Final report

Project title:

Management options for reducing the reliance on insecticides for FAW in sweet corn

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Public summary

Following the incursion of Fall armyworm (FAW) (*Spodoptera frugiperda*) in northern Australia in 2020, the pest rapidly established as a major threat to sweet corn from crop emergence through to harvest, and to capsicum production in northern regions. Historically, sweet corn pests such as *Helicoverpa* were largely confined to reproductive stages and managed effectively through integrated pest management (IPM) based on parasitoids and biopesticides. FAW's arrival led to increased reliance on broad-spectrum insecticides, elevating production costs, accelerating resistance risks, and severely reducing natural enemy populations. Growers' perception that zero tolerance to FAW is essential has further intensified insecticide use.

This project aimed to raise grower awareness of non-chemical management options and reinforce IPM principles. Area-wide management (AWM) groups in the Bowen–Burdekin and Lockyer regions identified several tactics for evaluation, including: (i) floral resources to support parasitoids, (ii) efficacy of the egg parasitoid *Trichogramma pretiosum*, (iii) intercropping to disrupt FAW and support beneficials, (iv) use of the natural enemy compatible *S. frugiperda* nucleopolyhedrosis virus (SfMNPV), (v) assessing capsicum susceptibility to FAW, and (vi) use of pheromone traps for decision-support. Ongoing collaboration with VG22006 strengthened engagement, with trials at the Bowen and Gatton research stations providing opportunities for field walks and discussion.

For the widely grown sweet corn variety Garrison, no economic threshold could be established because plants showed so little resilience to FAW impacts. Infestations of one larva per plant for 1–3 weeks during mid- to late-vegetative stages resulted in stunting, infertility, and poorly filled cobs. This lack of tolerance highlights the need for intensive chemical intervention with current varieties and signals an urgent breeding priority for improved tolerance and recovery capacity.

Reduced insecticide use in trials demonstrated positive increase in natural enemies. Parasitism rates of 20–60% by *T. pretiosum* challenge perceptions of its limited effectiveness. Providing refuges and floral resources, such as buckwheat or intercropping systems, supported beneficial activity with minor production downside, and with potential benefits to the production system, for example nematode suppression, cover cropping and nitrogen fixation.

Host-preference studies involving cluster caterpillar (*S. litura*) and *Helicoverpa* confirmed capsicum is not a preferred FAW host. FAW moths rarely oviposit on capsicum, and infestations in the field are most likely to result from larval movement or moth spillover from nearby crops. These findings are available to industry in a factsheet and peer-reviewed publication.

IPM-compatible FAW control options are a high priority for the industry. Commercial SfMNPV products were ineffective under moderate to high infestations, even with repeated applications. Preliminary data on the relationship between pheromone traps and FAW oviposition showed a strong correlation with brown eggs, but a poorer relationship with white egg density. The role of traps in forecasting infestations warrants further investigation, as does in-crop sampling strategy to better support decision-making.

Project outcomes have been communicated to growers and agronomists through AWM engagement activities including field walks, presentations, and the FAW eHub.

Technical summary

Keywords

Fall armyworm; *Spodoptera frugiperda*; integrated pest management; natural enemies; pheromones; economic thresholds; sweet corn; capsicum; host preference

Introduction

Establishment of FAW in the key horticulture production areas in Bowen, the Burdekin and Lockyer Valley has significantly impacted sweet corn and vegetable producers in those districts. Very rapidly after the first detection of FAW in the Burdekin region of Queensland (March 2020), sweet corn growers were reporting major losses from direct feeding damage to both vegetative crops and marketable cobs (up to 90%). Significant losses were also recorded in maize (grain and fodder), particularly in north Queensland and coastal regions of Qld and NSW. FAW has now been recorded from all sweet corn production areas in Australia, but the greatest risk to production remains the Queensland production regions in the Burdekin, Bowen, Bundaberg, and Lockyer and Fassifern Valleys.

In 2019, the Bowen and Burdekin sweet corn production area was estimated at 2200 ha with a value of $90 million.

The impact of FAW on sweet corn poses a major threat to the IPM practices that have served the industry well over the past 20 years (since the completion of VG97036 – Integrated Pest Management in Sweet Corn). The increased frequency of insecticide applications to control FAW are largely incompatible with an IPM program that is reliant on the activity of natural enemies, particularly parasitoids. Whilst growers continue to release *Trichogramma pretiosum* as part of their Helicoverpa management program, it is likely that the survival of these biocontrol agents is greatly reduced with the increased insecticide use targeting FAW. Similarly, the need to protect crops from FAW impacts from crop emergence reduces the opportunity for endemic natural enemies to establish and persist in crops. As a result of overall reduced natural enemy populations in sweet corn, there is a high likelihood of secondary pests to thrive (e.g. aphids, thrips, mites), inevitably resulting in additional insecticide applications to control these pests.

The Bowen-Burdekin regions of Queensland produce the vast majority of Australia's capsicum crop (66%), with the bulk of production in the field rather than under cover. Other tropical/subtropical production areas in NSW, the NT and WA are also likely to be exposed to FAW. In 2019, capsicum production was valued at $171M, with 94% of the crop grown for the fresh market, both domestic and export (https://www.orchardtech.com.au/capsicums-production-in-australia-2019/).

Recent crop survey results (Hort Innovation project MT19015) also showed that FAW infestation in capsicum crops is widespread across several commercial farms in the Gumlu and Bowen region where fruit damage was between 10 and 30% recorded in the field and packhouse. Given the significant movement of capsicum fruit within Australia and for export, the risk of FAW larvae infesting fruit being undetected poses a risk to growers. In the absence of clear guidance around how to effectively monitor FAW in susceptible capsicum crops, growers are resorting to frequent treatment of crops with insecticides (PHA 2023). The regular application of insecticides to capsicum crops, particularly during flowering, has the potential to negatively impact the activity of pollinators.

On the 17-18th November 2022, several key grains and vegetable industry stakeholders met in Brisbane to co-design a response to FAW for the Australian Vegetable industry. Stakeholders identified four sustainable goals for FAW in vegetables, one of which was "Efficient Integration of Multiple Management Tools – Objective 3". Key components they documented that required R, D and E investment were biological control, biopesticides, economic assessments, permit applications, resistance monitoring, female attractants, resistant varieties, habitat/behaviour of beneficial and cross-industry collaboration (e.g. grains). Clearly, there remains a strong interest in IPM and tools that will improve their ability to manage FAW with less reliance on insecticides alone.

Because FAW is widespread globally, and has been a major pest for many decades, there are tools available overseas, or in development or under evaluation in Australia currently that may be useful non-insecticide options for controlling or suppressing FAW populations. There are also long-standing IPM tactics for facilitating the buildup and persistence of natural enemies in sprayed environments and suppressing the buildup of the pest species in-crop. The approach proposed in this project is to pyramid tactics that, in combination, suppress FAW populations and reduce the frequency of insecticide applications required to control damaging infestations.

Sorghum and maize (both for grain and fodder) have been significantly impacted by FAW in key production areas in Queensland and northern NSW. The use of economic thresholds to guide decisions about control are fundamental considerations in the grains industry, and the development of thresholds for FAW was a high priority for the grains industry. GRDC and QDAF have invested in R&D (DAQ1207 in conjunction with UQ and Cesar Australia) to develop economic thresholds for managing infestations in the vegetative stages of maize and sorghum growth. In these crops, loss of canopy size prior to flowering is the major driver of yield loss caused by FAW. The project anticipates the delivery of an online tool that uses APSIM crop models to enable growers to model the potential yield loss (for a given FAW density and crop stage) for crops grown anywhere in Australia.

Sweet corn crops are grown in 60-100 days, with the vegetative (pre-tasselling) stage making up most of the crop's life at 40-60 days. Consequently, multiple insecticide applications target FAW infestations in the vegetative stage, with the widely held perception that a zero-tolerance approach to FAW infestation, and the defoliation it causes, is necessary to safeguard post-tassel (reproductive) stages when direct cob damage occurs. It is likely that in the vegetative stage there may be 2-3 generations of FAW and the potential to tolerate some crop damage without risking carryover of damaging larvae from the vegetative to reproductive crop stage. However, the potential impact of defoliation on sweet corn growth rate and yield (cob size, % grain fill, weight) is not known. It is also unclear whether the APSIM maize model can adequately describe the interaction between FAW and sweet corn, but if it does, there is potential to extend the outcomes of this GRDC/QDAF project to benefit sweet corn growers.

At the outset of the project, the following were proposed as options to pursue:

- semiochemicals (e.g. QM FAW, Magnet®),
- biocontrol agents (e.g. *Trichogramma pretiosum, Telenomus remus*, predators)
- biopesticides (e.g. FAW NPV, *Metarhizium*)
- management of pupae in-crop
- nursery/refugia for beneficials within the crop.

The suite of project activities was revised through consultation with participants in the VG22006-led area wide management (AWM) groups operating in the Bowen-Burdekin and Lockyer Valley. The resulting list was:

- investigate the viability of economic thresholds for FAW in sweet corn,
- evaluate IPM-compatible options (floral resources, biopesticides, natural enemies)
- test the 'push-pull' tactic
- understand how FAW infests capsicum
- evaluate the forecasting potential of pheromone traps.

Methodology

**detailed methodology is provided for each output in the trial reports provided as Appendices.*

The focus of this project was on Queensland as it is the region most severely and persistently impacted by FAW to date. Whilst growers in other regions (NSW, Victoria) have recorded FAW and suffered some losses, feedback from these regions suggests that outcomes of the trials in Queensland will have direct relevance to these other production systems. Communication of results was supported through VG22006 to increase the accessibility of the outputs to as many sweet corn growers and their advisors as possible.

The geographic spread of trials (Gatton and Bowen) safeguarded against low FAW pressure that could impact the success of trials. The temporal separation of production also provided the opportunity to test methodology at one site before a larger scale trial was implemented at the other, or to repeat a trial.

The trials and trial locations are presented in Table 1.

Evaluating the potential for vegetative stage economic thresholds for FAW

A replicated trial was established at the QDPI research station in Gatton (Jan-Apr 24) to quantify the impact of naturally occurring FAW infestations at different stages of crop growth, and for differing lengths of time. The timing and duration of infestations were managed effectively with insecticide treatment. Four periods of exposure to FAW were implemented: 1) nil FAW = treated control, 2) V6-V8, 3) V6-V10 and 4) V8-V10. Vx = Vegetative crop stage with x fully expanded leaves. A maize check plot was grown alongside the sweet corn plot. The widely grown fresh market variety Garrison (Syngenta Vegetable Seeds Australia) was used in the trial. All treatments were protected from further FAW impacts before and/or after the period of exposure to FAW. FAW infestations did not persist past V10 and there was no direct FAW damage to tassels, silks and cobs. Two harvests were conducted, a fresh harvest and one at crop maturity. The fresh harvest assessed harvestability (height of primary cob), marketability (cob size, filled kernels). Canopy size was assessed by measuring light interception. At maturity crop biomass, and impact of FAW infestation on plant growth was assessed.

Growers visited the trial site on three occasions (separate groups) during the infestation period to discuss the objectives of the trial and the tangible outcomes.

<u>Options to reduce the reliance on insecticides for FAW management in sweet corn</u>

The suite of project activities undertaken was derived through consultation with participants in the VG22006-led area wide management (AWM) groups operating in the Bowen-Burdekin and Lockyer Valley. The resulting list was:

- evaluate IPM-compatible options (floral resources, biopesticides, natural enemies)
- test the 'push-pull' tactic
- investigate how FAW infestations establish in capsicum
- evaluate the potential of pheromone traps to inform management decisions

Table 1. Trials and trial locations for VG23006, 2023-2026 .

Project year	**Evaluation of vegetative stage thresholds for FAW**	**Reduced reliance on insecticides (IPM trial)**	**Characterisation of FAW infestation in capsicum**
1 Feb 2024-Jan 2025	<u>Bowen</u> Aug 23 – Dec 24 • test field trial protocol • low FAW pressure • yield impacted by ducks. • Trial not reported <u>Gatton</u> Jan- Apr 24 - Field trial.	<u>Bowen</u> Aug 2023 – Field demonstration floral resource (Buckwheat) Nov 2023 – Field trial. NPV time of application. Sept 2024 – intercropping/push-pull field trial. <u>Gatton</u> Jan - Apr 24 - IPM demonstration field trial (floral resource)	Gatton Feb 24 – May 24 • Open field trial (no infestation) • Controlled infestation in cages (minor infestation) • Initial characterization of damage.
2 Feb 2025-Jan 2026		<u>Gatton</u> Jan – Apr 25 - Field trial. Intercropping/push pull March 25 - Field trial. Repeated application of SfMNPV.	<u>Bowen</u> Nov 24 -Established a demonstration site for field walk with growers and agronomists. No infestation, no useable data. <u>Toowoomba</u> Jan – Mar 2025 - Controlled host preference cage trials in glasshouse.

Floral resource to support IPM – buckwheat

Field trials in Bowen and Gatton established buckwheat as a floral resource and potential refuge for natural enemies in the early stages of sweet corn crop establishment, when there is limited canopy. In Bowen, the trial was established as a demonstration for the Bowen-Burdekin AWM group to inspect as the concept was new and buckwheat unfamiliar as a resource in the production system.

At Gatton the buckwheat was established prior to the sweet corn so that it was flowering when the sweet corn emerged. The buckwheat was centrally located in a block of five large plots (12 x 50 m) of sweet corn. The trial experienced very high FAW pressure and were treated weekly with conventional insecticide to prevent total loss of the trial. Commercially sourced *Trichogramma pretiosum* (egg parasitoid) was released into each of the blocks from tassel emergence. Each block was assessed weekly to determine FAW egg and larval density and the abundance of natural enemies. FAW egg masses were collected for egg parasitism assessment. The buckwheat was sampled during the vegetative, flowering and post-flowering stages and the samples examined for natural enemies and pest species. A fresh market harvest assessment was made of the five sweet corn blocks (cob height, cob size, kernel fill and fertility of plants) to determine if the proximity to buckwheat influenced these outcomes. A basic economic assessment of the costs and benefits of the IPM approach was undertaken.

Biopesticide evaluation (SfMNPV)

The only commercially available biopesticide for FAW currently is the *Spodoptera frugiperda nucleopolyhedrosis* virus (SfMNPV) (Fawligen ™, SpodovirPlus™). Many growers are including one of these products in their spray program, but there has been data available to industry on the efficacy of them and how to optimize their performance in the field. QDPI (Queensland Treasury Investment) had done laboratory bioassays and field efficacy testing which suggested field performance was at a level that is not commercially acceptable. The sweet corn growers wanted to know if application at different times of day/night would make a difference. They also suggested that repeat applications of the SfMNPV increased efficacy over a single application. We undertook two field trials to address these questions. The first trial at the Bowen research station was a replicated small plot trial to compare the efficacy of 3 treatments: 1) Fawligen 200 mL/ha + 1L/ha Optimol applied at 8 am, 2) Fawligen 200 mL/ha + 1L/ha Optimol applied at 6 pm, 3) untreated control. Destructive sampling was employed to assess larval infestations prior to treatment and then at 6- and 12-days post treatment. Larval collections were made pretreatment, and at 2 days post treatment to assess the level of virus infection and larval parasitism. Larval density data were analysed to determine the impact of the treatments on the level of FAW infestation and larval survival.

The second field trial undertaken at Gatton looked at the impact of repeated application of Fawligen. The commercial SfMNPV products allow up to 10 applications per crop. The trial had two treatments 1) Fawligen at 200 mL/ha + 1L/ha Optimol applied at 4-day intervals with a total of 8 applications over 4 weeks (V4 – tassel), 2) Treated control where insecticides were applied judiciously to prevent major crop loss, but much less intensively than the approach taken in a commercial sweet corn crop. The treatments were applied by commercial boom spray delivering 200 L/ha. Egg and larval densities were assessed by destructive sampling weekly and plant damage rated using a modified Davis scale. Six collections of susceptible larval cohorts were reared to determine the level of virus infection in the population.

Push-pull tactic or intercropping to increase in-crop diversity

In 2024-25 we have undertaken two evaluations of a push-pull designed sweet corn cropping layout, the first conducted at the Bowen Research Station in September 2024. In the Bowen trial we instituted a 1:1 ratio of intercrop (sunn hemp *Crotalaria juncea* L., and cowpea *Vigna unguiculata*) to sweet corn (row:row) as the 'push' crops, with a border of forage sorghum as the 'pull' crop established four weeks prior to the sweet corn. A sweet corn monoculture was established in an adjacent block for comparison (var Garrison). Neither the *Brachiaria* push option, nor the *Desmodium* pull option used in Africa were deployed in this trial (Midega *et al* 2018, Khan *et al* 2000, Sobhy *et al* 2022). The establishment time for the *Brachiaria*, and the weediness potential of this and the *Desmodium* were considered risks that could not be adequately managed. The alternate intercrops selected for the trial were sunn hemp and cowpea.

Egg density was assessed in the sweet corn component in the intercrop plot and the monocrop block over a four-week period. A fresh harvest assessment made 3 weeks post tassel and cobs assessed for marketability.

Given the interest of industry in the initial Bowen trial, we modified the trial design for Gatton to: i) minimise the potential shading effect of the sunn hemp, and ii) make the intercropping approach more commercially feasible by including different ratios of sunn hemp and sweet corn in blocks and iii) consider impact of the sunn hemp on FAW oviposition in the adjacent sweet corn blocks and the interaction of the sunn hemp with key natural enemies

At Gatton the sweet corn (Variety: Garrison) and Sunn hemp (Variety: Cresent) planted on 16 January in a replicated trial with the sweet corn (SC) and sunn hemp (SH) were planted in each of three configurations, 1) 8 rows of SC, 2) 2 rows SH/ 8 rows SC/2 rows SH and 3) 6 rows SC/ 6 rows SH. These treatments were replicated four times. Plots were 100 m long and divided into 4 quadrats (subplots) from north to south to facilitate structured sampling within plots. Assessment of egg and larval density in the sweet corn plots were made at 3–4-day intervals using destructive sampling; egg masses were retained for parasitism assessment. Sunn hemp was sampled with a suction sampler on five occasions and these samples examined in the laboratory to identify and quantify the natural enemies and pests. A fresh harvest was undertaken on 25 March and assessed for damage and marketability.

Pheromone traps to inform in-field management – pilot studies

Sweet corn (var. Astronaut) was planted at the Bowen Research Station, in a trial plot 80 m long by 12m wide (16 rows of corn at 4 plants/m), grown under trickle irrigation as required. The trial was planted on 9th May 2025 and from day 2 post- emergence (17th May) it was scouted every day for two weeks. Plants were non-destructively searched for eggs on each day at 8:00am by stepping out 3 paces along each row. Twenty-seven plants were checked in each row on each day, totaling 432 plants per day. Records were made of egg masses as white, brown or black. Only white egg data is analysed. The manual bucket trap (PO61Chemtica lure) was placed adjacent to the crop and checked daily. An automated RapidAIM®Mega trap (Pherolure® lure) was located within 20 m of the crop, providing daily moth trap data accessible from the RapidAIM portal. Comparison was made of the trap catches in the two traps and the number of new (white) egg masses recorded each day.

At Gatton, Maize was planted on 11 November into a block 94 rows wide and 100 m long. Maize was used rather than sweet corn as it is less costly to plant and the plants more robust when infested with FAW. We wanted the trial to be sprayed as little as possible to avoid disrupting the moth activity, and to be attractive to female moths for as long as possible. Once the crop was sown, six manual bucket-style pheromone traps were placed around the western and eastern crop margin at approximately 50m intervals. The PheroLure™ (Insect Science) was used and replaced at 3-week intervals to maintain potency and checked every 1-2 days. Results from the RapidAIM and bucket trap in the Bowen trial provided the confidence that either trap would provide similar trap catches.

At each sampling date, individual plants were destructively sampled from the plot to determine the number of white and brown eggs deposited. Sampling was conducted on a grid with plants inspected every 3 metres along the row (north to south) and every 5th row across the field (east – west). On each sampling occasion between 630 and 665 plants were inspected from the trial plot.

Data were used to produce heatmaps of the distribution of egg masses for each sampling date (Sadie, R statistical software), and regression analyses conducted to examine the relationships between trap catches and egg mass density.

Characterising FAW infestation fruiting capsicum

Open field trials designed to characterize infestation of capsicum by FAW (Gatton and Bowen) were unsuccessful. In both instances capsicum seedlings (cv Warlock) were transplanted into plots where natural infestations were expected to arise. In Bowen, no FAW were recorded from vegetative, flowering or fruiting plants. At Gatton, introducing moths and egg masses to caged plants in the field still failed to establish infestations. Consequently, we determined to conduct glasshouse host preference trials which we hoped would allow us to understand how infestations reported from the field were eventuating.

We conducted three experiments in the glasshouse at the QDPI facility in Toowoomba. I) moth oviposition, ii) larval establishment and iii) neonates on caged fruit.

Insects of all three pest species used in experiments were sourced from QDPI laboratory colonies. Capsicum plants (cv. Warlock) were grown from seed and at 9 weeks transferred into a temperature-controlled glasshouse (27°C night, 25°C night) under natural photoperiod, where they were grown until their use in experiments. All experiments were conducted under these conditions. During plant growth all flower buds were regularly manually removed from plants until the plants reached 11 weeks after sowing, to prevent fruits from forming on small plants and ensuring synchrony in fruiting for the experiments.

Experiment 1: Moth oviposition

For oviposition assays groups of n=6 moths of a single species (1:1 sex ratio) were placed into cages in the glasshouse. Within each cage we placed three capsicum plants, one for each crop stage – flowering, green fruit, and red fruit. Flowering plants were between 95-102 days after sowing (DAS), green fruit 123-130 DAS, and red fruit 158-165 DAS.

We allowed moths four nights to feed, mate, and lay eggs. After four nights we terminated assays and recorded the number of surviving moths, the count and the location of eggs/egg masses along with recording the size and length of egg masses for the *Spodoptera* species. The experiment was a randomised block design, and ten replicates were performed for each pest species.

Experiment 2: Larval establishment

In this experiment we examined larval survival and feeding behaviour on capsicum plants of the same three crop stages (flowering, green fruit, and red fruit) On each plant we placed n=50 neonate larvae on a fully-expanded leaf at the top of the plant. Larvae were left to feed and disperse for 10 days, after which we destructively sampled plants and searched for larvae. We recorded the number of surviving larvae, along with their location and instar. This experiment was a randomised block design, and four replicates were conducted for each crop stage x pest species combination.

Experiment 3: Neonates on caged fruits

In the third experiment we caged neonate larvae of the three species of caterpillars on a capsicum fruit of one of four fruit stages. The four fruit stages we used in this experiment were: 1) small (expanding) green fruit, 2) green fruit, 3) turning fruit, and 4) red fruit. Small green fruit were under 40mm in diameter and selected to represent the feeding sites available to larvae soon after flowering and turning fruit were transitioning in colour from green to red. Neonate larvae (n=10 per fruit) placed onto fruits where they were restricted with the use of 13x12cm organza bags which were tied around the fruit's peduncle. After 4 days, bags were removed, and fruits were examined for the presence of larvae. We recorded the number of surviving larvae, their location, and the presence of feeding damage. We also measured capsicum fruit wall toughness by using a fruit penetrometer (FT-011) on the fruit wall, and we recorded a proxy for soluble sugars in the fruit wall by using a Brix refractometer (Atago, PAL-1). This experiment was a randomised block design, and four replicates were conducted for each fruit stage x pest species combination.

Statistical analysis

For the moth oviposition experiments, response variables were analysed with one-way ANOVAs with replicate used as a blocking factor. For both larval experiments we analysed larval survival/establishment using two-way ANOVAs with moth species and crop/fruit stage as the independent variables. All analyses were conducted using the statistical software R. Post-hoc comparisons were made with Fisher's protected LSD test and significance was set at p<0.05, for these comparisons we used the R package ‘agricolae’. Finally, graphs were made with the R package ‘ggplot2’.

Photos/images/other audio-visual material

< Refer to *Attachment A3: Final report guide* or the guidance note at the start of this template >

Results and discussion

Evaluating the potential for vegetative stage economic thresholds for FAW

The largest reductions in canopy size in response to FAW infestations of 1-1.5 larvae per plant were in the V8-V10 (late vegetative) and the V6-V10 (longest exposure) treatments. These magnitude of these impacts show just how limited the capacity of this sweet corn crop was to compensate or recover from the FAW infestation. As a result of the canopy size impacts, all measures of harvestability (height of primary cob) and marketability (cob weight, length, filled length) were significantly lower than the untreated control. To illustrate the magnitude of the impact on growth, cob heights for the each of the treatments are presented in Table 2.

Table 2. Impact of FAW infestations on plant growth and harvestability of sweet corn in response to exposure at different growth stages and durations. Means followed by the same letter are not significantly different (within column). Vx = vegetative growth stage where x= number of fully expanded leaves.

Treatment	Primary cob height from ground (cm)
Treated Control	49.83 a
V6-V8	25.7 b
V6-V10	18.92 c
V8-V10	14.99 d
	$F=300$, $df=(3, 314)$ $p<0.001$

At the outset of this trial, it seemed logical that sweet corn, like maize, would be tolerant of at least some FAW feeding damage in at least the early – mid vegetative stages. If a damage threshold could then be quantified it would create opportunities for growers to reduce the frequency of spraying in vegetative crops when if infestations of FAW fell below the threshold.

The indirect impacts of FAW infestation on harvestability and marketability of the crop were major, with 30-70% reduction in cob weight, length and filled length. It is clear from these results that this widely grown sweet corn variety (Garrison) does not have the capacity/resilience to recover from moderate defoliation in the vegetative stages that results from infestation levels of 0.5-1.5 larvae per plant. Essentially, this potential impact demands a zero tolerance for FAW infestation in sweet corn.

Based on these trial outcomes, an economic threshold for vegetative crop stages for sweetcorn growers managing moderate to high FAW infestation levels is not feasible at this time, at least for the widely grown variety Garrison. There may be value in establishing damage thresholds for growers in regions where FAW infestations are low, with the view to providing empirical evidence to guide crop monitoring and management (e.g. Sydney Basin, Central west NSW, Riverina).

Our trial was conducted with the variety Garrison, widely grown for the fresh market. It is possible that there is some variation in the resilience of across the suite of varieties available to growers. Anecdotally, growers have not identified alternate varieties currently available that are more resilient to FAW impacts (discussions with growers and agronomists as part of VG22006 activities). There may be value in evaluating the relative impact of FAW on a range of sweet corn varieties, but there is nothing in the peer-reviewed or industry literature overseas that indicates there are significant differences in the susceptibility of available varieties. Considerable research effort has been invested in identifying host plant resistance (HPR) to FAW in maize (Prasanna *et al.* 2022). If HPR is pursued for sweet corn, then this maize work will provide a sound basis and possibly germplasm for integration into sweet corn breeding programs.

