frugiperda* in Tanzania:

Possibilities and Constraints for smallholders

Results – Trap Capture

- SPLAT-FAW was able to significantly lower the number of FAW found in the treatment plots (displayed in Figure 1)
- The treatment caught an average of 3.6 adult FAW per trap and the control catching an average of 11.5 adult FAW per trap (across the eight inspections).

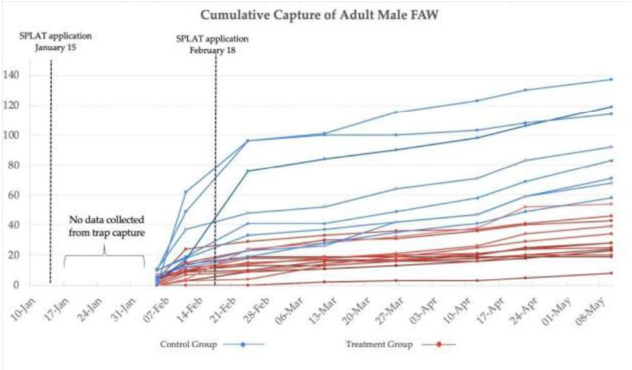


Figure 1. Cumulative number of adult male FAW caught per trap between treatment (red) and control (blue)

Results – Leaf Damage

- Directly prior to the start of application of SPLAT-FAW, the percentage of plants with signs of *S. frugiperda* damage was identical between the control and the treatment
- After this initial inspection, damaged was assessed on three occasions - 2 weeks after pheromone application, 4 weeks after pheromone application and 9 weeks after pheromone application. In all instances, the control showed an overall higher levels of leaf damage (Figure 2).

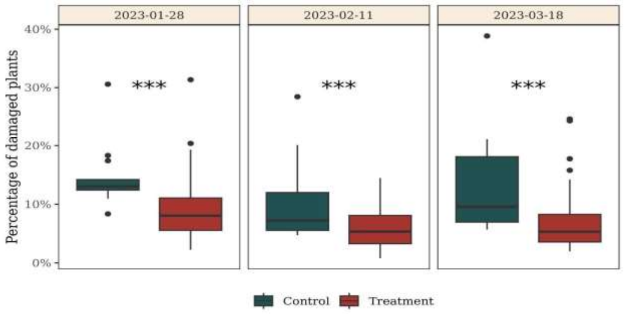


Figure 2. Percentage of damaged plants that showed some signs of leaf damage in the control (green) and treatment (red)

Results – Qualitative Interviews

- Farmer interviews showed that there was very little variation amongst farmers in management practices. Most farmers used hybrid seeds, ploughed once with an ox-driven mouldboard plough, planted in December, used inorganic fertiliser and did not use herbicide.
- One major difference between the control and the treatment was that the treatment used significantly less insecticide. Only 23% of farmers sprayed with any insecticide in the treatment, with only 8% spraying more than once. This compares to 90% of farmers in the control that used insecticide.
- Farmers had little implementation of integrated pest management, with generally poor knowledge of ways to control pests beyond the use of insecticide.
- Farmers were generally not willing to invest large amounts of capital into food production, particularly due to the uncertainty of rainfall.
- There was generally poor coordination between farmers that were interviewed, with none of them having any formal organisation that grouped together farmers in the area.

Possibilities	Constraints
• Reduction in FAW population and leaf damage from two applications of SPLAT-FAW pheromone	• Link between FAW infestation, leaf damage and yield loss is not well understood
• Sharp reduction in insecticide use in treatment plots after application of pheromone	• Current cost of pheromones may be unaffordable for many smallholder farmers to purchase
• High farmer satisfaction with performance and safety of pheromone	• Area-wide application of pheromone may be challenging for smallholders that lack coordination with neighbouring plots

Conclusions

- Two applications of SPLAT-FAW led to significant reductions in FAW populations and leaf damage
- Farmers in the treatment were generally satisfied with the performance of the pheromone and recognised its efficacy and safety through direct observation, which in turn led to a significant reduction in the number of farmers that used insecticide.
- Challenges in affordability and coordination between farmers will need to be overcome before more widespread use of PBMD is found in Tanzania.

Recommendations

- Pheromones may be a more sustainable option for government-subsidised pesticides. Pheromones could be applied directly by trained Government staff in areas where pest pressure is particularly high.
- As the cost of pheromones is predicted to fall, they may become affordable for small scale farmers. Farmers that have a high degree of organisation and coordination will be more likely to adopt this technology, as they can more effectively apply the pheromone at an area wide scale.

SCIENCE AND EDUCATION FOR SUSTAINABLE LIFE