Options to reduce the reliance on insecticides for FAW management in sweet corn

Floral resource to support IPM – buckwheat

The timing of the buckwheat planting resulted in it flowering from the emergence of the sweet corn through until tasselling, critical periods for crop development and yield formation. As a refuge crop, it performed well in terms of form and function, establishing easily, producing high biomass and long flowering.

The buckwheat hosted a diversity of species, including parasitoids, predators, pollinators and few pest species. Predatory bugs were the most abundant natural enemy in the sweet corn e.g. pirate bug (*Orius* sp) and the mirid *Tytthus* sp. and were also present in the buckwheat throughout the trial. Spiders were abundant in both the buckwheat and the sweet corn, but not at the same time. Spiders were largely absent from the sweet corn until the buckwheat had finished flowering and was scenescing. This does not necessarily imply that the spiders moved from the buckwheat to the sweet corn when the buckwheat scenesced. It is possible that the spiders we sampled were able to establish only when there was adequate 'cover' in the crop to host them. It is also possible that the spiders active in the sweet corn were nocturnal and/or easily disturbed from the plants and not visible in the crop during the day when sampling was conducted.

Over 5 sampling occasions, a total of 435 viable egg masses were collected and cultured in the laboratory until wasps emerged. *Trichogramma pretiosum* was the dominant egg parasitoid observed in the trial. Parasitism by *T. pretiosum* ranged from 20-60% of collected egg masses. These results clearly demonstrate that *T. pretiosum* is an effective parasitoid of FAW, and that in most instances parasitises the entire egg mass. These findings challenge the perception of growers and agronomists that *Trichogramma* is relatively ineffective against FAW and that the scale covering and stacked arrangement of eggs in FAW egg masses reduces the effectiveness of this species. A low level of *Telenomus* sp. was observed towards the end of the trial and did not exceed 6% of collected egg masses. *Chelonus* sp is one of the most common parasitoids recorded from field collections of small FAW larvae, and females are often observed ovipositing into egg masses in the field. We do not have reliable methods for determining the level of *Chelonus* sp parasitism, so the contribution of this species is underestimated.

Biopesticide evaluation (SfMNPV)

In these trials, neither repeated applications (8 applications over 27 days) nor the single application at different times of the day (morning, evening) provided commercially acceptable control of moderate infestations of FAW in sweet corn at the highest label rate (200 mL/ha).

In the time of spraying trial, no significant differences were observed in larval densities or crop damage between the SfMNPV treatment and the untreated control, clearly demonstrating the lack of efficacy of the SfMNPV. Post treatment assessment revealed a mean infection rate of susceptible larvae of 2.4-7.4%. SfMNPV is ingested by the larvae as they feed. In comparison, parasitism 24-38% death of larvae, with *Chelonus* sp the most common parasitoid. This level of parasitism, in a sweet corn crop would make a valuable contribution to the control of FAW.

In the Gatton trial where eight applications of SfMNPV were applied consecutively, we again saw low levels of virus infection (4-29%) across the trial. This low level of infection was reflected in the survival of larvae that developed to be damaging 5^{th} – 6^{th} instar by the end of the trial. The density of large larvae and the damage rating in the SfMNPV treatment increased steadily throughout the trial. In combination, the SfMNPV mortality and parasitism was 20-40% of larvae collected (instars 1-4). At the FAW density experienced in this trial the crop damage suffered was not commercially acceptable. At lower pest density, biocontrol can make a valuable contribution to the suppression of an infestation, even more so if there was a more effective biopesticide option.

Push-pull tactic or intercropping to increase in-crop diversity

The period over which this trial ran was characterised by low FAW activity. We also experienced high variability in FAW activity spatially and temporally during the trial. The forage sorghum border crop (pull) did not attract FAW oviposition or support populations of larvae. Despite vigorous growth, high biomass and rapid regeneration post slashing, there was no evidence that it provided the same benefits reported for *Brachiaria* pull options.

Both the cowpea and sunn hemp established easily and grew vigorously. The cowpea was low growing until the sweet corn tasselled and then it rapidly climbed the corn plants. The sunn hemp grew at a similar vertical rate to the sweet corn during the vegetative stages and continued to elongate after the sweet corn growth ceased at tassel. The sunn hemp flowered prolifically from the late vegetative stages right through to the fresh harvest. Oviposition across the treatments was considered a key indicator of the efficacy of the PPT approach and significant effort was deployed to sample intensively for eggs. Analysis of data across all dates suggests a trend towards lower egg mass numbers in the cowpea and sunn hemp than in the sweet corn monocrop. However, high variability in the low density data makes this analysis challenging. No differences in the damage rating of the sweet corn was observed across the treatments. The sunn hemp treatment yielded significantly lower cob weight than that from cowpea and monocrop sweet corn. Competition for resources and/or shading by the sunn hemp may have directly contributed to the lower cob weight, a consequence of the sweet corn plant having reduced resources to fill the cob.

At Gatton we saw no differences in the number of eggs laid between treatments, or any influence of sunn hemp on the number of eggs deposited by moths. Despite there being no influence of treatment on the number of egg masses laid, we did see significant differences in the level of crop damage with the lowest overall damage rating observed in the treatment with the highest SC:SH ratio (6 SC/6 SH). Damage ratings were low, so the practical implication of this result is limited in this instance (1.8-2.6 on the 1-9 modified Davis scale we use to assess damage, where 9 is major damage and 1 is very minor damage). At Gatton we looked at the abundance of natural enemies in the sweet corn blocks and in the sunn hemp. *Trichogramma pretiosum* was again the most abundant egg parasitoid with 40-50% of egg masses collected (1409 total) parasitised. Treatment did not influence *Trichogramma* parasitism. Bug predators were the most common natural enemies observed in the sweet corn and in the sunn hemp, along with ladybeetles and spiders. It is likely that there is movement between the sunn hemp and the sweet corn. Sunn hemp is known to be a host of green vegetable bug (GVB) and we recorded GVB in the sunn hemp throughout the trial. In the fresh harvest assessment, we recorded 20-30% of cobs with GVB damage to kernels (discoloured, shrunken), but there was no significant difference in the rate of GVB damage between treatments with and without sunn hemp adjacent. It is possible that the GVB damage experienced in this trial is high by industry standards and that the presence of sunn hemp in the trial elevated GVB abundance across all plots. Again, this may be a question of scale and the capacity of GVB to move freely across the trial between the sunn hemp and corn. There was no difference between the treatments in terms of the proportion of marketable cobs harvested. We observed no negative impacts of sunn hemp as an intercrop option, but the benefits for FAW mitigation are not evident either, other than the probable contribution to natural enemy abundance.

At the field walks in Bowen and Gatton, growers and agronomists were very interested in the sunn hemp as a potential cover crop and were curious about the mechanics of handling the crop (aspects that are being address by other Hort Innovation investments). The additional benefits of sunn hemp (nematode suppression, nitrogen fixation, cover crop) warrant further consideration in terms of integrating it as an option that does not host FAW. It may not be the most effective option for disrupting FAW, but if the concept of diversifying the production system to capture a range of benefits, then evaluating other options could yield greater benefits in terms of FAW impacts.

Pheromone traps to inform in-field management – pilot studies

There is a good relationship between the manual pheromone trap counts and those from the real-time automated trap. The correlation between the two trap types was R^2=0.76. The high correlation between the catches in the two pheromone trap types is reassuring for growers as it suggests they can use either option with confidence. The automated traps clearly provide the convenience of providing data without having to visit the trap. Strategically placed manual traps that can be visited daily, or regular intervals, would provide the same information.

A weak relationship was found between trap catches and the density of white egg masses in the Bowen trial, but no relationship was found in the Gatton trial where moth catches and egg density was much lower than that observed in Bowen. However, there was a strong positive relationship (R^2=0.81) between the number of moths trapped per day and the number of brown egg masses in the crop. Brown egg masses were far more numerous than white egg masses, providing a more robust dataset for analysis. Brown eggs are more abundant because they accumulate over several days between 24 hours post oviposition until hatching at 3-5 days post oviposition. It is possible that with higher FAW activity the relationship between moth catches and oviposition would be clearer. These preliminary data suggest that the usefulness of pheromone traps in predicting egg density and risk in adjacent fields warrants further investigation.

These Gatton trial also shows how multiple traps provide a more reliable view of FAW activity in the vicinity of the crop, but clearly there is a point at which more traps is simply not feasible. It would be worth pursuing this question with a gridded trap approach to address the question of the cost:benefit of pheromone trapping to support FAW management.

Visual representation of the egg mass distribution during the trial shows a trend towards higher frequency of egg masses on the western side of the trial. A non-random distribution indicates that a structured sampling plan is required to reliably determine the level of infestation of FAW (Binns & Nyrop 1992). Currently there has been limited assessment of in-crop distribution of FAW eggs and larvae in crops and consequently there are no guidelines for crop monitoring to assist growers and agronomists. More work to determine if edge effects are characteristic of FAW infestations, and appropriate sampling strategies would be of value to growers and agronomists engaged in making management decisions for FAW. An effective sampling strategy for FAW must be developed in conjunction with existing strategies for other key pest species e.g. *Helicoverpa*, *Nezara viridula*, and natural enemies e.g. egg parasitoids, larval parasitoids, predators.

Characterising FAW infestation fruiting capsicum

The very low level of eggs laid on plants in oviposition experiments by FAW*,* particularly in comparison to the other moth species indicates a low preference of this pest for the crop. The FAW moths in our study preferred to oviposit on cage walls rather than plants. This behaviour has been seen in previous studies and strongly indicates that moths do not have a preference for laying on the focal plant species (Volp *et al*. 2022).

Despite the low levels of oviposition on plants by female moths, FAW larval establishment and survival was comparable to that of *H. armigera*. Although both these species did much poorer than cluster caterpillar *(S. litura)*.

Importantly, over two-thirds of surviving FAW larvae were found on or inside capsicum fruits. These observations suggest that FAW larvae do not prefer to feed on capsicum leaves, despite some people regarding the pest as a ‘leaf-feeder’. The results of the third experiment further demonstrated the ability of FAW larvae to establish feeding sites on capsicum fruits, with two first instar larvae even able to find their way inside the fruit within 4 days.

The are several key messages based on the FAW results. Firstly, female FAW moths do not have a strong preference for laying eggs on flowering or fruiting capsicum plants. We expected this to be the case given the difficulty of infesting capsicum plants in the field using populations of moths. Additionally, despite the pest having long been present in the Americas, a major capsicum production region, there is limited research interest in this pest on capsicum (e.g. a Scopus search for "Spodoptera+frugiperda+capsicum+annum" does not yield a single result).

Moths of FAW can oviposit on non-preferred plant species when there is a high population of FAW moths in the landscape and/or a lack of suitable host plants. Such events may be driving field infestations in Australian capsicums. Or alternatively, FAW larvae may be entering crops as small larvae silking off a grass host (volunteer maize/sorghum, wind breaks, or grass weeds) or crawling older instars.

The major gap in our understanding for FAW in capsicum is the in-field understanding of how these infestations are generated. Interviews with agronomists, conducted in collaboration with VG22006, has led us to believe that FAW in capsicum is more sporadic and overall less problematic than initially suggested.

Photos/images/other audio-visual material

< Refer to *Attachment A3: Final report guide* or the guidance note at the start of this template >

Outputs

Table 3. Output summary

Output	Description	Detail
Evaluation of the potential to adapt maize/sorghum thresholds to provide sweet corn growers with economic thresholds for FAW in vegetative sweet corn.	Trial results that discuss the research that examined the capacity of sweet corn variety Garrison to tolerate or compensate for moderate to severe FAW damage.	The trial report is provided as Appendix 1.
Demonstration of a suite of non-chemical management tactics that could reduce reliance on conventional insecticides.	Growers, agronomists, researchers, extensionists and R&D managers are target audiences for these reports that are designed to address key industry questions and stimulate discussion about the challenges and opportunities to reduce reliance on insecticides for FAW management in horticulture.	Trial reports are provided as Appendices 2, 3, 4 and 5.
Characterisation of FAW oviposition and larval establishment in flowering and fruiting capsicum as a basis for crop scouting recommendations.	Growers, agronomists, researchers, extensionists and R&D managers are target audiences for the trial reports. The factsheet is designed to provide basic information to growers, agronomists, and extensionists working with growers.that are designed to address key industry questions and stimulate discussion about the challenges and opportunities to reduce reliance on insecticides for FAW management in horticulture.	The trial report is provided as Appendix 4. The factsheet is provided as Appendix 5. The trial results have been presented at a Bowen-Burdekin AWM group meeting in late 2025 and discussed with individual agronomists managing capsicum. The researcher (T Volp) is travelling to WA (Carnarvon) in March 2026 to present/discuss his findings with growers there. The factsheet can be uploaded to the FAW eHub, distributed to VegNet IDOs, AusVeg for information and sharing with relevant industry.
Grower and advisor engagement and discussion of concepts and trial outcomes through collaboration with the VG22006 (FAW Area wide	Lead and participate in field walks at VG23006 trials in Bowen and Gatton. Share and discuss trial results with AWM groups (Bowen-Burdekin, Lockyer Valley,	These activities are captured in VG22006 milestone reporting. Bowen-Burdekin and Lockyer Valley AWM group meetings all attended by at least 1 team member, min 2 per year. The AWM groups are the primary vehicle for participatory development of research questions and sharing results of the R&D undertaken.

management) project team.	East Gippsland). Communicate project outcomes to industry via the FAW eHub and newsletters. Increased awareness and knowledge of FAW ecology and management options, including those being evaluated and discussed.	There is potential to extend these outputs through the proposed FAW Roadshow, the eHub and other grower focused extension and communication channels.

Photos/images/other audio-visual material

< Refer to *Attachment A3: Final report guide* or the guidance note at the start of this template >

Outcomes

< Detail the intermediate and end-of-project outcomes and how these support relevant Fund outcomes (as per industry Strategic Investment Plan(ies) or Hort Frontiers Strategy). Outcomes are the desired result of the project and represent the project's unique contribution to the relevant Fund outcome(s), strategy(ies) and Key Performance Indicator(s). For grant projects (or projects with external funding sources) the linkage to grant outcomes should also be included where appropriate.

A summary of the project's outcomes should be completed using the table below, supported with monitoring data collected to provide evidence of outcomes as per the project's M&E Plan. Where possible provide a statement of costs and benefits achieved in delivery of the project. For more information, refer to *Attachment A3: Final report guide* >

Table 4. Outcome summary

Outcome	**Alignment to fund outcome, strategy and KPI**	**Description**	**Evidence**
A recommendation around the potential for vegetative stage economic thresholds to guide decisions on FAW control in sweet corn.	Vegetable Industry Strategic Plan 2022-26 Outcome 1.	Research trials that revealed the inherent limitations with the sweet corn plant. The outcome was not to pursue a threshold for FAW, the challenge is not an entomological pest management one, but a crop physiology/breeding one.	Appendix 1. Trial report.
Recommendations for capsicum growers on how to effectively monitor for FAW during flowering and fruiting stages.	Vegetable Industry Strategic Plan 2022-26 Outcome 1.	New knowledge about the relatively low risk posed by FAW to capsicum relative to the risk of the other key pests has been shared with industry at Bowen-Burdekin AWM meetings, private discussions with agronomists managing capsicum crops. Resources (factsheet, journal article) inform current management and future research direction. Other drivers influence behaviour (grower attitude vs agronomist knowledge, uncertainty about how FAW infestations arise) and behaviour change is not evident at this point.	Appendix 4, appendix 5. VG22006 (John Stanley, Ramesh Puri) interviews with agronomists about their concerns and practices.
Improved awareness of growers and advisors around non-chemical management options for FAW, and their practical implementation.	Vegetable Industry Strategic Plan 2022-26 Outcome 3.	Discussion of industry questions at AWM meetings and field walks (Bowen-Burdekin, Lockyer Valley). Responsive to information and knowledge gaps, sharing current and past research	VG22006 compiles a KASAP survey and evaluates KASAP based on discussion at AWM meetings. This longtitudinal data collection is, and will, reveal changes evident in

		results that help clarify uncertainties e.g. LV AWM group unclear what the relative toxicity of insecticides was to parasitoids – was able to share recent QDPI bioassay results and hort industry information from previous project. Demonstration trials at research stations where AWM meetings and other industry activities happen.	the conversations over time.

Recommendations

1. Economic thresholds are only viable if there is a level of pest infestation or damage that can be tolerated, otherwise the management threshold is essentially zero pests. Selecting for increased tolerance must be prioritised to provide growers with varieties that do not demand a zero-tolerance approach to managing FAW to avoid economic crop loss.
    a. In the meantime, avoiding periods of peak FAW activity will provide some mitigation of the most severe impacts and increased input costs. Growers are reluctant to consider shifting production to avoid these risky periods. A cost benefit analysis that identifies (through consultation with growers) the barriers to them changing their production window would be of value in supporting these more significant practice changes.
2. There is value in empirical research that provides clear guidelines to assists growers in identifying levels of defoliation/infestation that will not result in economic loss for regions where FAW activity is low, well below the sustained 0.5-1.5 larvae per plant that caused significant loss in our trial. Such a guide would increase the confidence of growers and their advisors to reduce the application of insecticides to crops where there is defoliation at levels that pose no risk of loss. This information has application in regions, and seasons when FAW infestations are low, sporadic and patchy.
3. We have demonstrated that *Trichogramma pretiosum* is parasitizing FAW at high rates in sprayed environments. Growers need to be able to confidently assess and quantify egg parasitism before they can harness its contribution. Techniques for efficiently assessing egg and larval parasitism, in combination with the development of strategies for deploying *Trichogramma* are warranted, along with integration of what is already known about floral and refuge resources in horticultural production systems. A similar approach was adopted in sweet corn when parasitoids and virus were promoted for the management of helicoverpa. It would be worth revisiting this R, D and E.
4. An effective biopesticide option is a priority for FAW control. It would offer benefits in terms of preserving natural enemies and reducing the selection pressure for insecticide resistance. The variable performance of SfMNPV on Zea mays (maize and sweet corn) warrants investigation to understand the mechanism of the poor performance. QDPI bioassays with other crops (e.g. ginger, soybean) show significantly higher levels of virus acquisition by larvae, compared to what we see in maize and sweet corn. Increased efficacy might be achievable with the inclusion of an adjuvant that corrects for whatever is limiting infection in these crops.
5. Intercropping to increase diversity in the production system has stimulated interest in the Bowen-Burdekin and Lockyer Valley growers. Sunn hemp has created interest, possibly because it offers greater perceived benefits as an intercrop that contributes to invertebrate pest management, but also because of the nematode suppression potential and as a cover crop option. Growers probably need support to weigh up the relative benefits and costs of incorporating something like sunn hemp into their production systems. Opportunities for researchers to come together to discuss risks and opportunities would be of value to industry.
6. An improved understanding of the characteristics of FAW infestations in sweet corn production systems (temporal and spatial factors) could guide efficient (especially in terms of time) and reliable sampling strategies that would increase grower and agronomist confidence in monitoring management decisions for FAW. An effective sampling strategy for FAW must be developed in conjunction with existing strategies for other key pest species e.g. *Helicoverpa*, *Nezara viridula*, and natural enemies e.g. egg parasitoids, larval parasitoids, predators.
7. The pilot trial shows that multiple traps provide a more reliable view of FAW activity in the vicinity of the crop and can potentially predict in-crop oviposition by FAW. Clearly there is a point at which more traps is simply not feasible, but there is value in pursuing this question with a gridded trap approach to address the question of cost:benefit of pheromone trapping to inform in-field management decisions.
8. Designing sampling strategies for FAW in capsicums is difficult. We do not know the mechanism by which larval populations are finding their way into a crop (by oviposition, silking or crawling). However,

once these populations are present, we can expect some survival (10-15%). The larvae that do survive are likely to be found feeding on or inside capsicum fruits, where they prefer cryptic feeding sites. It is unlikely that sampling early instars in the field would be practical, given the only way to detect larvae in the caged fruit experiment was to dissect the fruit. The main priority moving forward for managing FAW in capsicums is 1) understanding the environmental context that generates infestations and 2) guiding growers/agronomists on how to decrease the risk of such spillover infestations.

Refereed scientific publications

Journal article

Volp TM, Quade AD, Zalucki MP.(2026). Oviposition and larval establishment of three 'generalist' noctuids on *Capsicum annuum*. *Austral Entomology*. Article 70058 **In press.** https://doi.org/10.1111/aen.70058

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https://doi.org/10.1146/annurev.en.37.010192.002235

Khan, Z. R., Pickett, J. A., van Den Berg, J., Wadhams, L. J., and Woodcock, C. M. (2000). Exploiting chemical ecology and species diversity: stem borer and striga control for maize and sorghum in Africa. *Pest Management Science* 962, 957–962.

Midega, C. A. O., Pittchar, J. O., Pickett, J. A., Hailu, G. W., and Khan, Z. R. (2018). A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (J E Smith), in maize in East Africa. *Crop Protection* 105, 10–15.

Plant Health Australia Ltd (2023) Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*). Plant Health Australia, Canberra, ACT.

Prasanna, B.M., Bruce, A., Beyene, Y. et al. (2022). Host plant resistance for fall armyworm management in maize: relevance, status and prospects in Africa and Asia. *Theoretical and Applied Genetics* 135, 3897–3916 https://doi.org/10.1007/s00122-022-04073-4

Sobhy I.S., Tamiru A, Chiriboga Morales X, Nyagol D.C. Heruiyot D., Chidawanyika F., Subramanian S., Midega C.A.O., Bruce T.J.A. and Khan Z.R .(2022). Bioactive Volatiles from Push-Pull Companion Crops Repel Fall Armyworm and Attract Its Parasitoids. *Frontiers in Ecology and Evolution* 10:883020.

Volp T. M., Zalucki M. P., Furlong M. J., (2022). What defines a host? Oviposition behavior and larval performance of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) on five putative host plants. *Journal of Economic Entomology*, 115, 1744-1751.

Intellectual property

No project IP or commercialisation to report

Appendices

Appendix 1. FAW vegetative threshold evaluation trial report.

Appendix 2. FAW IPM demonstration trial report.

Appendix 3. Biopesticide evaluation report.

Appendix 4. FAW capsicum host preference trial report.

Appendix. 5. FAW capsicum factsheet.

Appendix 6. Intercropping to diversify the sweet corn production system.

Appendix 7. Pheromone traps for management. Pilot trials report.

APPENDIX 1

Evaluation of the viability of thresholds for the management of Fall armyworm (FAW) in sweet corn.

Field trial: Gatton Research Station. 2024.

M. Miles, A Quade.

Background

In conjunction with crop monitoring to assess infestations, empirically derived economic injury levels and thresholds are fundamental to pest management in crops. In developing economic thresholds, the amount of crop damage/injury that will justify the cost of control measures must be quantified (Stern *et al*.1959). A review of the literature (Overton *et al*. 2021) revealed just one empirically derived yield loss estimate for FAW in the vegetative crop stages in sweet corn (Marenco *et al*. 1992), and no economic thresholds. A review of the more recent literature did not reveal any advance on this situation.

"Feeding damage by fall armyworm during the early and midwhorl stages (V1-V9) significantly reduced plant height, stalk diameter, leaf area, and fresh and dry weight of above ground portions of sweet corn plants. Protecting plants from fall armyworm damage during the late whorl stage (V9-R1) resulted in higher yields and reduced percentages of ears damaged by insects. Protecting the plants from fall armyworm damage during the midwhorl stage (V6-V9) was not as important as the late whorl stage but was more important than during the early whorl stage (V1-V6). Fall armyworm densities as low as 0.2-0.8 larvae per plant during the late whorl stage may be sufficient to reduce yields of US No. 1 ears by 5-20%" (Marenco *et al*. 1992).

Nominal thresholds, typically derived from experience rather than trial work, are presented in industry focused resources in the US, for example "*Florida sweet corn producers apply insecticides when ≥5–10% of plants (within 3 wk of emergence and during tassel push)* or ≥15–20% of plants (between 4 wk after emergence and tassel push)* are infested with S. frugiperda larvae. In addition, the presence of larvae triggers insecticide applications when ears are present*" (Buezelin *et al*. 2022).

*Note: 3 and 4 weeks after emergence would be approximately V6 and V8 respectively. Tassel push occurs at around V9-V10. These nominal thresholds are largely consistent with the critical crop stages identified in the 1992 research.

These statements indicate that there is potential to tolerate some damage (defoliation) in the early vegetative stages in sweet corn. It is this opportunity that we explore in this research, keeping in mind that there may be considerable differences in growth characteristics of sweet corn varieties from the 1990s and 2020s.

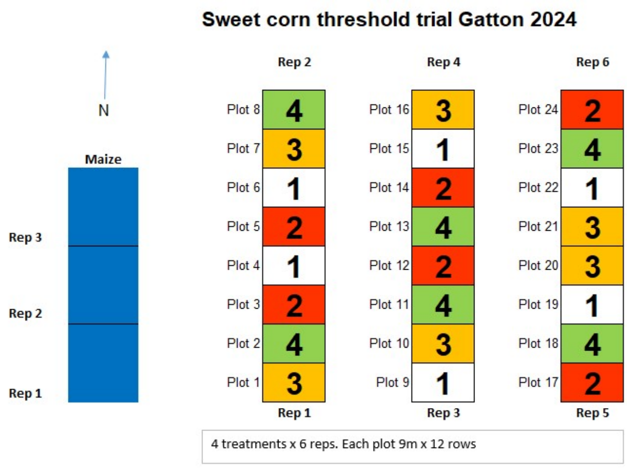
In Australia, sweet corn crops are grown in 60-100 days, with the vegetative (pre-tasselling) stage making up most of the crop duration at 40-60 days. Fresh harvest occurs approximately 21 days post tassel. Numerically, the majority of insecticide treatments targeting FAW are applied in the vegetative stage, but treatment frequency can increase from tassel to harvest to minimise damage to developing cobs. Frequent insecticide application is incompatible with an integrated pest management (IPM) approach that is inclusive of natural enemies (e.g. predators, egg and larval parasitoids) as many of the widely used insecticides are highly toxic to natural enemies. Tolerating crop damage in the vegetative crop stage, provided it doesn't impact negatively on yield and quality, is one way that growers can potentially reduce the frequency of insecticide use. For this to be an option for growers, we need to quantify the impact of defoliation on sweet corn growth rate and yield (cob size, % grain fill, weight) and provide clear guidelines for the effective monitoring of crops.

The development of economic thresholds for FAW is a high priority for the grains industry, with a focus on providing clear management advice for sorghum and maize. GRDC and QDPI have invested in R&D (DAQ2407 in conjunction with UQ and Cesar Australia) to develop economic thresholds for managing infestations in the vegetative stages of maize and sorghum growth. In these crops, reduction in canopy size is the major driver of yield loss caused by FAW. This research uses empirically derived crop loss values along with the APSIM sorghum and maize crop models to enable growers to obtain an estimate of potential yield loss (for a given FAW density and crop stage) for crops grown anywhere in Australia.

We could not find a comparable sweet corn crop model so we designed the trial to include a maize comparison with a view to calibrating the sweet corn crop growth parameters with maize to determine if the maize model was a useful proxy.

Methodology

A replicated field trial was established at the Gatton Research Station on 12 January 2024. The variety Garrison (Syngenta Vegetable Seeds Australia, fresh market, 79 days to maturity) was planted and the trial fully irrigated with subsurface drip. The trial layout and treatments are presented in Figure 1.



Treatment	Spray applied to control FAW	Exposure to FAW feeding
1	V2, V4, V6, V8, V10 to harvest	Nil - treated control
2	V2, V8, V10 to harvest	V6 to V8
3	V2, V10 & V12 to harvest	V6 to V10
4	V2, V4, V10 to harvest	V8 to V10
Maize 1467	V2, V4, V6, V8, V10 to harvest	Nil - maize standard

Figure 1. Sweet corn threshold evaluation trial design and treatments. Gatton Research Station. January – April 2024.

The development of economic thresholds for FAW is a high priority for the grains industry, with a focus on providing clear management advice for sorghum and maize. GRDC and QDPI have invested in R&D (DAQ2407 in conjunction with UQ and Cesar Australia) to develop economic thresholds for managing infestations in the vegetative stages of maize and sorghum growth. In these crops, reduction in canopy size is the major driver of yield loss caused by FAW. This research uses empirically derived crop loss values along with the APSIM sorghum and maize

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We could not find a comparable sweet corn crop model so we designed the trial to include a maize comparison with a view to calibrating the sweet corn crop growth parameters with maize to determine if the maize model was a useful proxy.

As the impacts on the sweet corn were so significant, the APSIM modelling was not pursued. The data for the maize plots are not presented as the analysis of FAW impact is made across the sweet corn treatments.

FAW infestations were managed with the application of insecticide where exclusion of FAW was required. The first spray was applied at V2 (19 Jan) and V4 (25 Jan) to ensure trial establishment and minimise early plant damage. Subsequently, plots were sprayed to exclude FAW (control) and terminate an infestation at the conclusion of the infestation period (V6-8, V8-10 treatments). From V10, all plots were sprayed weekly to minimise FAW infestation so that the impact of vegetative stage damage could be assessed at harvest without further infestation of cobs. This strategy was used to effectively manage infestations of FAW in maize and sorghum threshold development trials. Insecticide applications were applied with a commercial air-assisted boom. Weekly applications of insecticide were applied to the control treatment for the duration of the trial. It is important to recognise that this management strategy is not proposed for commercial management of FAW in sweet corn, it is technique for manipulating infestations in a research context.

Canopy size (light interception) was assessed using a Ceptometer on 29 February when the crop was at early silking and maximum canopy.

Two harvests were undertaken to evaluate the impact of the treatments on the 1) fresh harvest of 8 plants per plot to assess cob size, weight and quality/damage (14 Mar, 3 week post first silk) and 2) harvest at maturity (15 plants per plot) to assess biomass and fertility in line with the methodology for maize and sorghum (10 April).

For the duration of the trial, whilst treatments were exposed to FAW, assessments of FAW egg and larval densities were conducted weekly.

Unless stated, treatment differences were determined by one or two-way ANOVA with post hoc separation of means by Fischer’s protected LSD (p=0.05). Where necessary, data were transformed before analysis.

Results

Threshold evaluation trial on 1 February 2024 at 2 weeks post emergence (approximately V6). The impact of FAW infestation on the canopy of the treatments is evident. Dark green plots visible where the treated controls and V8-V10 treatments are protected from FAW whilst the treatments exposed from V6 have reduced canopy caused by defoliation (Figure 2).

Figure 2. Aerial photograph of the sweet corn FAW impact evaluation trial site at the Gatton Research Station. Image taken on 1 February when the crop was at V6. Dark green plots have greater canopy cover and lower levels of defoliation. Photo: Adam Quade, QDPI.

FAW infestation levels

Late summer 2024 (Dec-Mar) was characterised by extremely high FAW activity in the Lockyer Valley (Gatton). For the duration of the trial damaging densities of FAW were recorded. Data for FAW infestation, egg masses (indicative of FAW moth activity and potential larval recruitment) and 5th+6th instar larvae (the cohort that causes the majority of crop damage) are presented (Figure 3). The density of damaging FAW larvae was effectively minimised in the treated control (Control) throughout the trial.

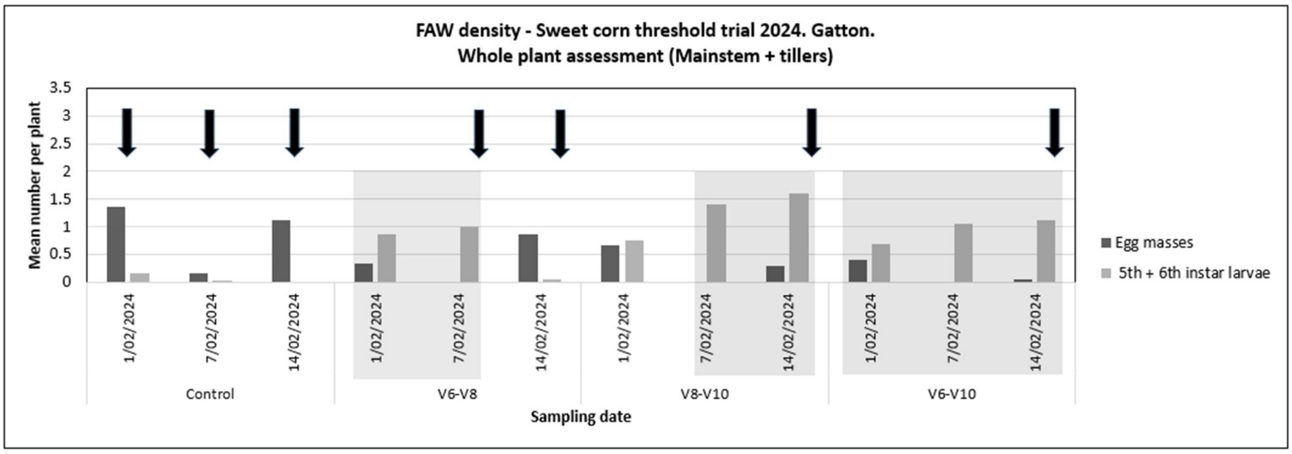

Figure 3. Mean FAW egg and large larva density per plant recorded for the duration of the trial (vegetative stages). The shaded boxes show the period of exposure to FAW infestation for each treatment. The black arrows show the timing of insecticide applications during the vegetative stages. From 14/2 weekly insecticide applications were made up to harvest. Vx = crop growth stage describing the number of fully expanded leaves. The trial was at V6 on 1/2/2024, V8 on 7/2/2024 and V10 on 14/2/2024.

The density of large larvae (5th and 6th instar) were consistently around 0.5 to 1 larva per plant for the duration of the trial, reaching a maximum of 1.5 larvae per plant. Whilst these densities sound low, the cumulative impact of a persistent infestation is what makes FAW so damaging in terms of plant development and prevents plant recovery and compensation for earlier damage. This is a very different scenario to infestations of other defoliating pest species (e.g. helicoverpa, cluster caterpillar) that typically have a discrete period of infestation but do not persist beyond one generation.

Canopy size

Significant reductions in canopy, compared with the treated control, were measured in all FAW treatments at silking when maximum canopy size is expected (Table 1). If the control represents the maximum canopy, then the canopy reduction resulting from FAW direct feeding + the impact of this defoliation on crop growth ranged from 28-57%. These large impacts show just how limited the capacity of this sweet corn crop was to compensate or recover from the FAW infestation.

Table 1. Mean light interception (back transformed for presentation) at silking to quantify the impact of exposure to, and recovery from, FAW defoliation during the vegetative stages of growth. $F=129$, $df=(3, 39)$, $p<0.001$. Means followed by the same letter are not significantly different.

Treatment	Light interception (%) at silking	Reduction on control (%)
Treated control	13.2 a	
V6-V8	41.2 b	28.0
V8-V10	61.6 c	48.4
V6-V10	70.2 c	57.0

Fresh harvest

Fresh harvest of cobs determines how the treatments affect the yield of marketable cobs. Defoliation reduces canopy size and impacts the plant's ability to realise yield potential. What was observed, and measured, was a significant impact on the yield and quality of cobs even when exposed to the shortest period of FAW defoliation at early crop stages, V6-V8 (duration equal to the period to expand 2 leaves = approximately 1 week of infestation and damage). Impacts were greater for the later and more prolonged exposure treatments (V8-V10 and V6-V10). Data was analysed by ANOVA with transformation of data where appropriate and multiple comparisons of means by Fisher's protected LSD test (Table 2).

Table 2. Impact of FAW infestations on harvestability and marketability measures in sweet corn in response to exposure at different growth stages and durations. Means followed by the same letter are not significantly different (within column). Vx = vegetative growth stage where x= number of fully expanded leaves.

Treatment	**Cob weight (g) (% of control)**	**Cob length (cm) (% of control)**	**Filled length (cm)* (% of control)**	**Cob height from ground (cm)**
Treated Control	127.0 a	14.1 a	14.2 a	49.83 a
V6-V8	80.4 b (63)	11.8 b (83)	10.3 b (72)	25.7 b
V6-V10	39.2 c (30)	7.7 c (54)	7.9 c (55)	18.92 c
V8-V10	29.8 c (23)	6.3 d (44)	7.2 c (50)	14.99 d
	F =108, df=(3, 382), p<0.001	F= 52.5, df=(3, 382) p<0.001	*means back transformed for presentation. F=51.9, df=(3, 309) p<0.001	F=300, df=(3, 314) p<0.001

These data show that by all measures, treatments with FAW exposure suffered significant decreases marketability and harvestability compared with the treated control. Exposure to FAW resulted in major impacts (30-70% reductions) in cob weight, length and filled length compared with the control. The more prolonged and later exposure to FAW, the greater the negative impact. This finding is consistent with the literature that describes greater impacts with damage at late vegetative stages (Marenco *et al.* 1992). Whilst failure to set and fill kernels all the way to the tip of the cob is often considered to be a result of poor pollination, perhaps because of silk damage by larvae. In our trial the FAW infestation was controlled from tassel (V10) so FAW did not damage tassels (pollen) or silks and contribute to poor pollination. Cobs in the FAW treatments failed to fill because the plants had insufficient resources to yield. Assessment of cob height was suggested by a sweet corn farm agronomist who visited the trial prior to harvest. The agronomist indicated that cobs lower than 30 cm above ground height could not be picked mechanically, and in their system were unharvestable, contributing to lost yield. All treatments, with exception of the treated control, set cobs below 30 cm.

The physical appearance of the different treatments at the time of the fresh harvest is illustrated in Figure 4.

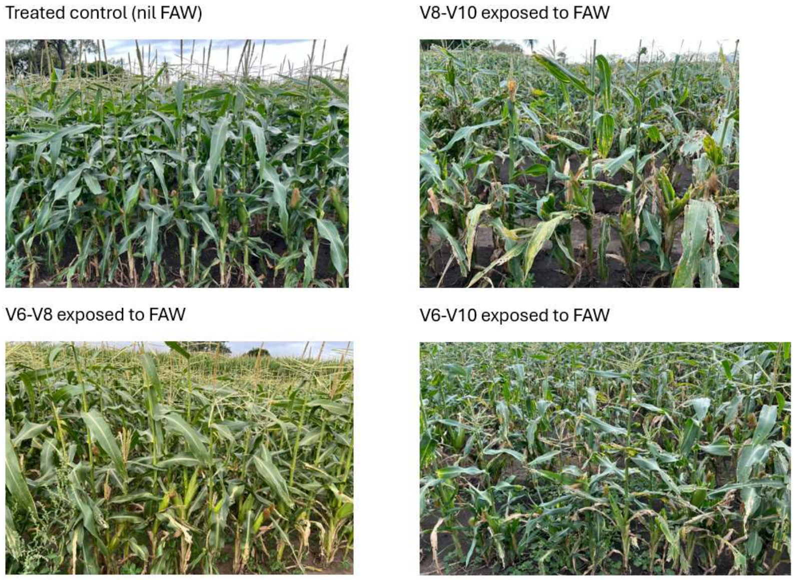

Figure 4. Representative areas of each of the treatments at the time of the fresh harvest on 14 March, 2024. The comparative level of damage and canopy reduction are evident. Photographer: Melina Miles, QDPI.

Maturity harvest

At maturity there is an opportunity to harvest the whole plant and examine the components of yield (biomass, effective stems) and understand how the treatments have impacted growth.

The results show that exposure to FAW significantly and negatively impacted overall plant biomass (canopy size and plant growth), the fertility of the mainstem and the number of plants with mainstems that were unproductive (Table 3). These data also show differences in plant responses to short and longer exposure, as well as time of exposure. For example, exposure from V6-V8 (early) did not result in plants suffering complete mainstem loss. However, a similar duration of exposure at a later crop stage (V8-10) did result in some mainstem loss, but not to the same extent as the longer V6-V10 exposure.

Whole plant biomass data, when considered along with the light interception data (Table 1) reveals that defoliation reduces canopy size, and the overall plant biomass (cumulative weight of stems and leaves). This reflects the impact of both direct (defoliation) and indirect (impact of reduced canopy on growth) that combine to impact the capacity of plants to realise yield potential.

Table 3. Harvest at physiological maturity revealed the extent of the impact of exposure to FAW on plant growth (biomass, mainstem loss) and the realisation of yield potential (infertility of cobs or no cobs set on the plant). Treatment means followed by the same letter are not significantly different (within columns).

Treatment	**Complete loss of mainstem (mean number per 15 plants)**	**Mean number of unproductive mainstems per 15 plants**	**Mean Whole plant biomass (dry weight g/plant)* (% of control)**
Treated Control	0 a	1.3 a	1433 a
V6-V8	0 a	3.0 a	730 b (50)
V8-V10	0.7 a	3.3 ab	491 c (34)
V6-V10	1.8 b	5.7 b	333 d (23)
	F=6.33, df=(3, 23) p=0.003	F=4.1, df= (3, 23) p=0.021	*means back transformed for presentation. F=96.7, df=(3, 23) p<0.001

Figure 5. Sweet corn plant so severely impacted by a persistent FAW infestation that the mainstem has failed to produce a cob. Photographer: Melina Miles, QDPI.

Discussion

At the outset of this trial, it seemed logical that sweet corn, like maize, would be tolerant of at least some FAW feeding damage in at least the early – mid vegetative stages. If a damage threshold could then be quantified it would create opportunities for growers to reduce the frequency of spraying in vegetative crops when if infestations of FAW fell below the threshold.

The indirect impacts of FAW infestation on harvestability and marketability of the crop were major, with 30-70% reduction in cob weight, length and filled length. It is clear from these results that this widely grown sweet corn variety (Garrison) does not have the capacity/resilience to recover from moderate defoliation in the vegetative stages that results from infestation levels of 0.5-1.5 larvae per plant. Essentially, this potential impact demands a zero tolerance for FAW infestation in sweet corn.

Based on these trial outcomes, an economic threshold for vegetative crop stages for sweetcorn growers managing moderate to high FAW infestation levels is not feasible at this time, at least for the widely grown variety Garrison. There may be value in establishing damage thresholds for growers in regions where FAW infestations are low, with the view to providing empirical evidence to guide crop monitoring and management (e.g. Sydney Basin, Central west NSW, Riverina).

Guidelines for low-level FAW infestations would be applicable in more northern regions in periods/seasons when FAW are less active.

When a sweetcorn crop can be negatively impacted in a way that impacts yield potential with exposure to FAW for just 1 week, there is no infestation level that can be tolerated. The margin for error with management decisions, monitoring and treating potentially damaging infestations, would be so slight that crop managers would likely resort to spraying rather than taking the risk of significant crop loss.

It is likely that the frequent application of insecticides in sweet corn crops has become established practice through experience with FAW infestations, reinforcing for crop managers that the most reliable management tactic is to tolerate very little, if any, FAW regardless of crop stage.

The susceptibility of sweetcorn to FAW is in large part a result of growing varieties that have short maturity/days to harvest, which leaves little capacity/time to compensate for early canopy loss. A comparison of maize, sorghum and sweet corn recovery post infestation is illustrated in Figure 6.

Our trial was conducted with the variety Garrison, widely grown for the fresh market. It is possible that there is some variation in the resilience of across the suite of varieties available to growers. Anecdotally, growers have not identified alternate varieties currently available that are more resilient to FAW impacts (discussions with growers and agronomists as part of VG22006 activities). There may be value in evaluating the relative impact of FAW on a range of sweet corn varieties, but there is nothing in the peer-reviewed or industry literature overseas that indicates there are significant differences in the susceptibility of available varieties. Considerable research effort has been invested in identifying host plant resistance (HPR) to FAW in maize (Prasanna *et al.* 2022). If HPR is pursued for sweet corn, then this maize work will provide a sound basis and possibly germplasm for integration into sweet corn breeding programs. In the US, genetically modified sweet corn, Bt hybrids, are commercially available (e.g. Syngenta Vegetable seeds US [Vegetable seeds | Syngenta Vegetable Seeds US]). Early research on Bt hybrids demonstrated a useful level of protection from FAW (Lynch *et al.* 1999). Regulation and consumer acceptance are potential barriers to the deployment of transgenic sweet corn in Australia. HPR does not face these same hurdles.

Conclusions and recommendations

The variety evaluated (Garrison) had suffered significant reduction in harvestability, yield and marketability when exposed to canopy loss resulting from moderate to high FAW infestations. Sweet corn exhibits little capacity to recover from the damage caused in the vegetative stage by even moderate FAW infestation.

The zero-tolerance approach to FAW infestation currently employed in sweet corn production in regions with moderate to high FAW activity is appropriate to manage the risk of significant crop loss. This situation creates challenges for the implementation of IPM in sweet corn and increases the risk of insecticide resistance development.

Without increased plant resilience to defoliation by FAW, an economic threshold is not a useful management tool in regions where moderate to high FAW activity is experienced. Grower experience, and the results of this trial, show that the threshold is effectively zero.

There would be value in empirical research that provides clear guidelines to assists growers in identifying levels of defoliation/infestation that will not result in economic loss for regions where FAW activity is low, well below the sustained 0.5-1.5 larvae per plant that caused significant loss in our trial. Such a guide would increase the confidence of growers and their advisors to reduce the application of insecticides to crops where there is defoliation at levels that pose no risk of loss. This information has application in regions, and seasons when FAW infestations are low, sporadic and patchy. Research to support efficient and reliable crop monitoring strategies for FAW should go hand in hand with the development of guidelines based on assessing FAW populations and/or damage.

Whilst a program of screening currently available varieties to determine relative tolerance to FAW is appealing, unless the varieties have been developed with FAW tolerance/resistance in mind it is unlikely that there will be useful differences in currently available commercial hybrids. Anecdotally, growers are not seeing useful differences in the varieties they grow. The introduction of germplasm that reduce susceptibility to FAW by Australian breeders should be encouraged and may already be underway (e.g. importing FAW HPR maize lines to cross with sweet corn lines).

Figure 6. Comparison of the recovery capacity of maize (left), sweetcorn (centre) and sorghum (right) exposed to the same FAW population for the same duration. Infestation levels were very similar in the maize and sweetcorn, and a little lower in sorghum. Once the infestations were controlled, both the maize and sorghum grew rapidly, but the sweetcorn did not respond, and the plants remained stunted with a small canopy despite adequate water, nutrition and temperatures for growth to resume.

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Appendix 2. IPM demonstration trial report. Gatton 2024.

Melina Miles, Adam Quade. QDPI.

Background

Agricultural production typically creates environments that are unfavourable to the establishment and persistence of natural enemies, and consequently their capacity to impact crop pests. The concept of habitat manipulation or management to increase the level of biological control is described by Landis *et al* (2000). They describe the provision of resources such as hosts, food and shelter for the adult natural enemies in a way that spatially and temporally favours them and is practicable for farmers to implement. Buckwheat (*Fagopyrum esculentum*) has been widely studied as a floral resource for natural enemies, providing nectar, pollen and hosts for a range of species. Buckwheat grown as a floral resource within or beside crops has been shown to increase the longevity and fecundity of specific parasitoids and increase parasitism rates (Lee & Heimpel 2008). However, the addition of such resources does not always deliver benefits in terms of crop yield or increased in-crop biocontrol (Lavandero *et al.* 2006, Quinn *et al.* 2017). Recently, Thurman & Furlong (2024) found that where buckwheat strips were paired with green bean (*Phaseolus vulgaris* L.) in the Lockyer Valley in Queensland, pest control costs declined, but they did not find higher densities of natural enemies in the crops with buckwheat strips. crop. They suggest that rather than increasing natural enemy abundance, the buckwheat was supporting the natural enemy populations in the crop.

Since 2020, surveys of natural enemies impacting Fall armyworm in Australia (Subramanium 2022, Fagan-Jefferies *et al.* 2024, Tadle *et al.* 2025) have identified a suite of species that could contribute to the biocontrol of FAW. With this knowledge we make the first attempt to introduce buckwheat as a floral resource and refuge for parasitoids and other natural enemies in the sweet corn production context.

The demonstration approach constrains the research but is critical in raising grower awareness of non-chemical options in an environment where they are almost totally reliant on insecticides currently. The purpose of these trials is not to devise solutions for growers with the expectation that they will simply adopt them. Rather it is to introduce the concept of diversifying their cropping environment as worthy of consideration and to provide the opportunity for growers and agronomists to assess the practicality of the tactic for themselves.

Methodology

A buckwheat plot (12 m x 50 m) was centrally located in the trial field and was sown a month before the sweetcorn blocks were planted. Buckwheat and sweet corn (variety Garrison, Syngenta) were irrigated throughout the trial (Figure 1).

Collections of egg masses were made at each field assessment. These egg masses were cultured individually in the laboratory until either FAW larvae or parasitoids emerged.

Releases of *Trichogramma pretiosum* were made on 15, 20, 27 March and 3 & 9 April, late in the trial (tasselling) because of supply issues with the commercial production. These releases were at a high release rate (180,000 wasps/ha).

Regular monitoring of the sweetcorn (visual) and the buckwheat (sweep net/suction sampler) to provide data on FAW infestations, natural enemy activity (egg parasitism, predator numbers and efficacy of insecticide applications).

In response to the high FAW pressure, the sweet corn blocks in the trial were sprayed 6 times, approximately weekly to avoid catastrophic damage to the trial (Table 1).

Table 1. Spray program applied to the trial to prevent catastrophic crop loss.

Date	**Active applied**
14 Feb	spinetoram
26 Feb	Emamectin benzoate
1 Mar	spinetoram
4 Mar	chlorantraniliprole
12 Mar	Spinetoram
19 Mar	Emamectin benzoate
4 Apr	spinetoram

In line with commercial practice, a fresh harvest was done on 15 April to assess yield and quality of the crop (8 x 10 (total 80) plants per plot). Cobs were assessed for harvestability damage and overall marketability.

A basic economic analysis of inputs and harvest outcomes was conducted.

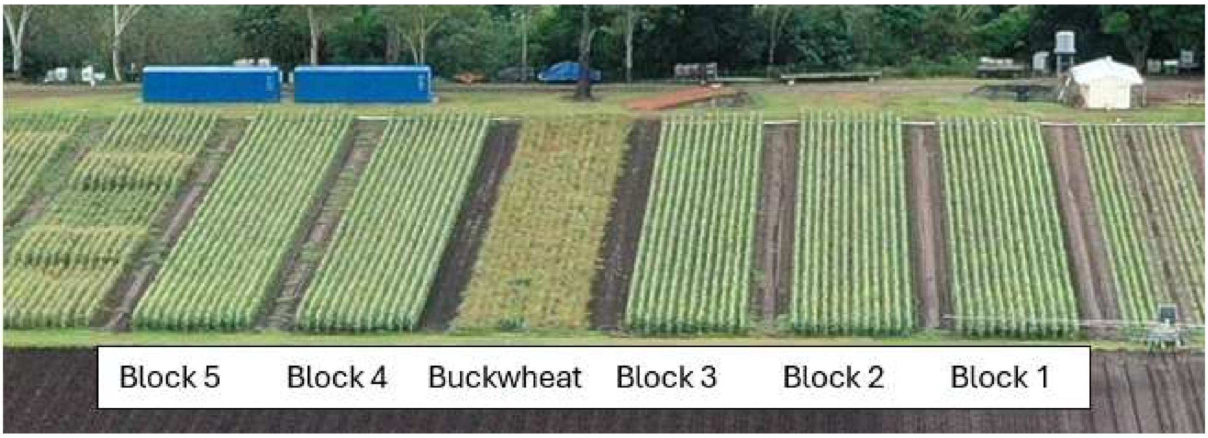

Figure 1. Aerial view of the trial at the Gatton research station. Photographer: Adam Quade, QDPI.

Results and discussion

The timing of the buckwheat planting resulted in this refuge/resource crop flowering from the emergence of the sweet corn through until tasselling, critical periods for crop development and yield formation. As a refuge crop, it performed well in terms of form and function, establishing easily, producing high biomass and being long flowering (Figures 2 and 3).

Figure 2. Left: Flowering buckwheat strip in the centre of the sweetcorn trial early Feb 2024. Right: The buckwheat showing the abundance of flowers and high biomass refuge. Photographer: Melina Miles, QDPI

The buckwheat hosted a diversity of species, including parasitoids, predators, pollinators and few pest species (Figure 3). Sweep and suction sampling is likely to facilitate the collection of 'flighty' groups like flies and wasps, compared with the visual sampling conducted in the sweet corn crop. Fly numbers, for example, peaked in the buckwheat during flowering but a corresponding increase in fly numbers was not observed in the sweet corn. Predatory bugs were the most abundant natural enemy in the sweet corn e.g. pirate bug (*Orius* sp) and the mirid *Tytthus* sp., and were also present in the buckwheat throughout the trial. Spiders were abundant in both the buckwheat and the sweet corn, but not at the same time. Spiders were largely absent from the sweet corn until the buckwheat had finished flowering and was scenescing (Figure 4). This does not necessarily imply that the spiders moved from the buckwheat to the sweet corn when the buckwheat scenesced. It is possible that the spiders we sampled were able to establish only when there was adequate 'cover' in the crop to host them. It is also possible that the spiders active in the sweet corn were nocturnal and/or easily disturbed from the plants and not visible in the crop during the day when sampling was conducted. *Trichogramma* and *Chelonus* egg parasitoids were observed in association with FAW egg masses when undertaking visual assessments.

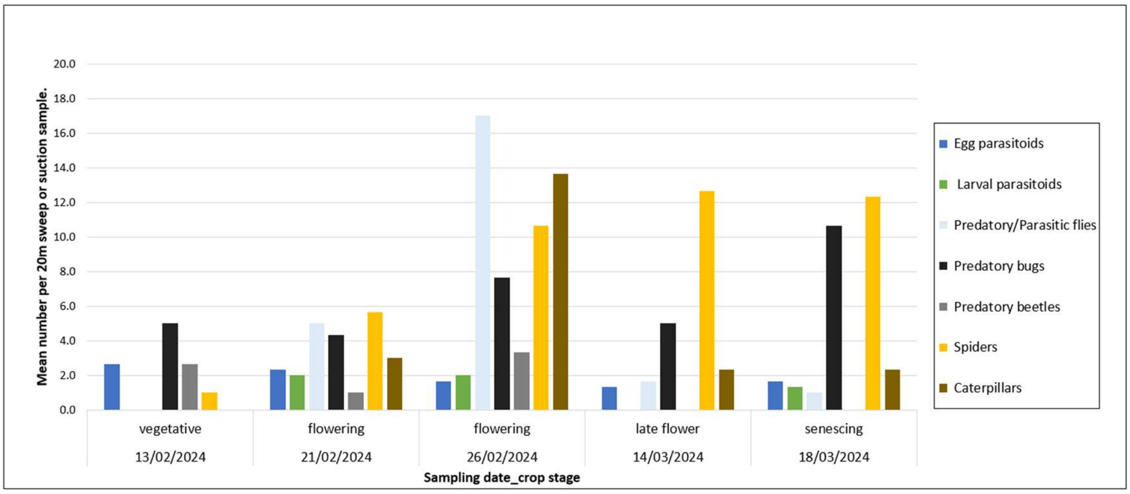

Figure 3. Invertebrate abundance in the buckwheat strip over 35 days, February – March 2024. The buckwheat strip supported a diversity of predators, parasitoids and pollinators over an extended period, coinciding with emergence – tasselling of the sweet corn.

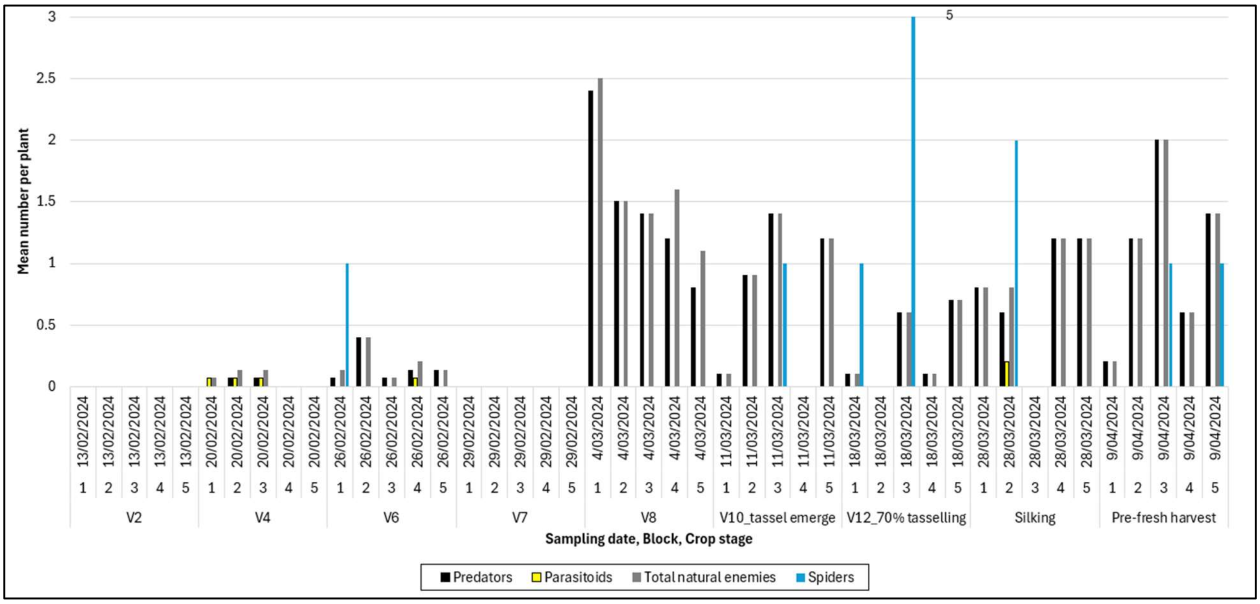

Figure 4. Predatory bugs were the most frequently recorded natural enemy in the sweet corn crop, particularly the pirate bug (*Orius* sp) and a predatory mirid, *Tytthus sp*. Parasitoid numbers are underestimated by visual crop inspections as they are highly mobile and easily disturbed, and potentially active at night. *Chelonus* sp and *Trichogramma* were observed parasitising egg masses in the field during daytime sampling. Spider abundance increased from tasselling.

The sweet corn blocks in the trial had very high egg and larval pressure throughout the growing season (Figure 5).

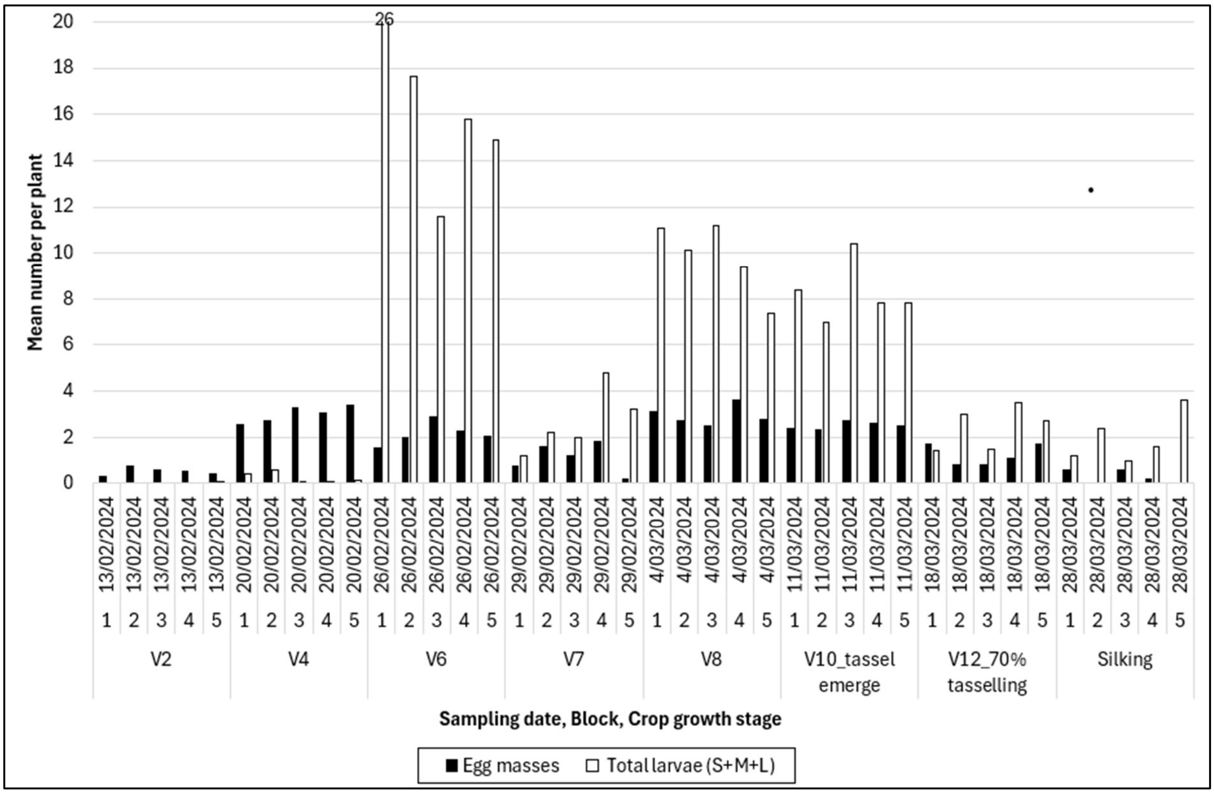

Figure 5. Fall armyworm egg and larval density in all blocks (1-5) were high for the duration of the vegetative crop stages with egg numbers only declining once the crop commenced tasselling. V2 – V8 are vegetative crop stages where Vx, x= number of fully expanded leaves. Assessments made at weekly intervals.

Over 5 sampling occasions, a total of 435 viable egg masses were collected and cultured in the laboratory until wasps emerged. *Trichogramma pretiosum* was the dominant egg parasitoid observed in the trial. A low level of *Telenomus* sp. was observed towards the end of the trial and did not exceed 6% of collected egg masses. We are missing the contribution of *Chelonus* sp to FAW mortality because we do not have reliable methods for determining the level of *Chelonus* sp parasitism of eggs. *Chelonus* sp are egg-larval parasitoids that lay their eggs into FAW eggs, but do not kill the larva until it reaches 2nd-3rd instar. In our current screening protocols, if FAW larvae emerge from egg masses, we record them as unparasitized. *Chelonus* sp is one of the most common parasitoids recorded from field collections of small FAW larvae, and females are often observed ovipositing into egg masses in the field.

Predominantly, where parasitism was recorded, the entire egg mass was parasitized. The percentage of egg masses were only partially parasitized (both FAW larvae and parasitoids emerged) ranged from 2-25% of egg masses (Figure 6). For the duration of the trial, parasitism by *T. pretiosum* ranged from 20-60% of collected egg masses. These results clearly demonstrate that *T. pretiosum* is an effective parasitoid of FAW, and that in most instances parasitises the entire egg mass. It is important to note that these levels of parasitism were achieved in a crop where egg densities were historically very high; consistently 0.5 – 3 egg masses per plant for the duration of the trial. The activity of the parasitoids also persisted in crops sprayed with insecticides six times between 14 Feb and 19 April, the period over which egg parasitism was assessed.

These findings challenge the perception of growers and agronomists that *Trichogramma* is relatively ineffective against FAW and that the scale covering and stacked arrangement of eggs in FAW egg masses reduce the effectiveness of this species. The levels of egg parasitism recorded in this trial were largely the result of natural infestations, the releases of commercially produced material not occurring until just before the final data point was collected. These results show there is potential to boost the impact of *T. pretiosum* with strategic releases, and this tactic warrants further investigation.

Developing a technique for capturing the contribution of *Chelonus* species, based on egg collections is also warranted.

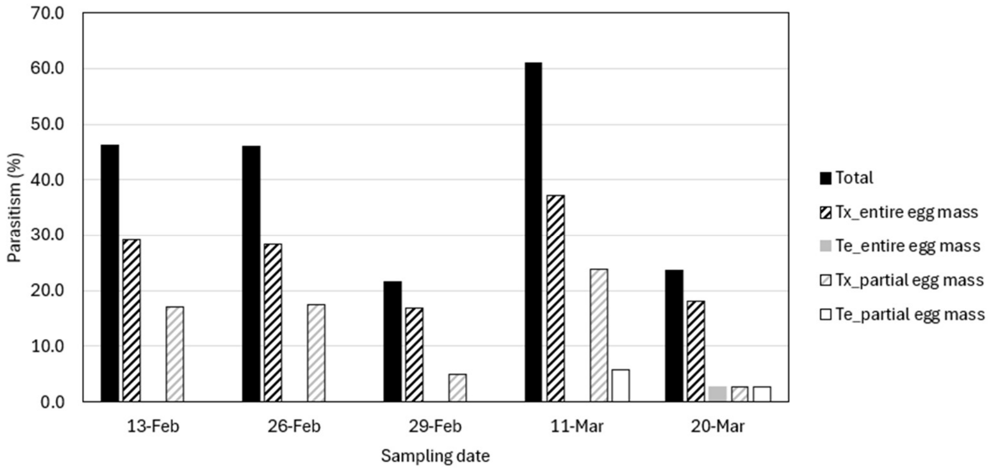

Figure 6. Recorded levels of FAW egg parasitism across the trial. *Trichogramma pretiosum* was the most frequently recorded egg parasitoid. Tx = *Trichogramma pretiosum*, Te = *Telenomus* sp.

No significant differences were observed across the blocks in cob height above the ground, primary cob weight, and the number of marketable cobs (filled an undamaged) per plant (Table 2). There was a significant difference in the number of delayed + undeveloped cobs per plant (Table 2), which is typically a function of reduced canopy size impacting the plants' capacity to fill cobs, or damage to silks impacting pollination. However, the differences between plots are not consistent with being influenced by the presence of the buckwheat refuge, but rather a gradient across the field, the cause of which is unclear and more probably environmental or agronomic.

Table 2. At harvest, key harvestability and marketability factors were assessed for each of the blocks. No significant differences were observed across the blocks, except for the delayed and undeveloped cob factor, which is inconsistent with the influence of the refuge, and cause unclear. The buckwheat strip was between blocks 3 and 4, highlighted with grey shading in the table.

Block	**Cob height (cm)**	**Primary cob weight (g)**	**Number of delayed+undeveloped cobs per plant***	**Filled and undamaged cobs per plant (%)** n=80
1	31.9 ± 0.71 a	112.6 ± 5.5 a	0.07 ± 0.03 a	72.5 ± 0.05 a
2	32.1 ± 0.73 a	113.5 ± 5.7 a	0.15 ± 0.04 ab	78.8 ± 0.46 a
3	32.5 ± 0.74 a	116.9 ± 5.8 a	0.23 ± 0.04 bc	67.5 ± 0.05 a
4	34.5 ± 0.73 a	125.3 ± 5.6 a	0.48 ± 0.06 d	62.5 ± 0.05 a
5	33.0 ± 0.79 a	118.7 ± 6.1 a	0.36 ± 0.06 dc	62.5 ± 0.05 a
	F=2.02, df=(4, 312), p=0.09	F=0.81, df=(4, 312), p=0.52	F=11.1, df=(4, 399), p <0.001.	F=1.8, df=(4, 399), p=0.12

*analysis on square root transformed data, back transformed means presented.

Economics of the IPM demonstration trial

The two key IPM tactics in the Gatton trial were regular releases of the egg parasitoid *Trichogramma*, and buckwheat refuge/resource for natural enemies.

There is clear evidence for *Trichogramma* as an effective parasitoid of FAW from the trial with parasitism levels of between 20 and 50% of egg masses during the period of wasp releases. Five releases were made at weekly intervals between from tassel emergence. A high release rate (180,000 wasps/ha) was adopted to ensure evidence of parasitism would be evident. This release rate is within the range recommended by the supplier (Bugs for Bugs) for sweet corn under high lepidoptera pressure (up to 200,000 wasps/ha). The cost of each release at this rate was $171/ha ($57/60,000 wasps).

The buckwheat was planted 25 days prior to the sweet corn and was flowering from sweet corn emergence to tasseling – a period of around 4 weeks. Costs associated with establishing and maintaining the buckwheat strip were:

- The earlier establishment required 3 additional irrigations of the buckwheat prior to the sweet corn being planted.
- Buckwheat was sown at a rate of 50kg/ha. Seed cost was $5.50 per kg, so $275/ha on 75 cm rows. It may be possible to reduce the amount of seed sown to 30-40 kg/ha.
- No additional nitrogen, fungicide or insecticides were required for the establishment and maintenance of the buckwheat over and above what would have been incurred had sweet corn been planted.
- Clearly there was an opportunity cost of planting buckwheat in place of sweet corn. This cost is equivalent to the gross margin per unit area planted to buckwheat. The precise cost of this is not calculated as it is too early to suggest the frequency of buckwheat in the sweet corn production blocks to provide benefit. It is also difficult to get estimates of the return of sweet corn from growers as these figures are commercial-in-confidence. The opportunity cost could potentially be reduced by planting the refuge/natural enemy resource in areas where it does not impact production e.g. inter-row, tractor rows, field edges. These configurations are worthy of consideration in evaluating the cost:benefit of this component.
- Additional potential benefits of including buckwheat in the production system are weed

suppression, increased organic matter and if managed as a green manure reduces the weediness that can result from seed set.

- There are potential risks posed by buckwheat such as hosting the root lesion nematode (*Pratylechus* sp) and weediness resulting from prolific seed set; appropriate agronomy and management can mitigate these risks.

Industry feedback at field walks

Growers and agronomists who inspected the trial were generally impressed with how prolifically the buckwheat was flowering, making the connection between the floral resource and potential benefits for pollinators and natural enemies. We did not record pollinators specifically in our sampling, but this was of interest to growers and agronomists. There was interest in how it could more practically be incorporated into their current cropping program, commenting that they would rather see smaller areas of buckwheat at more regular intervals across the farm than the large block we had in the trial. Agronomists were interested in the diversity of natural enemies we recorded as their monitoring practices typically don't allow them to sample crops so intensively. Monitoring egg parasitism levels is something that was discussed as requiring more time than they could justify – collecting eggs, holding them for a few days to assess for hatching or parasitism.

Conclusions and recommendations

The purpose of the trial was to generate data to stimulate grower interest in, and discussion around, the role of natural enemies in managing FAW in sweet corn. The establishment of demonstration trials provided growers and agronomists with the opportunity to see buckwheat in the field and consider if and how they might provide refuges and/or floral resources for natural enemies on their farms.

The stand out finding from this trial is the potential of the egg parasitoid *Trichogramma pretiosum* to contribute to the suppression of FAW in sweet corn. The persistently high levels of parasitism (20-60% of egg masses at densities of 0.5-3 egg masses per plant) challenges the perception of many growers and agronomists that T. *pretiosum* cannot effectively parasitise FAW eggs. These parasitoid populations were naturally generated at the Gatton trial site, adding weight to the idea that refuges and floral resources play an important role in sweet corn production systems. Further investigation into the benefits of strategic releases of *T. pretiosum* and floral resources is warranted. In addition, practical methods for growers and agronomists to assess egg (and larval) parasitism would be a valuable addition to routine crop monitoring.

This trial did not demonstrate significant yield or quality increases arising from the inclusion of buckwheat in amongst the sweet corn, nor did it show a significant detrimental impact. Natural enemy populations in the sweet corn closest to the buckwheat did not have higher natural enemy populations, but as suggested by Thurman & Furlong (2024), the buckwheat may be supporting the populations of natural enemies in the crop as they move backward and forwards between this resource and the crop.

Additional outcomes associated with the trial.

In addition to the demonstration trial, the site provided additional opportunities for R, D and E:

- Hosted a UniSQ prototype remote egg parasitoid monitoring device (QDPI – UniSQ collaboration).
- Hosted three key sweetcorn grower/agronomist visits to the threshold and IPM trials to discuss objectives, outcomes and get feedback (in conjunction with VG22006).
- Provided the backdrop for the ABC Landline episode (*Greedy grubs: fighting back against fall armyworm)* aired on 5 May 2024.

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Appendix 3. Evaluating a commercial biopesticide option for Fall armyworm (Fawligen (*Spodoptera frugiperda* MNPV), AgBitech).

Melina Miles, Adam Quade, John Stanley (QDPI).

Background

One of the non-chemical options that is both compatible with integrated pest management (IPM) and insecticide resistance management is biologicals. Biologicals are typically insect pathogens (viruses, fungi, bacteria) that kill target species. Australia has a reasonably long history of biologicals, including nucleopolyhedrosis virus (NPV) (Buerger *et al*, 2008). NPV has been used for over 20 years for the control of Helicoverpa sp. in sweet corn (Deuter 2009) and sweet corn growers have been using *Spodoptera frugiperda* multiple nucleopolyhedrovirus (SfMNPV) as part of their Fall armyworm (FAW) control program since it became available under permit in 2021. The inclusion of an effective biological in a FAW management program is a sound approach, potentially reducing the frequency with which conventional insecticides are applied; reducing the selection pressure for insecticide resistance and limiting the detrimental impacts of insecticides on natural enemies.

There are two permitted SfMNPV products in Australia, Fawligen® (AgBitech) and SpodovirPlus® (Organic Crop Protectants/Andermatt). They are typically used in sweet corn crops in a mixture with conventional insecticides at the full permitted rate (200 mL/ha), at a cost of approximately $40/ha (in the case of Fawligen). Grower and agronomist perception is that it "does something".

However, despite the widespread use, there has been little evaluation of the efficacy of SfMNPV in sweet corn systems. QDPI has conducted several laboratory bioassays and field evaluations of SfMNPV in maize. In summary, these trials have shown good efficacy against small (1st-2nd instar) larvae in laboratory bioassays, with efficacy declining rapidly when targeted against older larvae. In the field, trials have shown poor acquisition (infection of susceptible larvae) and poor overall control, even with repeated applications (up to 3 applications), and the addition of recommended adjuvents e.g. Optimol®(AgBitech). Trials show no significant difference in the resulting crop damage incurred in the SfMNPV treatments and the untreated control (QDPI unpublished data, 2025). In the side-by-side evaluations of SpodovirPlus® and Fawligen® the QDPI trials showed no significant difference in efficacy of the two products.

Growers and agronomists participating in the Bowen-Burdekin and Lockyer Valley FAW AWM group meetings (VG22006) were curious about the value of including the SfMNPV in their spray program, and in options that might increase the efficacy of the product e.g. repeated applications, timing of application and the perceived advantage that application by overhead irrigation might have.

The trial results reported here address the first two questions: i) Does applying SfMNPV in the evening, to be available in the crop at night when FAW larvae are most active, increase the efficacy compared with application in the morning, and ii) Is a strategy of consecutive repeated applications of SfMNPV a more effective way to deploy NPV to control FAW. An increased understanding of how effective SfMNPV is will provide growers with the confidence to use it, or to remove it from their program if it is ineffective.

Materials and methods

Trial 1: Time of application of SfMNPV.

This trial was conducted at the Bowen research station in November 2023 (Table 1).

Sweet corn was established under irrigation in mid-October. On 7 November, the trial was at V6-V7 crop stage and was assessed to have an established infestation suitable for the evaluation of NPV. The mean total across all instars = 11/larvae per plant, 60% of these larvae at a stage susceptible to SfMNPV (neonate, 1^{st}, 2^{nd} and 3^{rd} instar) based on previous QDPI evaluation.

The trial design was randomised with 3 treatments:

1) untreated control (x 6 reps),

2) SfMNPV treated at 6 pm 7/11 (x5 reps),

3) SfMNPV treated at 8 am 8/11 (x5 reps).

Plots were 14.5 m long and 16 rows wide.

Fawligen (SfMNPV, AgBitech) was applied with a hand boom at the permitted rate of 200 mL/ha + 1L/h Optimol with a water rate of 300 L/ha. These rates mirror commercial practice in sweet corn.

The trial was assessed as follows:

i) Pre-treatment egg – larval density assessment (-1 DAT*). Crop at V¥6-V7.
ii) Pre-treatment larval collection to assess background NPV infection and parasitism
iii) Post-treatment larval collection to assess NPV acquisition and parasitism (2 DAT).
iv) Post-treatment egg – larval density assessment (6 DAT). Crop at V8.
v) Post-treatment egg – larval density assessment (12 DAT). Crop at V9-10.

Destructive sampling of 5 plants per plot was undertaken to establish egg and larval densities. *DAT = days after treatment application, ¥Vx = vegetative crop stage, x = number of expanded leaves present.

The proportion of the susceptible population infected with SfMNPV was assessed on twice on -1 DAT (to establish the baseline infection level pre-treatment) and at 2 DAT to determine the level of NPV acquisition post treatment. Only larvae of a size susceptible to SfMNPV (instars 1-3) were collected. These larvae were collected randomly from all treatment plots across the trial. Collections were maintained individually in the laboratory on artificial diet at 28° C. The fate of the larvae was determined 6 days after collection.

Data were analysed by two way ANOVA with significant treatment means distinguished by post-hoc Fisher's Protected LSD test (P=0.05) (Genstat v24).

Table 1. Summary of the trial activities, crop growth stages, and predicted FAW growth rate (DARABUG2) is provided in Table 1. DAT = days after treatment, Vx = vegetative growth stage where x = number of expanded leaves. The Darabug development rate prediction used temperature data for Bowen from 2000 – 2023.

Date (November)	DAT	Rate of development (Darabug)	Crop stage	Activity
7	-1 DAT	L1		pre-treatment
8	0 DAT		V7	Spray
9	1 DAT	L2		post-treatment collection
10	2 DAT			
11	3 DAT	L3		
12	4 DAT			
13	5 DAT	L4	V8	
14	6 DAT			1st assessment
15	7 DAT	L5		
16	8 DAT			
17	9 DAT	L6	V9	
18	10 DAT			
19	11 DAT			
20	12 DAT	Pupation		2nd assessment

Trial 2: Repeated applications of SfMNPV.

The commercial SfMNPV products allow for 10 applications per crop. This trial was designed to apply NPV alone repeatedly at 4-day intervals up to a maximum of 10 applications, and to compare this approach to a monitoring-guided application of conventional insecticide to manage damaging FAW infestations in the treated control.

The trial plot was planted at the Gatton Research Station in early March and the trial block treated at V2 (spinetoram) to protect the establishing crop prior to the commencement of the trial. The first trial treatment was applied at the V4 crop stage on 21 March (Table 2).

This trial had two treatments:

1) Fawligen at 200 mL/ha + Optimol additive at 1 L/ha,

2) Treated control where insecticides were applied judiciously to prevent major crop loss, but much less intensively than the approach taken in a commercial sweet corn crop. The treatments were applied by commercial boom spray delivering 200 L/ha.

Each treatment was replicated in five times in a randomised complete block design. Plots were 50 m x 16 rows. Treatment and infestation assessment timetable is presented in Table 2.

Table 2. Treatment and trial assessment timetable for repeated Fawligen application trial, Gatton March-April 2025.

Date	Fawligen application	Stage	Treated control applications	FAW infestation & damage assessed
19-Mar				X
21-Mar	1	V4		
25-Mar	2		chlorantraniliprole	
26-Mar				X
30-Mar	3	V6		
4-Apr	4		Spinetoram	X
8-Apr	5	V8		X
11-Apr	6		Spinetoram	
14-Apr	7	V10		
16-Apr				X
17-Apr	8	Tassel emerging		
23-Apr				X

Assessments of damage and FAW density were made on five plants per plot on each assessment date. Damage was assessed using the modified Davis scale rating, where 1= no visible damage and 9= severely impacted plant with no leaf remaining in the whorl. Egg and larval density assessments were made by destructive sampling of whole plants.

The proportion of the susceptible population infected with NPV was assessed on 6 occasions with collected larvae maintained in a constant temperature room on artificial diet until mortality occurred, or they successfully pupated. The number of larvae collected on each occasion varied depending on the abundance of the different instars/size classes of larvae. Larvae were collected randomly from a minimum of 50 plants across the plots with no more than two larvae collected from each plant.

Data were transformed where necessary to normalise and analysed by one way and general ANOVA. Significant treatment means were distinguished by post-hoc Fisher's Protected LSD test (P=0.05) (Genstat v24).

To assess the impact of the SfMNPV treatment, the large larval cohort is assessed because we would not expect these larvae to eventuate in the population if the treatment was effective. Large FAW larvae cause most crop damage, so a practically relevant measure of success is limiting the presence of this cohort in the crop.

Results and discussion

Trial 1. Time of application of SfMNPV

For the duration of the trial, no new egg masses were detected, which means that there was no recruitment of larvae. This simplifies the interpretation of the data in terms of the direct impact of the treatments on survivorship of the susceptible cohort (1-3 instar) to 6 DAT, and then as 4^{th}+ instar larvae to 12 DAT.

No significant differences were observed between treatments ($F=2.43$, df =(2, 239) $p=0.09$ or when all larval cohorts (Total larvae) were examined together. There was no significant treatment difference for small larvae (1^{st}-3^{rd} instar) ($F=2.35$, df=(2, 239) $p=0.08$) or medium – large larvae (4^{th} – 6^{th}) ($F=0.44$, df=(2, 239) $p=0.64$)(Figure 1).

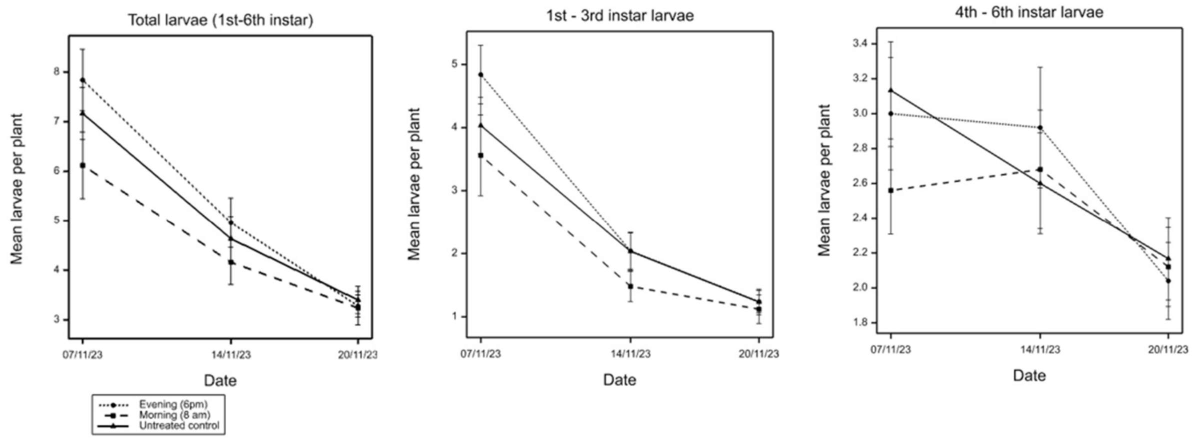

Figure 1. Fall armyworm larval density assessed pre-treatment (7/11. -1 DAT), and post treatment (14/11 = 6 DAT; 20/11 = 12 DAT) for application of SfMNPV in the evening and morning. Results presented for Total larvae (all instars combined), medium- large larvae (4th – 6th instar) and small larvae (1st – 3rd instar) on each assessment date. Error bars are standard error of the mean.

Whilst the total larval count declines over time, there is no significant difference between the SfMNPV treatments and the untreated control. Whilst this result clearly demonstrates the lack of efficacy of the SfMNPV treatments, it also demonstrates that there is no difference in the efficacy of the two the spray timings.

The overriding issue is the efficacy of the SfMNPV; larval survival in the treated plots was the same as that in the untreated. If, in time, there is a more efficacious SfMNPV available commercially there may be value in exploring spray timing as a factor in optimising efficacy.

The level of SfMNPV in field collected larvae was zero in the pre-treatment assessment (Table 3). At 2 DAT acquisition was extremely low, the highest rate of infection was 12% of 1st instar larvae collected. There is insufficient data to analyse, but the data presented in Table 3 suggests that there is little difference between the levels of parasitism observed across the treatments, all being benign in terms of impact on parasitism. The level of parasitism observed across treatments is considerably higher than the level of mortality from SfMNPV; 24-38% parasitism compared to the 2.4-7.4% SfMNPV infection. The most abundant parasitoid identified from these collections was *Chelonus* sp, the egg-larval parasitoid that completes its development in 3rd instar larvae.

This level of larval parasitism would make a valuable contribution to the suppression of a FAW infestation.

Table 3. Larval collections made on -1 DAT and 2 DAT were assessed 7 days post collection to determine the level of survival and mortality from SfMNPV and parasitism.

Collection date (DAT)	Instar (number collected)*	Alive (%)	SfMNPV infected (%)	Parasitised (%)
-1	1 (n= 27)	100	0	0
-1	2 (n= 25)	84	0	0
-1	3 (n=34)	64.7	0.0	17.6
-1	**Total (n= 86)**	81.4	0.0	7.0
Untreated control				
2	**L1 (n= 34)**	82.4	0.0	0.0
2	**L2 (n= 37)**	70.3	0.0	29.7
2	**L3 (n=40)**	32.5	0.0	67.5
2	**Total (n=111)**	60.4	0.0	34.2
Evening application				
2	**L1 (n=45)**	88.9	0.0	4.4
2	**L2 (n=67)**	68.7	3.0	26.9
2	**L3 (n=58)**	58.6	3.4	36.2
2	**Total (n=170)**	70.6	2.4	24.1
Morning application				
2	**L1 (n=16)**	87.5	12.5	0.0
2	**L2 (n=24)**	79.2	4.2	16.7
2	**L3 (n=28)**	14.3	7.1	78.6
2	**Total (n= 68)**	54.4	7.4	38.2

* the difference between total collected and counts recorded in the table are deaths of unknown cause.

Trial 2: Repeated applications of SfMNPV.

At the commencement of the trial the FAW population was close to zero (Figure 2A), which means that all the larvae were susceptible to SfMNPV through until midway through the trial (Figure 2B). The approach of evaluating the efficacy of the SfMNPV treatment based on surviving large larvae is practically relevant because the population exposed to SfMNPV can be followed through the trial. The decline in larval density observed from mid-way through the trial (early April) is related to the reduced oviposition observed (Figure 2C), which is typically what occurs in crops as the level of damage increases, making it less attractive to oviposition by female moths. The late rise in oviposition is likely related to the commencement of tasselling in the crop.

Across all dates, there was a significant difference between the treatments in the density of large larvae with the SfMNPV mean density = 1.1 and control = 0.68 large larvae per plant (F=15.4, df=(1,299), p<0.001). There is a trend towards a lower density in the SfMNPV treatment initially, but survival of large larvae as the trial progresses in the SfMNPV treatment. From this point the large larval population declines in the control treatment following insecticide treatments on 4 and 11 April (Figure 3A).

There was a significant difference between the treatments for the damage score with the SfMNPV treatment having a mean =4.1 and the control mean = 4.5 ((F=4.2, df=(1,204), p=0.040). There is evidence of slower crop damage in the SfMNPV treatment initially which corresponds to the slower build up of large larvae to 8 April (Figure 3B). Although the density of large larvae declines in the control after treatments are applied in early April, plant damage continues to accumulate even at this low density (around 1 larva per plant) (Figure 3B). Significant crop damage resulting from an infestation of 1 large larva per plant is consistent with observation in other trials, and the commercial experience.

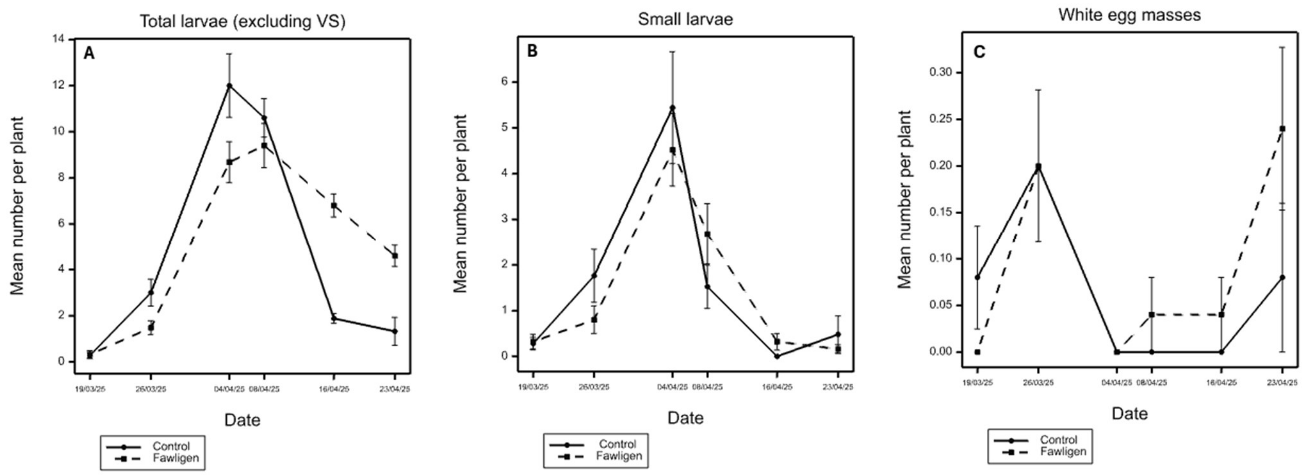

Figure 2. The trial commenced with very low numbers of FAW larvae (A) with oviposition and survival of larvae contributing to a high-density infestation by 4 April. In the early stages of the trial there was a high-density infestation of SfMNPV-susceptible small larvae present (B). As is typical in FAW trials, oviposition (number of white egg masses) declined as the crop damage increased (C). Error bars represent mean error.

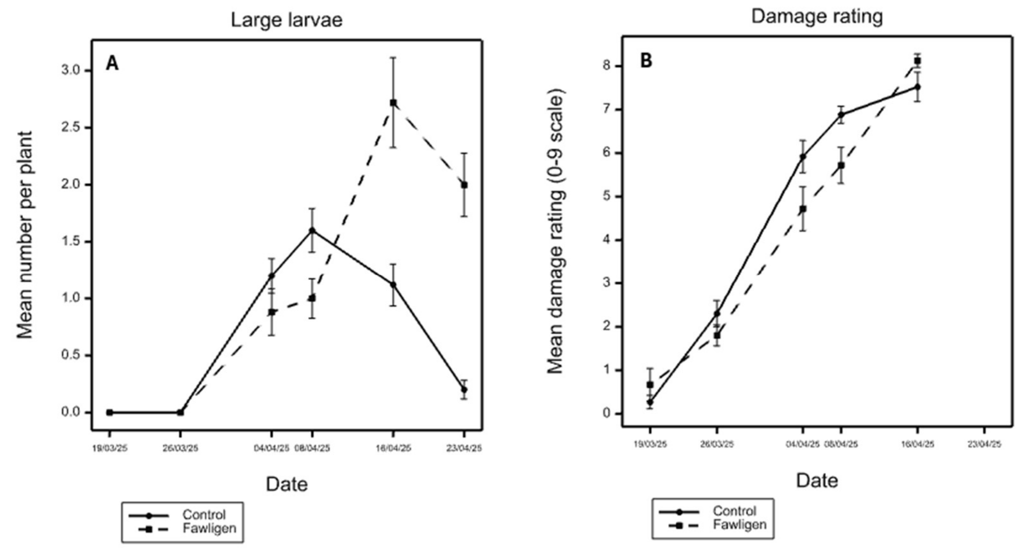

Figure 3. A: Mean number of large larvae in the treated control and repeat SfMNPV treatments. B: Damage ratings at each assessment date (1=no damage, 9=plant growth severely suppressed). Error bars represent mean error.

SfMNPV acquisition varied from 4-29% across the sampling dates, with a trend to higher levels of infection as the trial progressed (Table 4). This relatively low level of infection provides insight into the survival of larvae in the trial. Larvae infected early (VS-SM) die at a rate of 90-70%. Older larvae die at much lower rates, (<30% of infected larvae), as laboratory bioassays have demonstrated. (QDPI unpublished data). It is unclear whether larvae are avoiding contact with the SfMNPV because of their behaviour, or spray application issues. It is possible that the SfMNPV is inactivated on the leaf surface or simply has a very short life when exposed to sunlight in the field. Investigation of these possible influences on SfMNPV warrant further investigation. These results are consistent with results from other trials conducted by QDPI in maize.

In combination, mortality from SfMNPV and parasitism was between 20 and 40% of larvae collected; this is a significant contribution to larval mortality. One of the benefits of NPV in other systems (e.g. Helicoverpa NPV use in sorghum) is the 'bioresidual' benefit of using an option that does not disrupt the activity of natural enemies. A viable option for growers under less damaging infestation levels, and even more so if they had a more effective biopesticide option.

Table 4. Identified causes of FAW larval mortality (instars 1-4) collected from sweet corn treated with SfMNPV at approximately 4 day intervals from 21/3/25 – 17/4/2025.

Collection date	Total larvae collected	Alive (%)	SfMNPV (%)	Parasitised (%)
26/03/2025	100	71	4	16
4/04/2025	68	48	13	8
8/04/2025	26	16	19	3
10/04/2025	82	37	29	11
16/04/2025	58	28	17	10
23/04/2025	98	47	29	11

The number of large larvae in the SfMNPV treatment was initially lower than in the control treatment where the infestation was not controlled. A key challenge with managing FAW in sweet corn is that the damage threshold is so low that the tolerance for larvae in the crop is effectively zero larvae per plant. SfMNPV alone did not provide sufficient suppression or control of the developing FAW infestation in this trial to keep crop damage below commercially acceptable levels. The levels of damage observed progressed rapidly to Davis ratings of 5+, and earlier trial work conducted as part of VG23006 (Appendix 1. Threshold evaluation) showed that at this level of damage sweet corn growth slowed and yield and harvestability are severely impacted. That such limited control was achieved with this high product rate and frequency of application will illustrate for growers the relatively modest contribution of SfMNPV in their pest management strategies.

However, when viewed in combination, the total biocontrol observed (SfMNPV + parasitism) was a very useful 20-40%. We did not assess egg parasitism in this trial as the egg densities were relatively low, but in previous trial work for this project, we demonstrated up to 50% FAW egg parasitism by *Trichogramma pretiosum* following releases into sweet corn. At present growers would be unlikely to harness the benefit of using a biological like SfMNPV as most of the conventional chemistry that they use in mixtures, or rotation, to manage FAW is toxic to parasitoids.

Conclusions and recommendations

These trial results are consistent with the findings of other QDPI studies that show low levels of acquisition and consequently poor efficacy of SfMNPV (Fawligen®, AgBitech) in sweet corn.

In these trials, neither repeated applications (8 applications over 27 days) nor the single application at different times of the day (morning, evening) provided commercially acceptable control of moderate infestations of FAW in sweet corn at the highest label rate (200 mL/ha).

We cannot recommend the use of SfMNPV either as a stand alone control option, or as likely to provide benefit to the grower when added to conventional insecticides for potentially damaging infestation levels (1+ large larvae per plant).

These results do illustrate a potential benefit of biologicals in terms of natural enemy activity, parasitoids in particular. The level of parasitism recorded in small larvae collected during the trial was a very valuable 20-40% at Gatton and 16-78% at Bowen. These results are encouraging of an approach that allows for the survival and build up of natural enemies, especially parasitoids, in the sweet corn production system.

Evidence from laboratory and glasshouse bioassays (QDPI unpublished data) is increasingly pointing to crop x SfMNPV interactions that impact efficacy in maize and sweet corn, in comparison with significantly higher efficacy observed in other crops (e.g. soybean, ginger).

The underlying mechanism of SfMNPV poor performance in sweet corn warrants investigation. It is possible that it may be as simple as correcting for high pH on the leaf surface of these crops by the addition of an adjuvant.

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APPENDIX 4. Characterisation of FAW infestation in capsicum. Glasshouse experiments, 2024/25

T. Volp, A. Quade, M. Zalucki*, M. Miles. VG23006

Notes:

1. the research reported here was accepted for publication in Austral Entomology on 23/01/2026. Title: Oviposition and larval establishment of three 'generalist' noctuids on *Capsicum annuum*.
2. A factsheet developed for industry to guide monitoring and management of FAW, helicoverpa and cluster caterpillar, incorporating the findings from this research is included as Appendix 5 in the VG23005 final report (Jan 2026).
3. *University of Queensland.

Background

Reports of *Spodoptera frugiperda* (Fall Armyworm; FAW) infestations in capsicums indicate that caterpillars have typically been detected during processing, with larvae found inside the capsicum fruits. Purportedly, early instar larvae burrow inside fruits, where they feed until they are detected post-harvest, pupate inside the fruit, or exit the fruit through a sizeable hole. The lack of apparent external damage to capsicum fruits when *S. frugiperda* larvae are feeding internally limits the ability of agronomists to detect and manage these infestations in capsicum crops. These infestations have the potential to result in significant quality downgrades and affect market access. Previous research conducted on VG23006 has demonstrated a substantial difficulty in experimentally generating *S. frugiperda* infestations in capsicums in the field, therefore in this report we have taken a more detailed approach to examine capsicum's susceptibility to *S. frugiperda*.

Capsicum is attacked by several insect pests which are largely managed by calendar spraying of synthetic insecticides. Lepidopterans other than *S. frugiperda* that typically infest capsicum, include the major pests *Helicoverpa armigera* (HA) and *Spodoptera litura* (SL). All three of these moths belong to the same moth family Noctuidae. *Helicoverpa armigera* and *S. litura* have long been pests of capsicum production in Australia (Innovation 2021; Kay 2007), whereas the extent of *S. frugiperda* as a problem in capsicum remains uncertain.

In this study we wanted to compare all three of these pest species on capsicum plants. We sought to identify similarities and differences in how these pests infest and damage capsicum plants. Therefore, obtaining the necessary data on *S. frugiperda* infestations in capsicum, but also generate information on how this pest differs from two known significant capsicum pets.

The aim of this study was to examine the oviposition behaviour, larval feeding behaviour, and larval survival on whole capsicum plants of *S. frugipdera*, *S. litura*, and *H. armigera*. Specifically, we investigated: i) moth oviposition onto capsicum plants at different crop stages, ii) the establishment and survival of caterpillar populations on capsicum plants at different crop stages, and iii) the survival and behaviour of neonate larvae on capsicum fruits of different development stages.

Methodology

We conducted three experiments in the glasshouse at the QDPI facility in Toowoomba, QLD (-27.534994, 151.930483). Insects of all three pest species used in experiments were sourced from QDPI laboratory colonies. These colonies were maintained on soybean flour-based artificial diet and reared using methods described elsewhere (Volp et al. 2023; Volp et al. 2022). Capsicum plants (cv. Warlock) were grown by germinating seeds in seedling trays of commercial potting mix (Searles Premium™) in controlled temperature plant growth rooms with artificial lighting (25°C, 12:12 L:D photoperiod). After 9 weeks seedlings were transplanted into 4L plastic ANOVA™ pots filled with potting mix and transferred into a temperature-controlled glasshouse (27°C night, 25°C night) under natural photoperiod, where they were grown until their use in experiments. All experiments were conducted under these conditions. During plant growth all flower buds were regularly manually removed from plants until the plants reached 11 weeks after sowing, to prevent fruits from forming on small plants and ensuring synchrony in fruiting for the experiments.

Experiment 1: Moth oviposition

For the oviposition choice experiment we sourced pupae from the laboratory colonies and separated them by sex by examination under a stereomicroscope (Nikon, SMZ800N). We placed male and female pupae in separate emergence cages. Cages were checked daily for moth emergence and upon emergence moths were removed and used in oviposition assays (i.e. no moths selected for assays were older than 24h post eclosion). For oviposition assays groups of n=6 moths of a single species (1:1 sex ratio) were placed into cages (68.5 × 68.5 × 121.9 cm) in the glasshouse. Moths were provided with 10% sucrose solution as a carbohydrate source from a wicking container. Within each cage we placed three capsicum plants, one for each crop stage – flowering, green fruit, and red fruit. Flowering plants were between 95-102 days after sowing (DAS), green fruit 123-130 DAS, and red fruit 158-165 DAS.

We allowed moths four nights to feed, mate, and lay eggs. After four nights we terminated assays and recorded the number of surviving moths, the count and the location of eggs/egg masses along with recording the size and length of egg masses for the *Spodoptera* species. This methodology has been successfully used previously for examining moth oviposition behaviour in *S. frugiperda* and *H. armigera* (Volp et al. 2023; Volp et al. 2022). The experiment was a randomised block design, and ten replicates were performed for each pest species.

Experiment 2: Larval establishment

For the next experiment we examined larval survival and feeding behaviour on capsicum plants of the same three crop stages (flowering, green fruit, and red fruit) used in Experiment 1. Capsicum plants were placed within the same type of cages used in Experiment 1, with only one crop stage per plant. On each plant we placed n=50 neonate larvae (<24h old) on a fully-expanded leaf at the top of the plant. Larvae were left to feed and disperse for 10 days, after which we destructively sampled plants and searched them for larvae. We recorded the number of surviving larvae, along with their location and instar. This experiment was a randomised block design, and four replicates were conducted for each crop stage x pest species combination.

Experiment 3: Neonates on caged fruits

In the third and final experiment we caged neonate larvae of the three species of caterpillars on a capsicum fruit of one of four fruit stages. The four fruit stages we used in this experiment were: 1) small (expanding) green fruit, 2) green fruit, 3) turning fruit, and 4) red fruit. Small green fruit were under 40mm in diameter and selected to represent the feeding sites available to larvae soon after flowering and turning fruit were transitioning in colour from green to red. Neonate larvae (n=10 per fruit) placed onto fruits where they were restricted with the use of 13x12cm organza bags which were tied around the fruit's peduncle. After 4 days, bags were removed and fruits were examined for the presence of larvae. We recorded the number of surviving larvae, their location, and the presence of feeding damage. We also measured capsicum fruit wall toughness by using a fruit penetrometer (FT-011) on the fruit wall, and we recorded a proxy for soluble sugars in the fruit wall by using a Brix refractometer (Atago, PAL-1). This experiment was a randomised block design, and four replicates were conducted for each fruit stage x pest species combination.

Statistical analysis

For the moth oviposition experiments, response variables were analysed with one-way ANOVAs with replicate used as a blocking factor. For both larval experiments we analysed larval survival/establishment using two-way ANOVAs with moth species and crop/fruit stage as the independent variables. All analyses were conducted using the statistical software R. Post-hoc comparisons were made with Fisher's protected LSD test and significance was set at $p<0.05$, for these comparisons we used the R package 'agricolae'. Finally, graphs were made with the R package 'ggplot2'.

Results

Experiment 1: Moth oviposition

Moths of all three species laid eggs in all cages except for a single *H. armigera* rep where not a single egg was found after the experimental period. As this cage was a substantial outlier we removed it from the analysis. Although both *Spodoptera* species in our experiment lay their eggs in masses, here we analyse and present data in total egg counts for ease of comparison among the three species.

Moth species differed in the total number eggs laid per cage in the oviposition assay (F_2=149.9, $p<0.001$; Figure 1). Interestingly, *S. litura* moths laid over ten times as many eggs as moths of the other two species. Moth species differed in the proportion of eggs they laid on plants (F_2=21.73, $p<0.001$; Figure 2). Both *H. armigera* (74%) and *S. litura* (99.5%) laid most of their eggs on the plants, whereas *S. frugiperda* (32%) laid few – instead mostly targeting their eggs to the cage wall.

Of the eggs laid on plants, we examined if the moth species preferred different crop stages (Figure 3). A two-way ANOVA showed no difference among crop stages (F_2=0.45, p=0.64) or moth species (F_2=0, p=1), but there was a significant moth species x crop stage interaction (F_4=5.23, $p<0.01$). *Spodpotera frugiperda* did not have a preference for certain crop stages, whereas *H. armigera* preferred to lay eggs on flowering plants and *S. litura* preferred to lay eggs on plants at the green fruit stage.

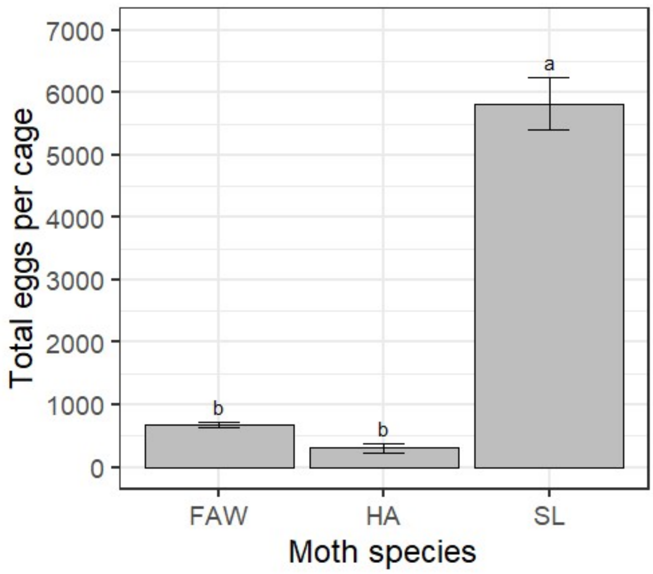

Figure 1: *The average number of eggs laid per cage by moths during the oviposition choice assay. Bars represent the means and error bars represent standard errors. Letters above bars indicate a significant difference according to Fisher's protected LSD test.*

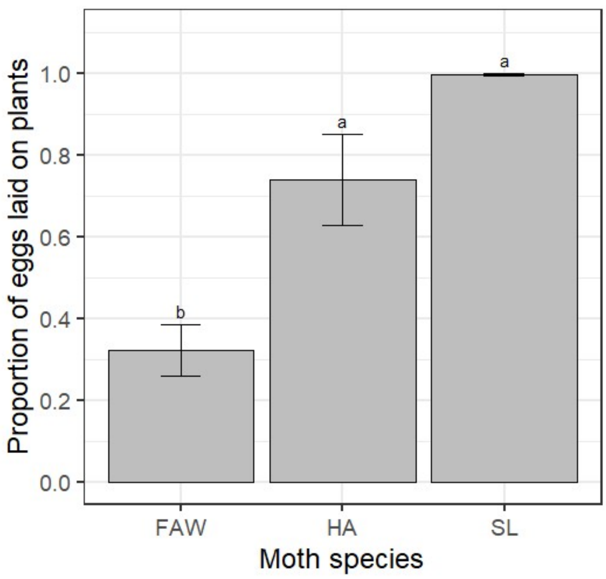

Figure 2: *The proportion of eggs per cage which were laid on capsicum plants (as opposed to other surfaces) by moths during the oviposition choice assay. Other surfaces include the cage wall and adult diet wick. Bars represent the means and error bars represent standard errors. Letters above bars indicate a significant difference according to Fisher's protected LSD test.*

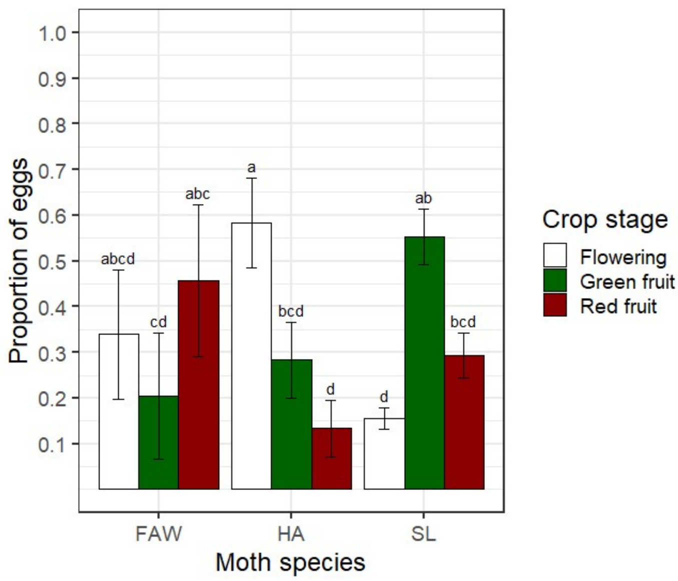

Figure 3: *The proportion of eggs laid onto capsicum plants of different crop stages during the oviposition choice assay. Bars represent the means and error bars represent standard errors. Letters above bars indicate a significant difference according to Fisher's protected LSD test.*

Experiment 2: Larval establishment

In the unrestricted larval experiment (10d length), larval survival was significantly influenced by moth species and crop stage along the interaction of the two factors (Table 1; Figure 4). *Spodoptera litura* had the greatest survival on capsicum plants, followed by *S. frugiperda* and then *H. armigera*. The three pest species differed in where they were found at the end of the 10d experiment, the majority (69%) of *S. frugiperda* larvae were found on or inside capsicum fruits. Of the *S. litura* larvae, most (77%) were found on leaves. Whereas very few *H. armigera* larvae were found (only 15 from the 600 neonates placed on plants) and therefore it is not useful to interpret the location data for this species.

Table 1: Two-way ANOVA results for the 10d larval survival experiment

Factor	**df**	**F-value**	**p-value**
Moth species	2	71.37	**<0.001**
Crop stage	2	8.42	**0.002**
Caterpillar species x crop stage	4	3.73	**0.02**
Block (replicate)	3	0.33	0.80

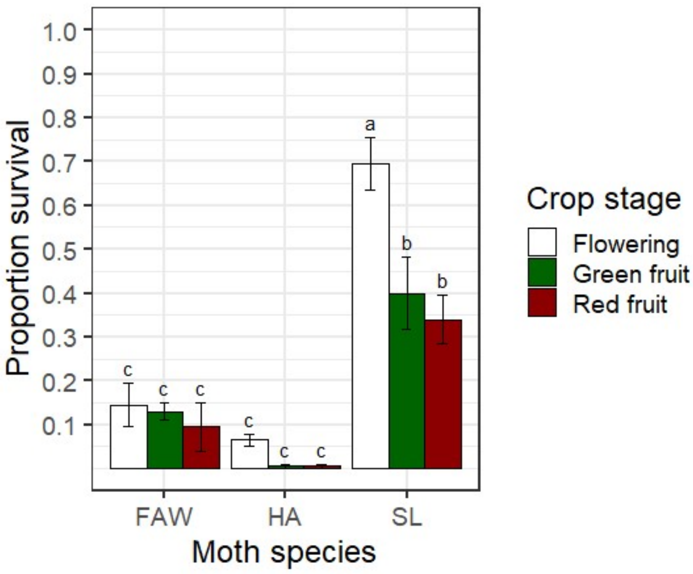

Figure 4: *Larval survival in the caged fruit experiment. Bars represent the means and error bars represent standard errors. Letters above bars indicate a significant difference according to Fisher's protected LSD test.*

Experiment 3: Neonates on caged fruits

At the end of the caged fruit assay there was no difference among lepidopteran species for their survival on capsicum fruits (F_2=1.70, p=0.198) nor was there an effect of fruit stage on larval survival (F_3=1.30, p=0.290; Figure 5). Of the 480 total larvae (of all three species) placed on fruits in the experiment, we were able to find 27 live larvae (14 FAW, 6 HA, and 7 SL) after 4 days. Of these larvae, most (18/27) were located feeding under the fruit's calyx (Figure 6) – this feeding behaviour occurred with all three moth species. Only two larvae had made their way to feed inside the fruits – both were FAW, one in a green fruit another in a turning fruit. Both larvae had tunnelled into the fruit through the bottom of the fruit rather than through the pith underneath the calyx. The four fruit stages differed in their penetrometer readings for fruit toughness (F_3=20.169, p<0.001) in addition to their Brix refractometer measurements (F_3=61.30, p<0.001).

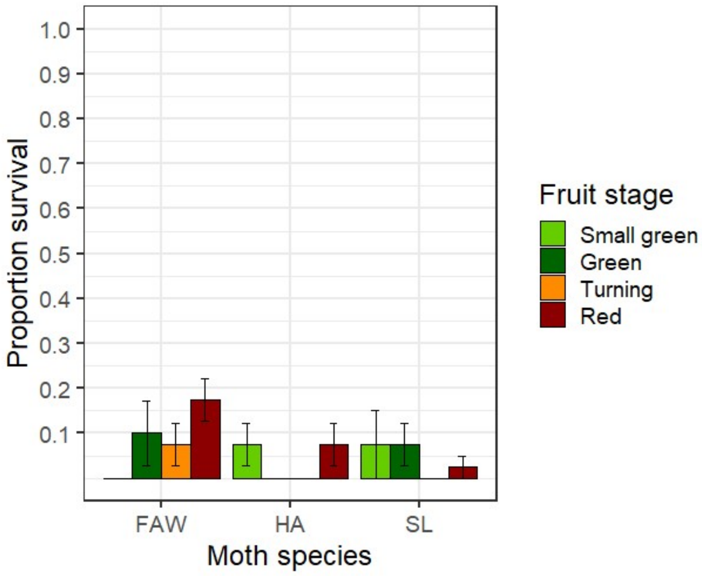

Figure 5: *Larval survival in the caged fruit experiment. Bars represent the means and error bars represent standard errors.*

Figure 6: *A S. fruigperda larvae demonstrates the most common feeding spot for early instars in the caged fruit experiment – hidden underneath the calyx.*

Conclusions and recommendations

We conducted a suite of glasshouse experiments to look in detail at the relationship between *S. frugiperda* and capsicum. We also include two other serious capsicum pests (*S. litura* and *H. armigera*) as a comparison.

The very low level of eggs laid on plants in oviposition experiments by *S. frugiperda,* particularly in comparison to the other moth species (Figures 1 & 2), indicates a low preference of this pest for the crop. The *S. frugiperda* moths in our study preferred to oviposit on cage walls rather than plants. This behaviour has been seen in previous studies and strongly indicates that moths do not have a preference for laying on the focal plant species (Guo et al. 2021; Sotelo-Cardona *et al*. 2021; Volp *et al*. 2022).

Despite the low levels of oviposition on plants by female moths, *S. frugiperda* larval establishment and survival was comparable to that of *H. armigera* (Figure 4). Although both these species did much poorer than *S. litura*.

Importantly, over two-thirds of surviving *S. frugiperda* larvae were found on or inside capsicum fruits. These observations suggest that *S. frugiperda* larvae do not prefer to feed on capsicum leaves, despite some people regarding the pest as a 'leaf-feeder'. The results of the third experiment further demonstrated the ability of *S. frugiperda* larvae to establish feeding sites on capsicum fruits (Figure 5), with two first instar larvae even able to find their way inside the fruit within 4 days.

The are several key messages based on the *S. frugiperda* results. Firstly, female *S. frugiperda* moths do not have a strong preference for laying eggs on flowering or fruiting capsicum plants. We expected this to be the case given the difficulty of infesting capsicum plants in the field using populations of moths. Additionally, despite the pest having long been present in the Americas, a major capsicum production region, there is limited research interest in this pest on capsicum (e.g. a Scopus search for "Spodoptera+frugiperda+capsicum+annum" does not yield a single result).

Moths of *S. fruigperda* can oviposit on non-preferred plant species when there is a high population of *S. frugiperda* moths in the landscape and/or a lack of suitable host-plants. Such events may be occurring to generate field infestations in Australian capsicums. Or alternatively, *S. frugiperda* larvae may be entering crops as small larvae silking off a grass host (volunteer maize/sorghum, wind breaks, or grass weeds) or crawling older instars.

The major gap in our understanding for S. fruigperda in capsicum is the in-field context for how these infestations are generated. Interviews with agronomists, conducted as a part of this investment, has led us to believe that *S. frugiperda* in capsicum is less problematic than believed.

Designing sampling strategies for *S. fruigperda* in capsicums is a difficult task. We do not know the mechanism by which larval populations are finding their way into a crop (by oviposition, silking or crawling). However, once these populations are present, we can expect some survival (10-15%, see Figure 4). The larvae that do survive are likely to be found feeding on or inside capsicum fruits, where they prefer cryptic feeding sites (Figure 6). It is unlikely that sampling early instars in the field would be practical, given to detect larvae in the caged fruit experiment we had to dissect the fruit.

The main priority moving forward for managing *S. frugiperda* in capsicums is 1) understanding the environmental context that generates infestations and 2) guiding growers/agronomists on how to decrease the risk of such spillover infestations.

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Identifying and managing key caterpillar pests in capsicum

A closer look at fall armyworm, cluster caterpillar and Helicoverpa spp.

Since the incursion of fall armyworm (*Spodoptera frugiperda*; FAW) into Australia there have been detections in capsicum crops and in capsicum fruit post-harvest.

Recent research by QDPI shows important differences in the behaviour of FAW moths and larvae and similar caterpillar pests, cluster caterpillar (*Spodoptera litura*) and helicoverpa (usually *H. armigera*).

Pest identification

FAW and cluster caterpillar lay eggs in masses, and newly hatched larvae are often in tight groups. Helicoverpa lays single eggs.

Early instar caterpillars of these pest species are usually difficult to distinguish based on morphological features. As larvae grow, differences become more clearly visible (see Table 1).

ID tips

- Take good quality photos for reference
- Compare multiple traits simultaneously
- Use a hand lens or clip-on magnifier for your phone to see features more clearly

For more extensive caterpillar identification resources visit: www.thebeatsheet.com.au

Table 1. Distinguishing large caterpillars

Species	"Y" mark on head	Stripes along back	Segment spots	Body hairs	General appearance
FAW	Present	Three pale stripes	Raised dark spots in a trapeze and square patterns near rear	Some hairs on medium larvae, older larvae mostly smooth	Smaller larvae green, older larvae usually brown
Cluster caterpillar	Present	Three yellow/pale stripes	Dark crescents along back	Very smooth	Colouration variable, tapered head smaller than body
Helicoverpa	Absent	Central stripe often present, lighter thick stripes along sides	Raised dark spots with associated hairs	Hairy	Colour of medium-large larvae highly variable

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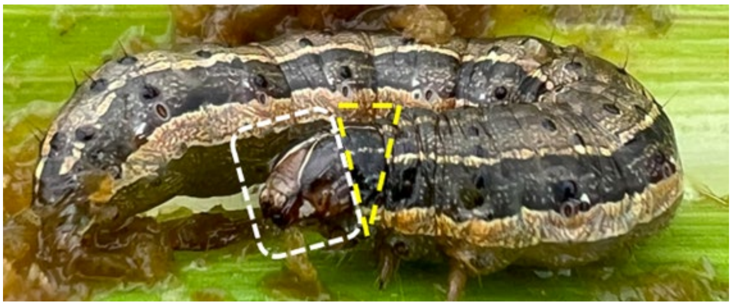
Different life stages

	FAW	Cluster caterpillar	Helicoverpa*
Eggs			
Medium larvae			
Large larvae			
Adults			

*Note: Helicoverpa species in capsicum crops are most likely to be *H. armigera* but may also be *H. punctigera* or *H. assulta*

Key FAW features



Left: Dark dots on the posterior upper-side of body in a square (abdominal segment 8) and trapezoid (abdominal segment 9) arrangement (yellow circles).
Right: Head with white Y and mottled pattern on side (white square) and thoracic shield similar in colour to head (yellow triangle). In helicoverpa, the head and thoracic shield are usually different colours.

Damage symptoms on capsicum

Caterpillars usually enter the fruit from underneath the calyx or via the apex, and the entry holes (particularly for smaller larvae) can be difficult to see.

Left: Common entry point of small caterpillars into fruits underneath the calyx (indicated by red arrow).
Centre: Feeding/burrowing underneath the calyx by a FAW larva.
Right: The apex of the fruit is another weak spot where caterpillars can enter.

Left: Medium sized FAW larvae feeding underneath the calyx of a green capsicum fruit.
Centre: Helicoverpa larvae damaging a capsicum fruit (FAW and helicoverpa enter the fruit in a similar manner).
Right: Typical cluster caterpillar damage to capsicum plants: the pest prefers to leaf feed and typically will defoliate plants rather than feeding in fruits, although large larvae can fruit-feed.

Understand pest behaviour to guide your sampling

Table 2. Different ways caterpillar pests infest capsicum

Pest	Typical infestation pattern	Sampling techniques
FAW	Moths prefer not to lay eggs on capsicum plants. Infestations are most likely from spillover of moths or larvae from nearby preferred hosts (e.g. sweet corn, maize, sorghum and weeds). Larvae do not preferentially feed on leaves in capsicum crops. Instead, they can be found around fruits – particularly under calyxes or at the apex. These are the common points of entry for small caterpillars and damage and larvae can be difficult to see.	Closely inspect underneath fruit calyxes and at the bottom of the fruit for small caterpillars or feeding damage.
Cluster caterpillar	Moths lay eggs on leaves in both vegetative and reproductive crops. Very small larvae will leaf-feed in clustered groups where they skeletonise leaves. Large larvae 'scallop' leaves and can eventually move into capsicum fruit.	Closely inspect leaves for egg masses and 'clustered' populations of young larvae. Feeding damage will be obvious as larvae develop.
Helicoverpa	Moths will infest capsicum crops from flowering onwards and lay single eggs on leaves and floral sites. Small larvae feed on flowers and eventually fruit. Larger larvae can tunnel into fruit causing obvious damage.	Closely inspect crops from flowering onwards for single eggs. Also inspect inside flowers, under fruit calyces and at the fruit apex for small larvae.

Integrated pest management

If left uncontrolled these caterpillars can cause significant damage. Feeding damage and insect presence can not only render fruit unmarketable, but pinhole feeding damage from small larvae can enable the entry of pathogens and cause fruit rot.

FAW and helicoverpa are unlikely to be present in vegetative capsicum crops. During this stage, prioritise IPM-compatible control options (e.g. Bt, chlorantraniliprole, methoxyfenozide) to conserve natural enemies that will help regulate pest infestations during later crop stages.

From flowering onwards, intensify in-field sampling as protecting fruit set and small fruit development is essential. When pest threshold levels are reached at these critical crop stages, select insecticides that have efficacy against the target caterpillars. Note that because of insecticide resistance, both helicoverpa and FAW are not well controlled by several of the older insecticide groups (carbamates, organophosphates, and synthetic pyrethroids).

Follow label/permit instructions to maximise spray efficacy. Rotate chemical mode of actions for insecticide resistance management and adhere to any local resistance management strategies. Ensure that chemical withholding periods align with fruit picking schedules.

Further reading

A paper developed from these studies is currently under peer review, and a link will be provided for the final version of this factsheet once the paper is accepted/published.

Appendix 6. Sunn hemp to diversify the sweet corn production system.

Melina Miles[1], John Stanley[2], Adam Quade[1]

Queensland Department of Primary Industries. [1]Toowoomba, [2]Bowen.

Background

The Push- Pull technique (PPT) deployed by smallholder farmers in Africa for the management of witchweed (*Striga hermonthica*) and stem borers (*Chilo partellus* and *Buseola fusca*) has been shown to also reduce the level of infestation by fall armyworm (FAW, *Spodoptera frugiperda*) in maize (Khan *et al* 2000, Midega *et al* 2018). A recent study on the mechanisms that underpin the effectiveness of PPT for suppressing FAW infestations (Sobhy *et al* 2022) suggests that the volatiles released by the push/companion plants repel FAW moths, and the pull crop attracts natural enemies. In combination, these effectively reduce oviposition and survival of FAW in the main crop. The approach has been evaluated in Brazil and Mexico, with some modification of the companion crop options, and shown to have similar benefits to those observed in Africa (Guera *et al*. 2021). Importantly, the work in the Americas with companion plant species that were not the same as those used in Africa but produced a similar result.

In 2024-25 we have undertaken two evaluations of a push-pull designed sweet corn cropping layout, the first conducted at the Bowen Research Station in September 2024. In the Bowen trial we instituted a 1:1 ratio of intercrop (sunn hemp *Crotalaria juncea* L., and cowpea *Vigna unguiculata*) to sweet corn (row:row). The positive outcomes of this trial were: i) the intercrop options were readily established and were largely compatible with the sweet corn cropping system, ii) local agronomists who inspected the trial as part of VG22006 activities, were interested in the potential additional benefits of the intercrop species, sunn hemp in particular.

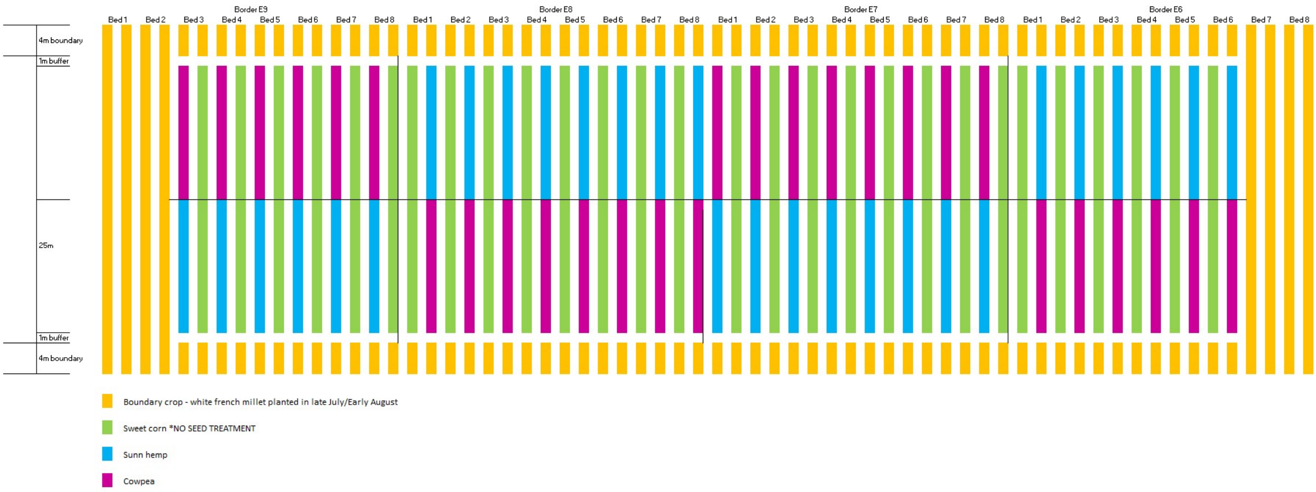
Given the interest of industry in the initial Bowen trial, we modified the trial design for Gatton to:

i) minimise the potential shading effect of the sunn hemp,
ii) make the intercropping approach more commercially feasible by including different ratios of sunn hemp and sweet corn in blocks
iii) focused on the influence of the sunn hemp on FAW oviposition in the adjacent sweet corn blocks and the interaction of the sunn hemp with key natural enemies.

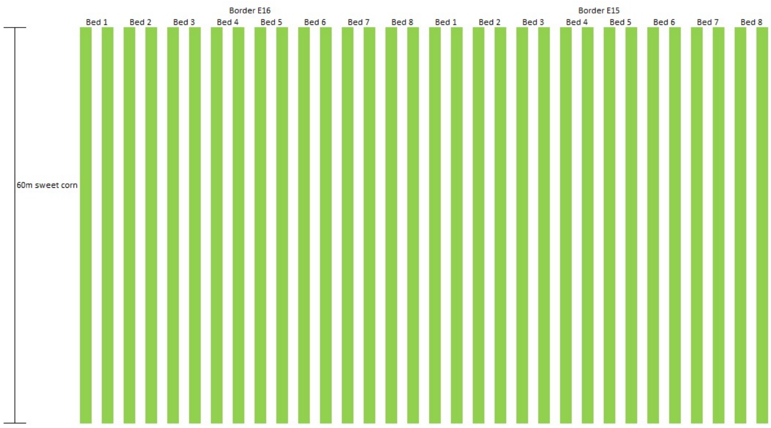
Materials and methods

Trial 1. Bowen Research station September 2024.

The trial was planted at the DPI research station on 16 September. The forage sorghum was planted 4 weeks earlier so that it was established prior to the sweet corn and companion crops being planted. The monoculture sweet corn block was adjacent to the PPT block and provided the industry standard configuration control against which to compare the PPT.



Layout of the push-pull trial, Bowen 2024. Yellow denotes forage sorghum (pull option), red denotes cowpea and blue is sunn hemp (push options). Green denotes the sweet corn (Var Garrison, Syngenta), planted without seed treatment.



The monoculture control plot of sweet corn planted adjacent to the push-pull block was planted with seed treatment to protect the early plants and minimise the disruptiveness of insecticide application to moth activity.

Neither the *Brachiaria* push option, nor the *Desmodium* pull option were deployed in this trial. The establishment time for the *Brachiaria*, and the weediness potential of this and the *Desmodium* were considered risks that could not be adequately managed. The alternate intercrops selected for the trial were sunn hemp and cowpea. Both options are readily available in Australia and potentially have additional benefits in a northern horticultural farming system with regard to summer cover crops, soil nitrogen and organic matter, and nematode disruption.

Both the control and the PPT block were monitored at approximately weekly intervals to quantify egg and larval densities. Egg densities were of particular interest as an indicator of the disruptiveness of the treatments to FAW moths. Crop damage was assessed using a modified Davis scale which focused on recent, inner whorl damage levels.

Only the sweet corn was assessed in both the intercrop and monocrop trial areas. The cowpea and sunn hemp were not intensively monitored, but observations were made for evidence of infestation and damage – none was observed. There were insufficient resources to allow for the collection of eggs and larvae for evaluation of biocontrol (pathogens and parasitoid) impacts on populations.

During the vegetative growth stage, the sweet corn control plots were treated with insecticide when crop growth was impacted (3 sprays to tassel), but the intercrop plots were not sprayed until tassel. From tassel, all plots were treated weekly to minimise FAW impact on cobs (3 treatments), and to provide an opportunity to assess the FAW impact during the vegetative crop stage across the different treatments.

A fresh harvest was conducted on 19 November to assess the marketability of the crops grown under the different treatments. Assessments were made of characters likely to be influenced by FAW and the presence of the intercrop. For example, the possible impact of shading by the sunn hemp and cowpea, or possibly competition for nutrients.

<u>Trial 2. Gatton research station January 2025</u>

Sweet corn (Variety: Garrison) and Sunn hemp (Variety: Cresent) planted on 16 January in the trial layout in Figure 1. The sweet corn (SC) and sunn hemp (SH) were planted in each of three configurations, 1) 8 rows of SC, 2) 2 rows SH/ 8 rows SC/2 rows SH and 3) 6 rows SC/ 6 rows SH. These treatments were replicated four times. Plots were 100 m long and divided into 4 quadrats (subplots) from north to south to facilitate structured sampling within plots.

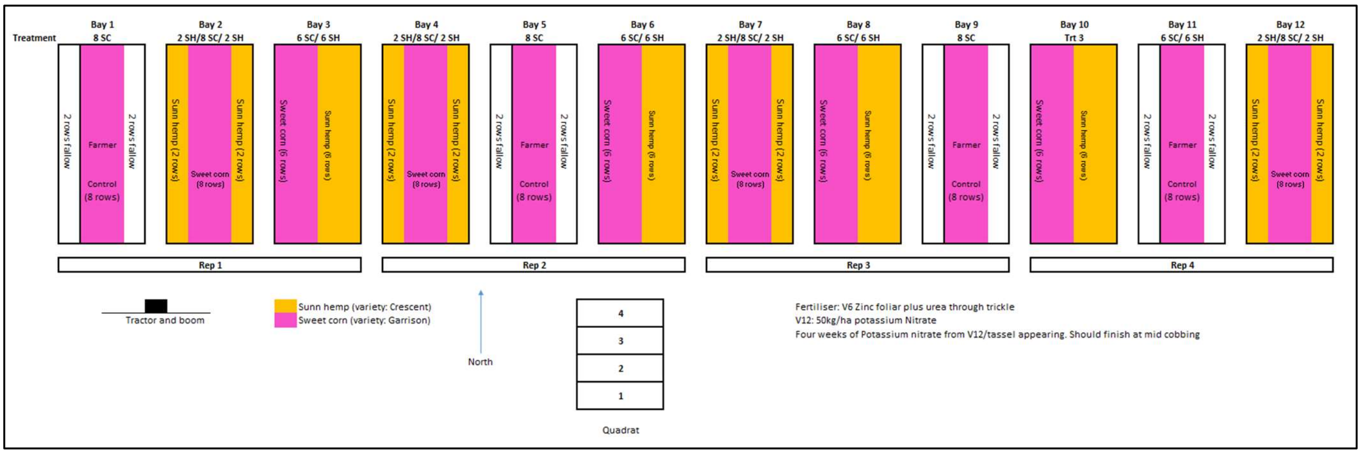


Figure 1. Trial layout for the sunn hemp x sweet corn trial to evaluate the potential to disrupt FAW oviposition. SC = sweet corn, SH = sunn hemp. Numbers (2, 6, 8) indicate the number of rows of each crop in the block.

Assessments of the sweet corn was made at 3-4 day intervals when egg and larval density was recorded, based on whole plant, destructive visual sampling.

The trial experienced extremely high oviposition in the first 3 weeks, necessitating insecticide applications to avoid plant death. Natural enemy densities were recorded at the same time.

The sweet corn only was sprayed on 30 Jan at V3 growth stage (spinetoram), 4 Feb at V5 growth stage (spinetoram), 11 Feb at V7 growth stage (chlorantraniliprole) and 14 Feb at V8 growth stage (chlorantraniliprole).

At each sampling date brown egg masses were collected to determine the level of parasitism.

Suction samples (20 m per bay, 4 bays per treatment) were collected from the sunn hemp on 5 occasions (7, 14, 19 February, 3, 17 March). Sunn hemp growth stages at each of the assessment dates were: vegetative (7 Feb), Budding 14 & 19 Feb), flowering (3 & 17 Mar). Collections were examined under the microscope and the key natural enemies identified and functional groupings made for other species.

Visual inspection of sunn hemp throughout the trial found no FAW eggs or larvae.

A fresh harvest assessment was undertaken on 25 March. Five consecutive plants were harvested from a plot that had been protected from sampling for the duration of the trial (5 plants from each of two rows in the plot = 10 plants). Each plot quadrat had a harvest plot, equating to 40 cobs assessed per treatment. Harvested plants were bagged and returned to the lab for assessment of each cob, looking for damage to the stalk, base, husk, silks, tip. Marketable cobs were those with no damage.

Analysis of treatment differences for eggs and damage by one and two way anova. Data transformed where required for normality. Treatment differences distinguished using post hoc Fisher's protected LSD (p=0.05)). The non-parametric Cochran's Q test was used to investigate differences in damage to cobs by GVB.

Results and discussion

<u>Trial 1. Bowen Research station September 2024.</u>

The period over which this trial ran was characterised by low FAW activity, in contrast to previous seasons. We also experienced high variability in FAW activity spatially and temporally during the trial. In many of the analyses, plot and date were more significant influences on the results than the treatments – far more that we typically see in field trials.

The forage sorghum border crop (pull) failed to attract FAW oviposition or support populations of larvae. Despite vigorous growth, high biomass and rapid regeneration post slashing, there was no evidence that it provided the same benefits reported for *Brachiaria* pull options.

Both the cowpea and sunn hemp established easily and grew vigorously. The cowpea was low growing until the sweet corn was post tassel when it rapidly climbed the corn plants. The sunn hemp grew at a similar vertical rate to the sweet corn during the vegetative stages and continued to elongate after the sweet corn growth ceased at tassel. The sunn hemp flowered prolifically from the late vegetative stages right through to the fresh harvest (Figure 2).

Figure 2. The push components of the trial just prior to the fresh harvest on 19 November 2024.

Left: cowpea in the foreground, Sunn hemp at the rear. Centre: cowpea climbing the sweet corn plants and covering the interrow. Right: Sunn hemp flowering and showing the height comparison with the commercial sweet corn variety Garrison.

In the Bowen trial we established the intercrops at a 1:1 ratio with the sweet corn crop, essentially a 'high dose rate'. If this approach is pursued further, a higher crop:intercrop ratio will be more cost effective.

Influence of intercrop on oviposition (egg density)

Oviposition across the treatments was considered a key indicator of the efficacy of the PPT approach and significant effort was deployed to sample intensively for eggs.

The relative abundance of eggs across the trial was highly variable, and oviposition declined after 24 October. There was no persistent effect of treatment (intercrop or monocrop) observed, with significant differences between the intercrop and monocrop treatments seen only on 3 October 2024 (Figure 3). On this date, the egg mass count in the sweet corn monocrop was significantly higher than in the cowpea and sunn hemp blocks. Analysis of data across all dates suggests a trend towards lower egg mass numbers in the cowpea and sunn hemp than in the sweet corn monocrop. However, high variability in the low density data makes this analysis challenging.

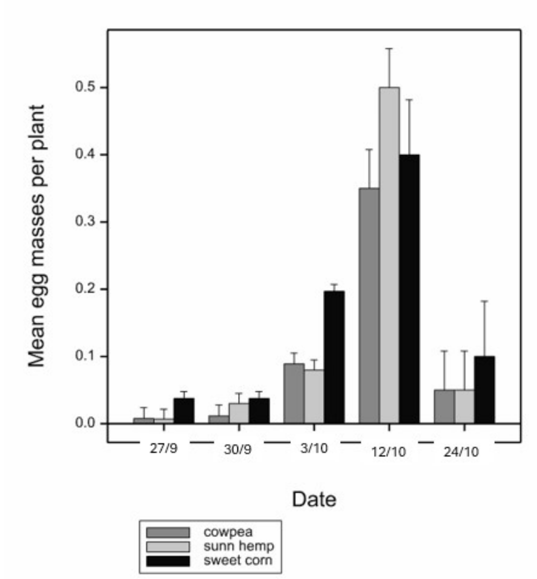


Figure 3. Significant differences in oviposition between the intercrop and monocrop treatments were not observed consistently throughout the trial.

Larval density and crop damage

High larval density was not observed until towards the end of the trial from 12 October to 5 November, and analysis is complicated by the effect of insecticide use in the different treatments. The management of the trial to prevent crop loss but allow for differences in the management approaches to be observed has been a major challenge in this and previous IPM trials. There is a tension between a research trial and these research-demonstration trials where industry may dismiss the work because of excessive crop loss being evident.

Despite the low larval densities, plant damage was assessed and damage levels increased as the crop progressed, with high levels of damage (rating 6-7 on a scale of 1-9) observed on 24 October and 5 November in all treatments. Analysis shows no clear treatment effect.

Fresh harvest assessment

The principal purpose of the harvest assessment was to determine if the intercrop treatments had negative impacts on the growth and subsequent yield and quality of the cobs. It is well known that competition for resources, including water, radiation, nutrients, can impact the ability of sweet corn to meet yield expectations. We were interested in the potential impact on cob weight, whether kernels were filled and also an assessment of how the cobs met the criteria for the fresh market (pers comm local agronomists re. specifications).

The sunn hemp treatment yielded significantly lower cob weight than that from cowpea and monocrop sweet corn (Figure 4). Competition for resources and/or shading by the sunn hemp may have directly contributed to the lower cob weight, a consequence of the sweet corn plant having limited resources to fill the cob. However, when we looked at the proportion of the cob that had been successfully filled, there was no significant difference across the treatments (Figure 4). Failure to fill kernels can result from inadequate plant resources and commonly, poor pollination.

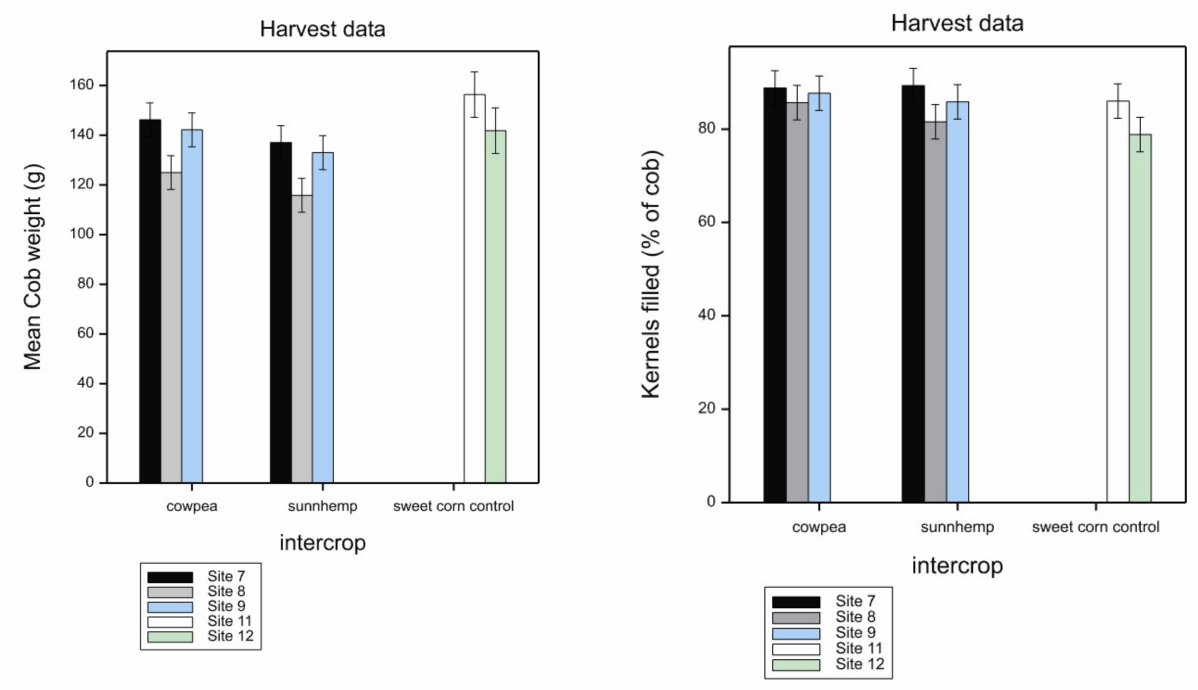


Figure 4. Key fresh harvest parameter, cob weight shows significant decline in sunn hemp intercrop treatment, but the intercrop treatments had no significant impact on the proportion of kernels filled.

A summary of the cob characteristics was used to categorise cobs as either marketable or unmarketable based on size, damage and appearance. The categorisation was informed by local agronomists involved with sweet corn production. Husk and silk damage were the most common reasons cobs were categorised as unmarketable for the fresh market. There were more marketable cobs harvested from the intercrop treatments than from the monocrop treatment (Figure 5). The superficial silk and husk damage was the key influence on marketability in this trial, reflective of the different FAW and helicoverpa pressure the monocrop experienced compared with the intercrop plots.

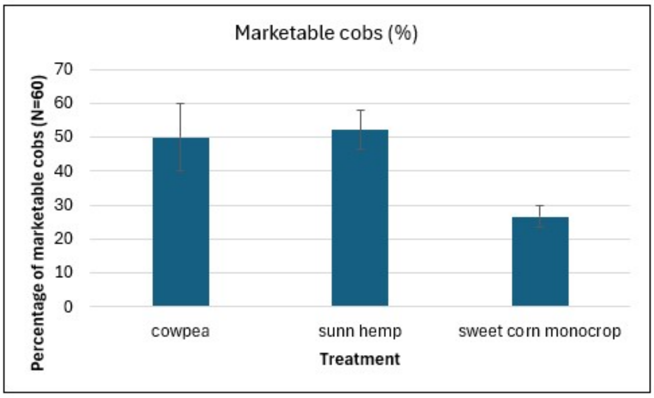


Figure 5. The intercrop treatments yielded a higher percentage of marketable cobs than the sweet corn monocrop.

<u>Trial 2. Gatton research station January 2025</u>

Corn and sunn hemp in early February and early March.

Left: Sunn hemp flowering. Centre: Sunn hemp was only marginally taller than the sweet corn at Gatton. Right: *Tytthus* sp. feeding on a FAW egg mass in sweet corn.

Oviposition by FAW

No significant treatment differences were observed for egg density (F=2.03, df=(2, 3479), p=0.132). Figure 6 shows the pattern of oviposition during the trial, with very high egg numbers over the first two weeks, peaking at V5 (3.2/25) and declining rapidly across all treatments through V6-early silking.

We looked at whether the proximity to Sunn hemp influenced oviposition. In this analysis we determined the distance from every egg mass to the closest sunn hemp row (Figure 7). There were no significant differences observed (F=0.97, df=(15, 3479), p=0.48). The pattern of oviposition at all distances follows the same pattern.

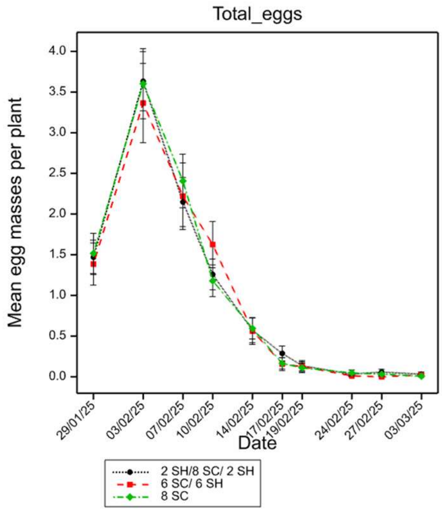


Figure 6. Total egg density (white + brown +black) for each treatment at each assessment date from V3 to early silking crop stages, peaking at V5 (3/2/25). Error bars are mean error.

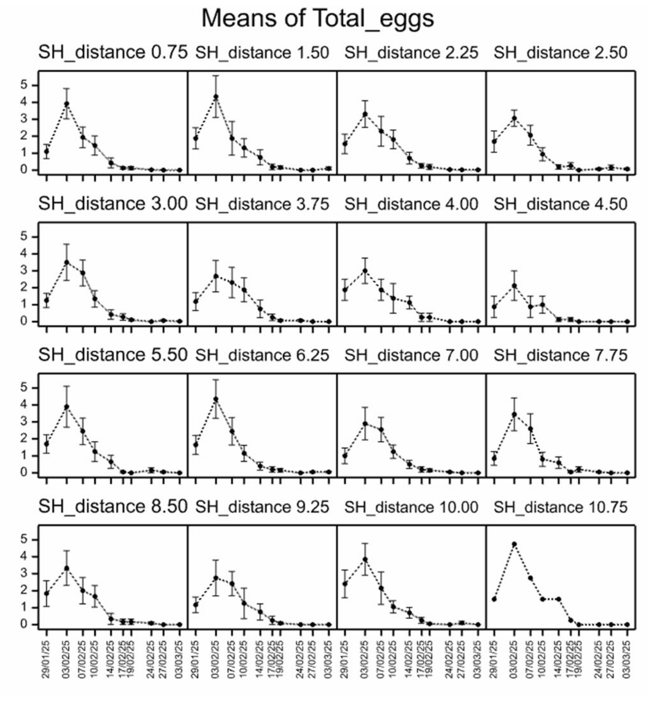


Figure 7. Oviposition by FAW in the sweet corn was not influenced by the proximity to Sunn hemp. The pattern of oviposition across the assessment dates is not significantly different at any distance from the nearest sunn hemp. SH_distance = metres from the nearest sunn hemp row to the egg mass. Error bars are mean error.

Damage to vegetative sweet corn

Despite the uniform oviposition rate observed, there were significant differences in the level of damage experienced in each treatment (F=25.1, df=(2, 1567), p<0.001) (Table 2A). Damage ratings were low, reflecting the low overall FAW pressure in the trial. In the later growth stages (V8-tassel emergence; 14/2 – 24/2), significant differences between 2SH/8SC/2SH (highest mean damage rating = 2.6), 8SC (middle mean damage rating = 2.2) and 6SC/6SH (lowest mean damage rating = 1.8) are evident (p=0.05) (Figure 8). All interactions (Treatment x date) are presented in Table 2B.

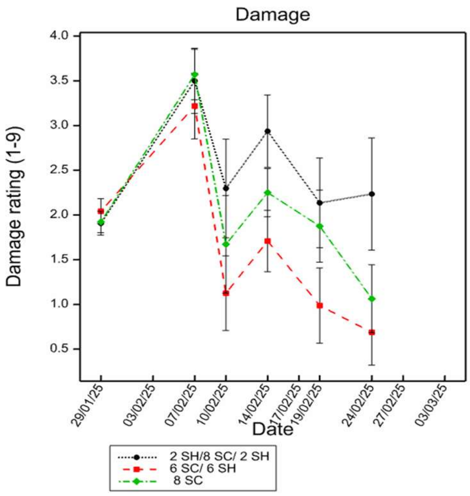


Figure 8. There are significant differences in the mean damage rating for the treatments and date interactions. SH = sunn hemp, SC = sweet corn. Numbers (2, 6, 8) indicate the relative number of rows in each treatment. Error bars are mean error.

Table 2A, 2B. There were significant differences in damage rating at the treatment level, ignoring date (A), and a significant interaction between treatment and date. These data are presented by date and treatment mean (B). Means followed by the same letters are not significantly different (p=0.05). SH = sunn hemp, SC = sweet corn. Numbers (2, 6, 8) indicate the relative number of rows in each treatment.

A

Treatment	Mean damage rating (1-9 scale)
6 SC/ 6 SH	1.829 a
8 SC	2.219 b
2 SH/8 SC/ 2 SH	2.58 c
F=25.1, df=(2, 1567) =<0.001	

B

Treatment	Date	Mean
2 SH/8 SC/ 2 SH	29-Jan	1.9 cd
8 SC	29-Jan	1.9 cd
6 SC/ 6 SH	29-Jan	2.0 cd
6 SC/ 6 SH	7-Feb	3.2 ef
2 SH/8 SC/ 2 SH	7-Feb	3.5 f
8 SC	7-Feb	3.6 f
6 SC/ 6 SH	10-Feb	1.1 ab
8 SC	10-Feb	1.7 bc
2 SH/8 SC/ 2 SH	10-Feb	2.3 d
6 SC/ 6 SH	14-Feb	1.7 bc
8 SC	14-Feb	2.3 d
2 SH/8 SC/ 2 SH	14-Feb	2.9 e
6 SC/ 6 SH	19-Feb	1.0 a
8 SC	19-Feb	1.9 cd
2 SH/8 SC/ 2 SH	19-Feb	2.2 d
6 SC/ 6 SH	24-Feb	0.7 a
8 SC	24-Feb	1.1 a
2 SH/8 SC/ 2 SH	24-Feb	2.3 d

Egg parasitism

Trichogramma pretiosum was the most abundant egg parasitoid recorded. Of the 1409 egg masses collected, *Telenomus* sp was recovered from only 1 egg mass. Egg parasitism data is presented for *T. pretiosum* only. No releases of *T. pretiosum* were made in the trial, parasitism resulted from endemic populations. Egg parasitism was consistently at 40-50% of collected egg masses across the trial with a dip in the percentage parasitism on 3 Feb (down to 13%) which corresponded with a large oviposition event (Figure 9 & Figure 6). Although *T. pretiosum* reportedly exhibits a Type 2 functional response (Kfir 1983), increasing its rate of parasitism in response to increased prey abundance, but at declining rate. The sudden increase in egg mass density observed, likely challenged the capacity of the existing *T. pretiosum* population.

There was no significant treatment difference in egg parasitism (F=0.05, df=(2,58) p=0.95).

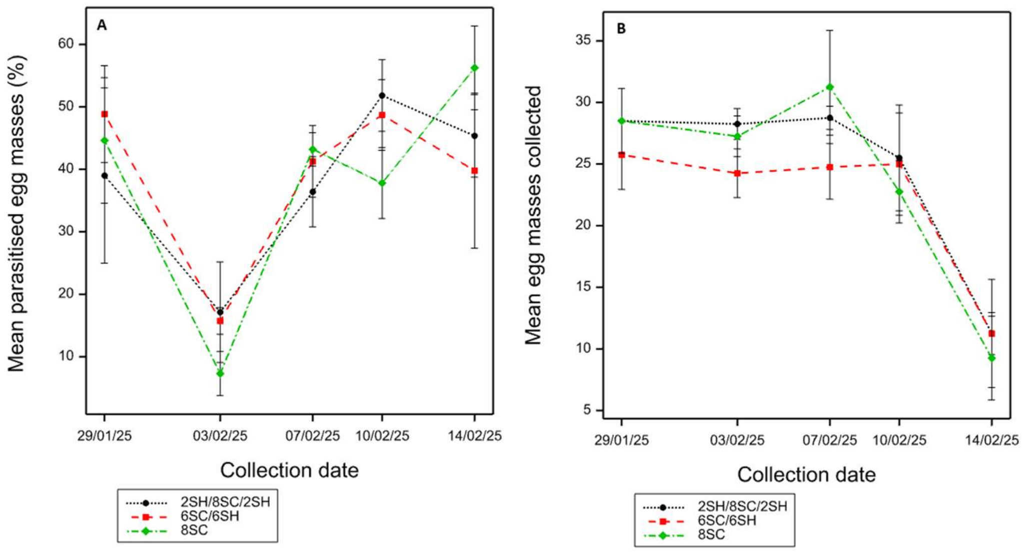


Figure 9. (A) *Trichogramma pretiosum* consistently parasitised 40-50% of collected egg masses across all treatments for the duration of the trial. (B) Number of egg masses collected on each sampling date. From 14 Feb, egg mass density declined to the point where adequate collections could be made. Error bars are mean error.

Predator abundance

The most abundant and frequent predators encountered in the sweet corn was the minute pirate bug (*Orius* sp), followed by the black headed predatory mirid *Tytthus* sp, and ladybeetle species (Coccinellidae). On average, the density of these predators in the sweet corn blocks was not influenced by the distance from the closest sunn hemp (Figure 10). There is a suite of other predator species that have been observed feeding on FAW eggs and larvae which occurred at consistently lower densities (mean of 1 per plant) and did not vary markedly in response to proximity of the sunn hemp strips (Figure 11). These species were spiders, *Geocoris* sp (Big eyed bugs), *Deraeocoris* sp (Brown smudge bug), *Nabis* sp (damsel bug), *Dicranolaius* sp (red and blue beetle) and ants.

Assessment of natural enemy abundance in the sunn hemp strips identified the same suite of predator species with *Tytthus* sp the most abundant (Figure 12). This result suggests that the predator populations are likely moving between the sweet corn and sunn hemp relatively freely and are not influenced greatly by the crop.

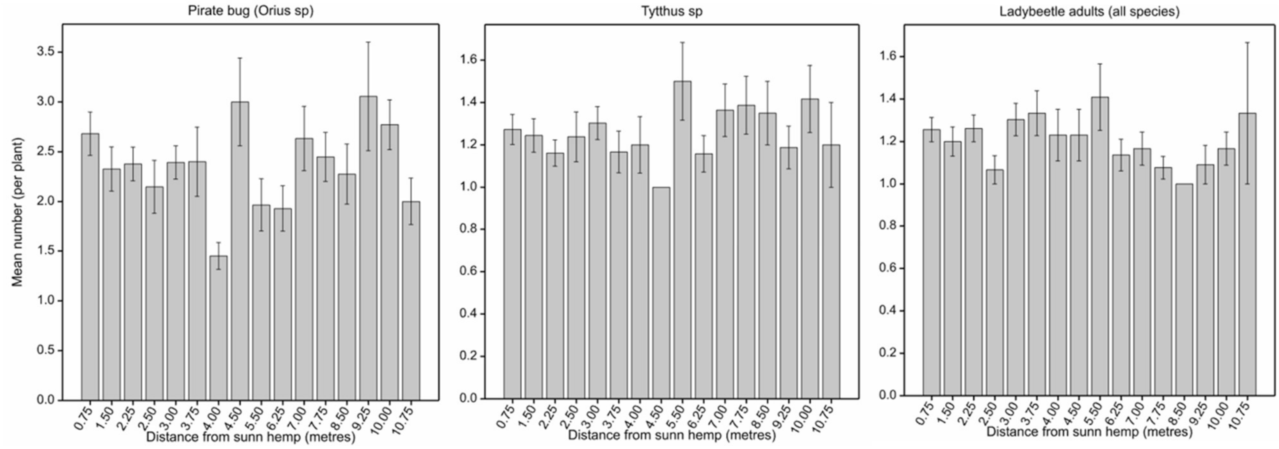


Figure 10. The abundance (mean number per plant) of key predatory species of fall armyworm (*S. frugiperda*) was not influenced by proximity, or distance, from the sunn hemp strips. Data is pooled across treatments and sampling dates. Bars are error of mean.

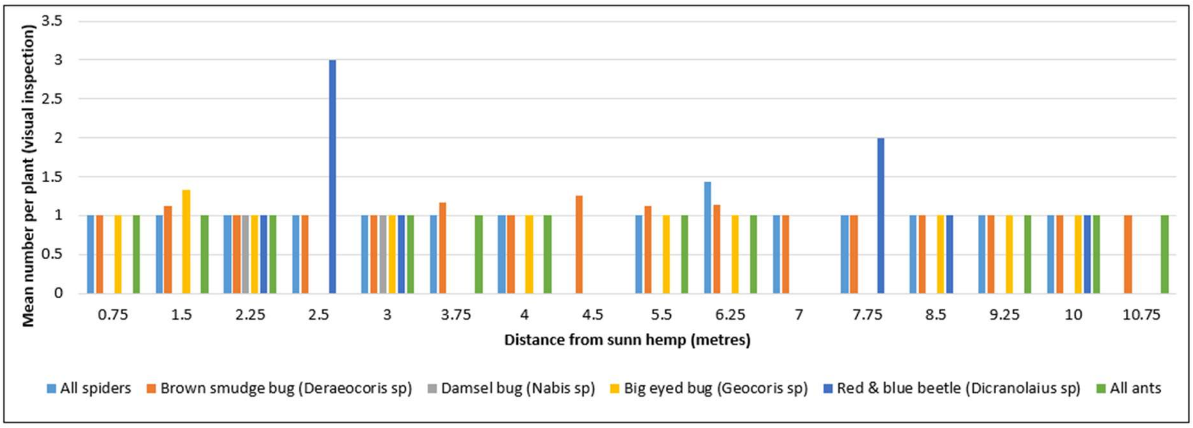


Figure 11. A suite of known predators of fall armyworm and other noctuid species was recorded at low density in sweet corn blocks. Abundance was not influenced by distance from sunn hemp strips.

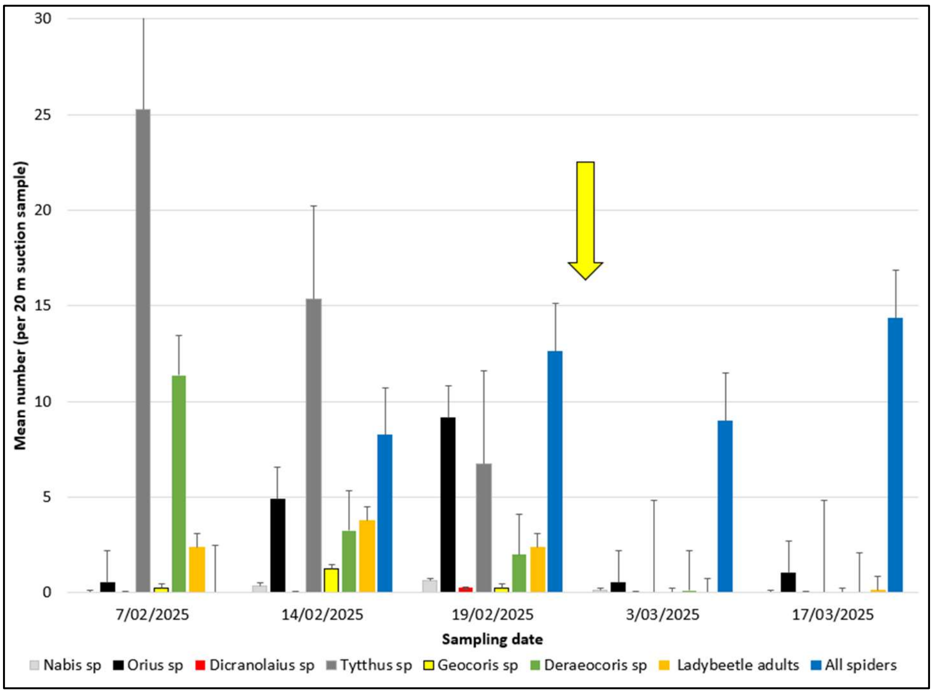


Figure 12. Mean density of the predatory species across the sunn hemp strips over five sampling dates covering vegetative and flowering crop stages. The yellow arrow shows when the sunn hemp started flowering. Bars are standard error of means.

An overview of natural enemy abundance and diversity in the sunn hemp is presented in Figure 13. The decline in the overall numbers of each group, other than spiders, from the point at which sunn hemp started flowering (24 Feb) is more likely a result of the increased biomass of the crop (height in particular) reducing the proportion of the crop that could be effectively sampled, compared with earlier sampling dates when the crop was vegetative and more compact. Sunn hemp does not have extra floral nectaries that may have been attractive to the some of the natural enemies (flies, wasps). In terms of invertebrate hosts, thrips were present throughout the trial at high densities, but aphids, caterpillar species were in very low densities.

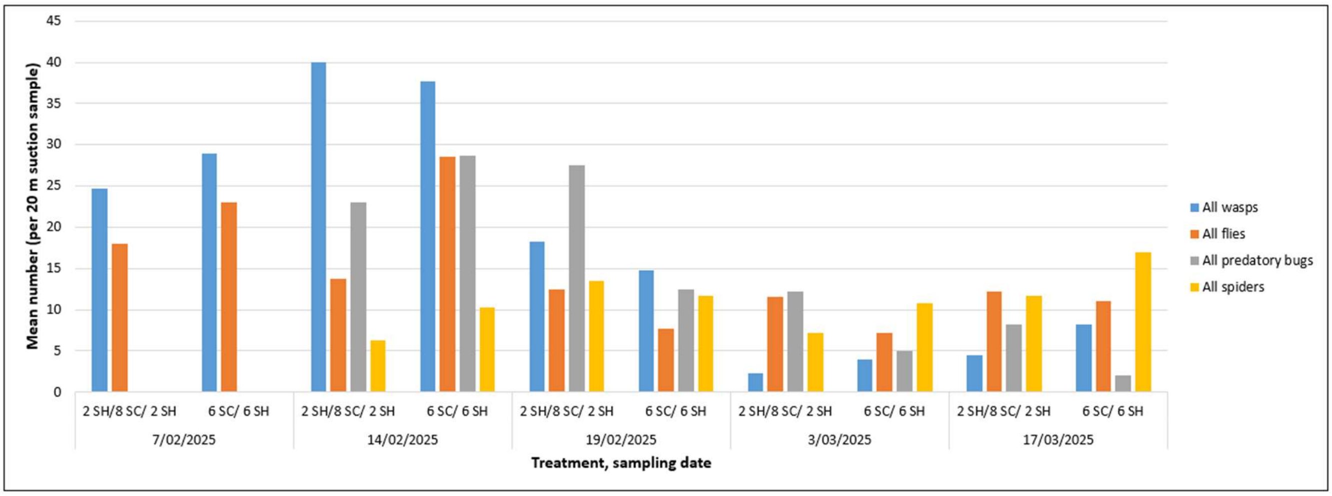


Figure 13. Overview of natural enemy abundance and diversity in sunn hemp over the duration of the trial. The sunn hemp started flowering on 24 February.

Harvest assessment

No significant treatment differences were observed for cob weight (F=1.69, df(2, 445) p=0.23) or the cumulative ‘marketability’ of cobs that is defined as cobs free from visible damage to the cob (F=0.48, df=(2, 119) p=0.63) (Figure 14).

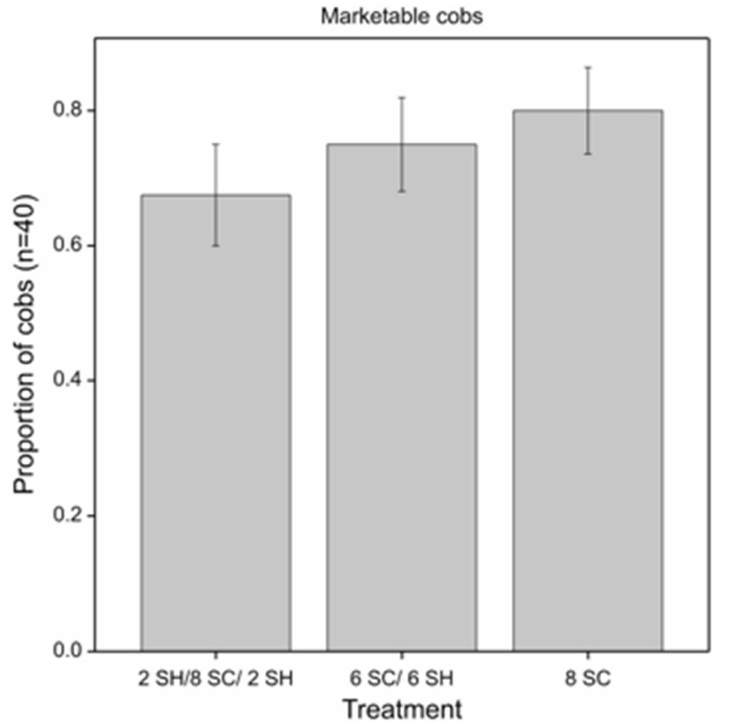


Figure 14. There was no significant treatment difference in the number of marketable (undamaged) cobs harvested. Bars are mean error.

We assessed green vegetable bug (GVB) damage, visible as depressed and discoloured kernels because sunn hemp is known to host GVB (Wang *et al* 2022). It was possible that introducing sunn hemp to sweet corn fields might increase the risk of GVB damage. Analysis of these data showed no significant difference for treatments with and without (8 SC) sunn hemp alongside the sweet corn (Q statistic = 6.0, df=2, p=0.05) (Figure 15A). It is possible that the GVB are moving between the sunn hemp and the sweet corn beyond the limits of the blocks with sunn hemp, increasing the incidence of GVB in the 8 SC treatment that had no sunn hemp adjacent. We do not have industry data for GVB incidence or damage, so it is possible that the level of damage observed is considerably higher than that observed in sweet corn monocultures and production systems where there are no nearby GVB hosts.

The sunn hemp sampling data reveals GVB present throughout the trial at similar densities across the bays, except for a peak in bay 12, on the edge of the trial on the last sampling date (Figure 15B).

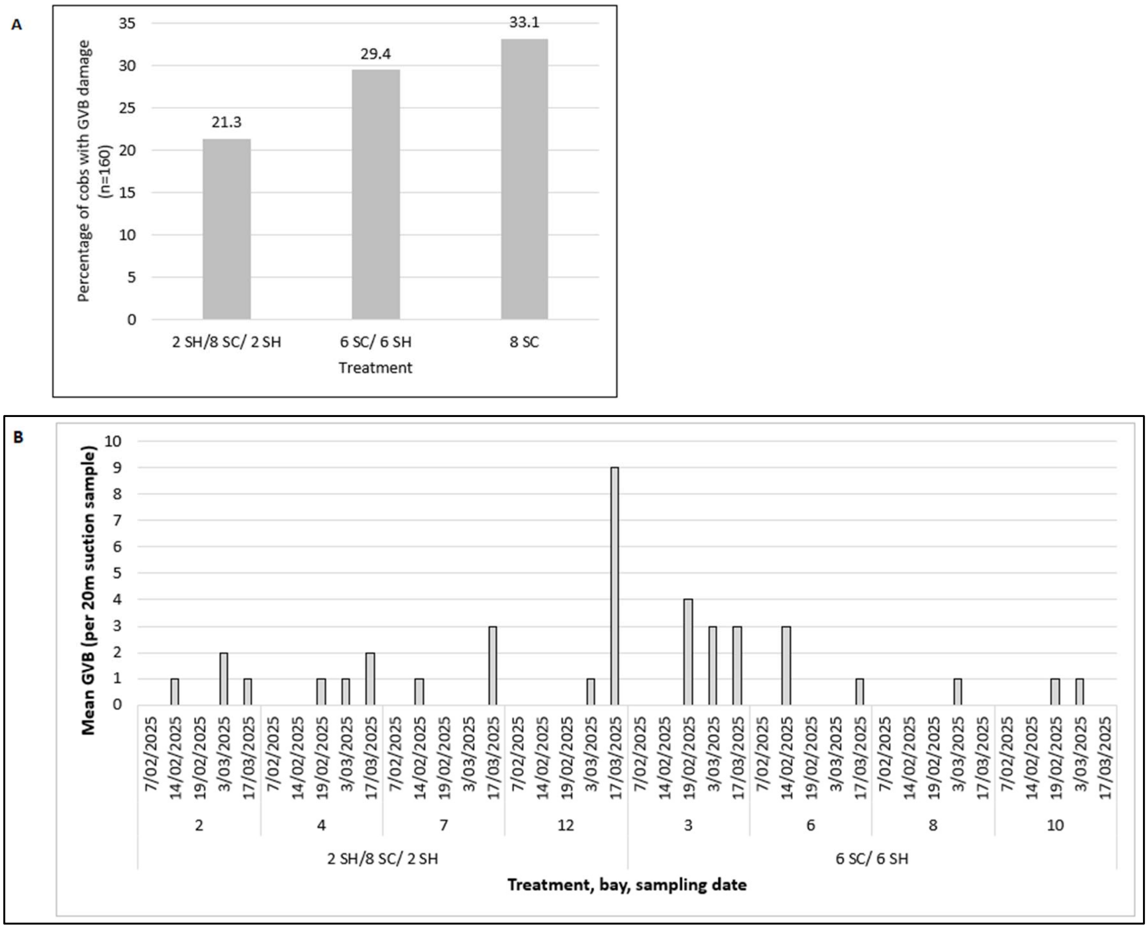


Figure 15. Sunn hemp is a known host for green vegetable bug, a pest of sweet corn during the cob development stage, impacting marketability of the cobs because of discolouring and shrinkage of kernels where the GVB have fed. A: the incidence of GVB damaged cobs was not significantly different across the treatments with and without sunn hemp components. B. GVB were captured in suction samples from the sunn hemp throughout the trial at similar densities across all dates and plots, with a couple of exceptions.

Conclusions and recommendations

The Bowen and Gatton trials in 2024-25 represent the first evaluation of a modified push-pull technique (PPT) for reducing the impact of FAW on a susceptible crop and contributed to our understanding of how diversification of the sweet corn production system to better support biocontrol.

We found that the intercrop options (sunn hemp, cowpea) were easy to establish and did not negatively impact on the production system. There are additional potential benefits to sweet corn production systems from including intercrop options, particularly sunn hemp, for example:

- summer cover crop in the north with the benefit of early establishment under irrigation with the last sweet corn planting
- nematode suppression (Wang *et al* 2019)
- increased organic matter and nitrogen fixation (ENY-717/NG043: Management of Nematodes and Soil Fertility with Sunn Hemp Cover Crop, Robinson & Reynolds 2021).

We observed no impact of the intercropping on oviposition of FAW in either trial. Whilst the overall FAW pressure (density) and defoliation in the vegetative stages was low, we did see significant treatment differences with the highest sunn hemp ratio treatment consistently having a lower damage rating than the other treatments.

In Bowen, the intercrop treatments yielded a higher percentage of marketable cobs than the sweet corn monocrop, but at Gatton we saw no treatment differences in the number of marketable cobs. In Bowen, the sunn hemp treatment had lower cob weight than the cowpea and sweet corn monocrop, most probably the result of shading of the sweet corn during cob development by the substantially taller sunn hemp, and potentially competition for other resources, constraining the ability of the sweet corn to realise its yield potential. We revised the design for the Gatton trial to limit shading, and the sunn hemp grew shorter.

Sunn hemp is known to be a host of green vegetable bug (GVB), and GVB were recorded in sunn hemp at Gatton (invertebrate populations in the sunn hemp were not assessed at Bowen), however, we did not see any difference in the level of GVB damage across the treatments with and without sunn hemp. Note that we do not know what levels are typically observed in commercial crops, and it is possible that we had an overall higher level of GVB damage in the trial across all treatments because of the inclusion of sunn hemp.

Natural enemy diversity and abundance was high in the trial, despite the repeated insecticide treatments. Egg parasitism by *Trichogramma pretiosum* and frequency of predatory bugs (particularly *Tytthus* sp and *Orius* sp) made a valuable contribution in terms of suppression of FAW infestations. This result confirms the potential that exists to harness the contribution of natural enemies in the sweet corn system. Other QDPI research has found limited efficacy in the commercial NPV products that would support the conservation of natural enemies in sweet corn crops.

At the field walks in Bowen and Gatton, growers and agronomists were very interested in the sunn hemp as a potential cover crop and were curious about the mechanics of handling the crop (aspects that are being address by other Hort Innovation investments). The additional benefits of sunn hemp warrant further consideration in terms of integrating it as an option that does not host FAW. It may not be the most effective option for disrupting FAW, but if the concept of diversifying the production system to capture a range of benefits, then evaluating other options could yield greater benefits in terms of FAW impacts.

Acknowledgements

We are grateful for the support provided by the Bowen and Gatton Research Station field staff for establishment and maintenance of trials. Ramesh Puri assisted with field and harvest assessments in Bowen and with industry communications.

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Appendix 7. Fall armyworm pheromone trapping to inform management – pilot studies, Bowen and Gatton 2025.

Melina Miles[1], John Stanley, [2], Adam Quade[1], Trevor Volp[1]. Queensland Department of Primary Industries. [1] Toowoomba, [2]Bowen.

Background

Pheromone trap catches of fall armyworm (*Spodoptera frugiperda,* FAW) can indicate the general presence and relative population size of this pest. Over the past 3 years, there has been increasing grower interest in pheromone traps as a tool for monitoring FAW. This interest has been sparked by investments in research through HIA2305-002FAX/AS21000 (pheromone lure development), and the VegNet RapidAim trap network monitoring FAW activity across horticulture production areas. Growers attending VG22006 (FAW area wide management) group meetings have expressed an expectation that pheromone traps will provide them with insights into the risk their crops face (pest density, timing of infestation) and inform their in-field management actions (e.g. to spray or not). If pheromone traps provided an 'early warning' of periods of high, or low, oviposition by females they would indeed be useful tools for growers and agronomists.

Whilst pheromone traps are used successfully in orchards for pest monitoring (Suckling 2000), and for monitoring seasonal abundance at a regional level (Fitt *et al.* 1989,Lytra *et al*. 2024), there no examples in the peer reviewed literature of pheromone traps being used successfully to provide field-scale information on FAW risk (see Cruz *et al* 2011 who conflate trap data and insecticide efficacy). There are also relatively few examples of trap catches being correlated with oviposition or crop damage for other Noctuidae, or in recent times (Tingle and Mitchell 1981, Johnson 1983, Witz *et al* 1992).

FAW pheromone traps use lures that attract only males, and there are many variables identified that influence what a pheromone trap catches, including trap location, nighttime temperature, wind direction, rain, local abundance, mating receptivity of female moths, abundance of females and so on. Furthermore, the level of males responding to pheromones indicates male reproductive activity, perhaps not indicative of the level of female oviposition on a nearby host.

Previous studies by QDPI (J Stanley) show that when pheromone traps are cleared weekly (moths counted), trap catches correlate poorly with fall armyworm infestation levels in adjacent fields. Recently automated, real-time traps (e.g. RapidAim) have become commercially available which could improve data collection and reveal useful correlations.

The aim of these studies is to explore the strength of correlation between FAW oviposition and daily pheromone trap catches at the field-level.

Methodology

Trial 1. Bowen Research Station

Sweet corn (var. Astronaut) was planted at the Bowen Research Station, in a trial plot 80 m long by 12m wide (16 rows of corn at 4 plants/m), grown under trickle irrigation as required. The trial was planted on 9th May 2025 and from day 2 post- emergence (17th May) it was scouted every day for two weeks. Plants were non-destructively searched for eggs on each day at 8:00am by stepping out 3 paces along each row and searching the plant that fell closest to the toe of the sampler. Twenty-seven plants were checked in each row on each day, totalling 432 plants per day.

Records were made of the egg masses as white, brown or black. Often egg masses needed to be lightly brushed with a tiny paint brush to remove hair-scales to reveal the colour of the developing eggs. White eggs are the freshly laid eggs whereas black eggs are about to hatch.

Two types of pheromone trap were operated:

1) Four typical bucket-&-funnel traps using Chemtica® PO61 lures were used to generate the manually daily cleared traps. The manual traps attract and kill the male moths for counting using the pheromone lure and a dichlorvos cube. Data is reported as an average of the four traps cleared and counted each day.

2) A single real-time (RapidAIM®) MEGA trap, located within 20m of the sweet corn plot. This trap is a catch and release. Data for the real-time trap was retrieved from the RapidAIM® dashboard (internet portal). The lure used in the RapidAIM trap is the same as that provided by RapidAIM and is not the same lure used in the bucket-&-funnel traps. Both types of traps were erected on posts at approximately 1.5 m from ground level.

Trial 1. Gatton Research Station

A block of maize was planted on 11 Nov 2025 at the Gatton Research Station. Maize was used rather than sweet corn as it is less costly to plant and the plants more robust when infested with FAW. We wanted the trial to be sprayed as little as possible to avoid disrupting the moth activity, and to be attractive to female moths for as long as possible. The block was approximately 94 rows x 100 m long. The crop emerged on 20 November and received an irrigation and two rain events (27 and 20 mm) prior to the first sampling event on 28 November.

Once the crop was sown, six manual bucket-style pheromone traps were placed around the western and eastern crop margin at approximately 50m intervals. The PheroLure™ (Insect Science) was used and replaced at 3 week intervals to maintain potency and checked every 1-2 days (Figure 1). Results from the RapidAIM and bucket trap in the Bowen trial provided the confidence that either trap would provide similar trap catches.

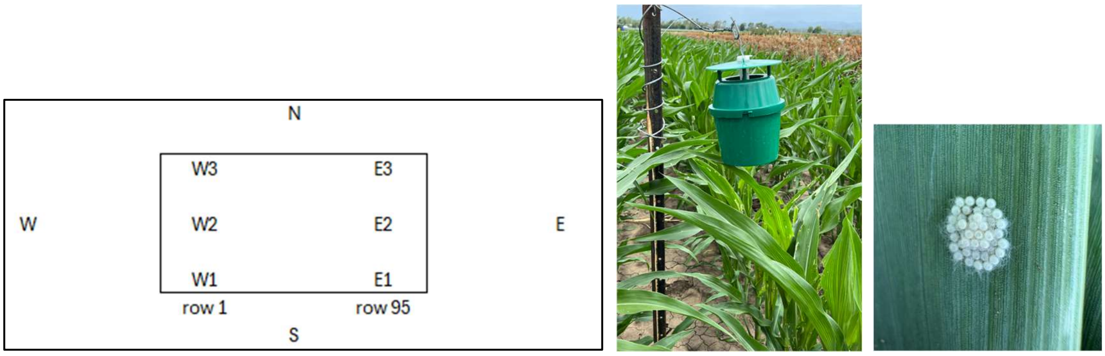

Figure 1. left: trial layout, the smaller box denotes the trial area. Centre: bucket-style pheromone traps were placed on the edge of the trial at 50 m intervals on the western and eastern sides. Right: a white FAW egg mass on a leaf.

At each sampling date, individual plants were destructively sampled from the plot to determine the number of white eggs deposited. Sampling was conducted on a grid with plants inspected every 3 metres along the row (north to south) and every 5th row across the field (east – west). On each sampling occasion between 630 and 665 plants were inspected from the trial plot.

Data were used to produce heatmaps of the distribution of egg masses for each sampling date (Sadie, R statistical software), and to examine the relationships between trap catches and trap catches and egg density.

Results and discussion

Trial 1. Bowen Research Station

Comparison of the two pheromone traps

There is a good relationship between the manual pheromone trap counts and those from the real-time automated trap (Figure 2). The correlation between the two trap types was R^2=0.76 (Figure 3).

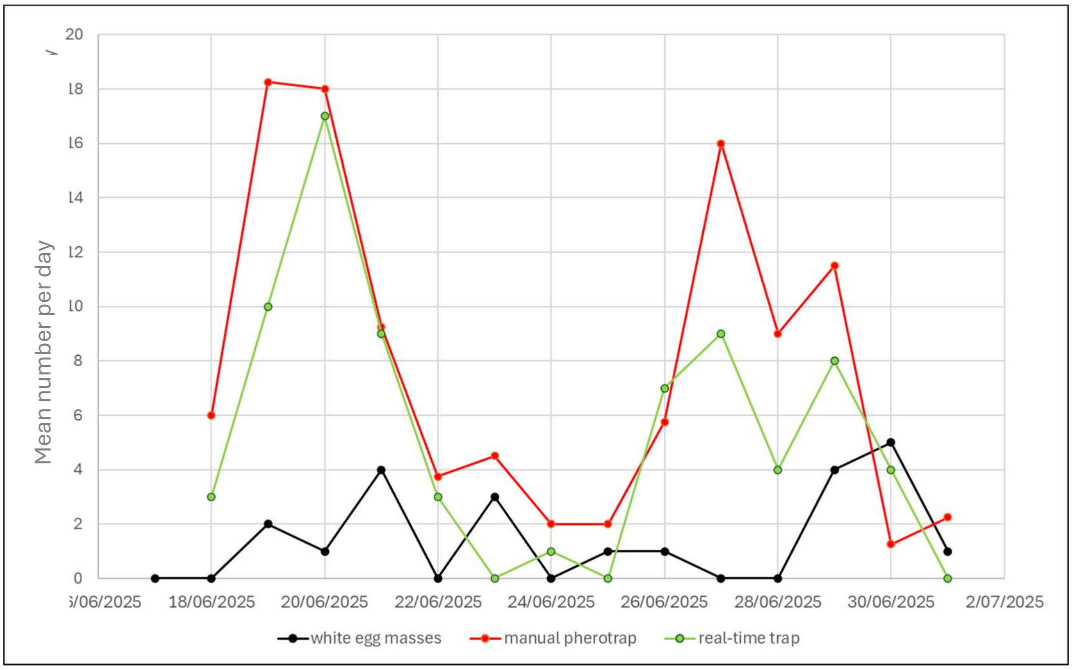

Figure 2: Mean daily FAW moth catches in the manual (n=4) and real-time (n=1), automated pheromone traps at the Bowen Research Facility, and total number of white egg masses (<24 hours old) from 432 plants, in the adjacent sweet corn crop.

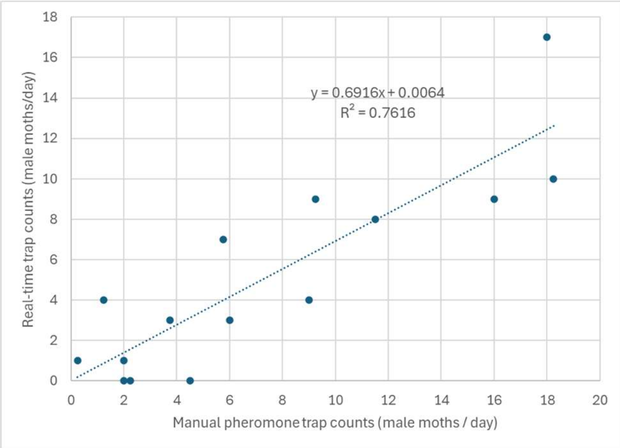

Figure 3. The correlation between manual and real-time daily pheromone trap moth counts over a 14-day period. Traps adjacent to an emerging sweet corn crop, Bowen Research Station, Qld.

Correlation between trap catches and oviposition

Very low pheromone trap catches appeared to correspond to low numbers of white eggs (Figure 2), but the relationship between higher male moth numbers in the traps and female oviposition activity in the crop is not consistent. The relationship, if present appears to be delayed by a day or two, perhaps reflecting the preoviposition period of the females following mating. The best correlation between the real-time trap and the appearance of white egg masses occurs with a two-day delay, $R^2 = 0.28$ (Figure 4). That is, the white egg masses correlate best with the pheromone trap catches two days after the peak in moth counts.

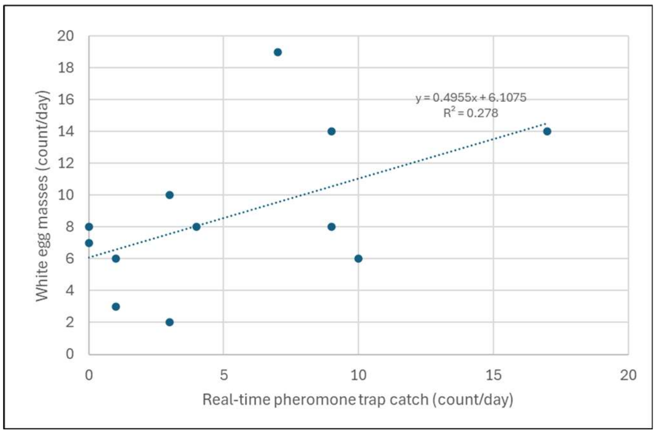

Figure 4. Correlation between real-time pheromone trap catches (number of moths per day) and daily counts of total white egg masses (n= 432 plants sampled) in the adjacent sweet corn field plot.

Despite temperatures and FAW moth numbers being low, correlations between trap catches and the number of eggs deposited in the crop were observed.

The high correlation between the catches in the two pheromone trap types is reassuring for growers contemplating whether they need to use an automated trap or persist with manual traps. The goodness of the correlation is likely highly influenced by the increased precision obtained from daily, rather than weekly, trap counts. Growers do not typically check pheromone traps daily, so the automated traps offer an improved option for monitoring moths with informing immediate management decisions as the goal.

The relationship between pheromone trap counts and the number of white egg masses is not strong but at $R^2 = 0.28$ suggests that pursuing this research across regions and at different times of the season when FAW activity is higher is warranted.

This pilot has established a useful methodology for examining the relationship between pheromone trap catches and FAW activity that directly impacts the crop (oviposition as an indicator of future damage). This experience informed the design of the subsequent trial undertaken later in 2025 at the Gatton Research Station (trial 2).

Trial 2. Gatton Research Station

There was considerable variation in the number of moths caught at each traps locations, and at each check date for the duration of the trial (Figure 5). The higher the moth counts, the greater the variation between the traps (Figure 5B).

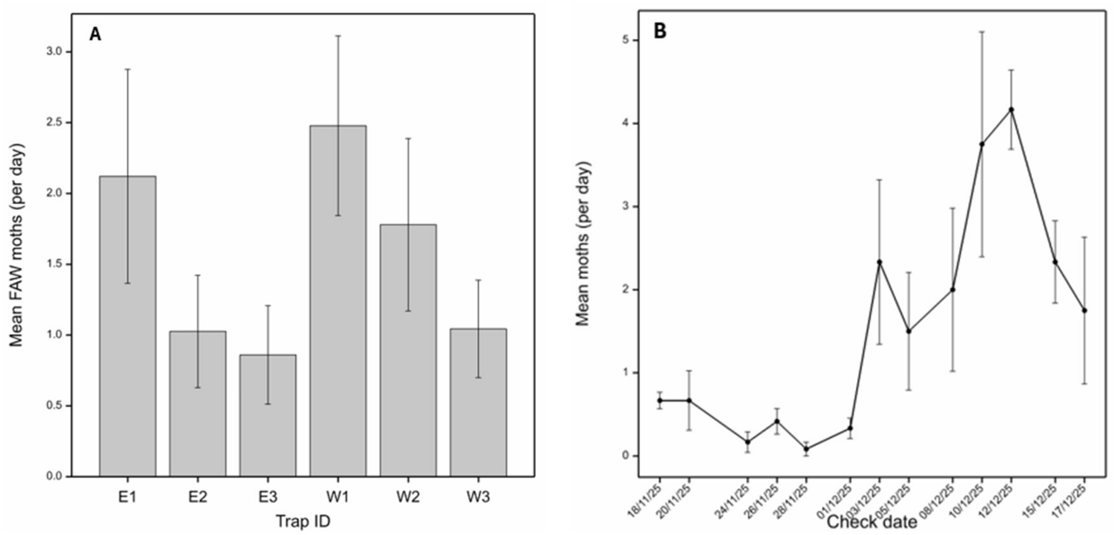

Figure 5. There was considerable variation in Fall armyworm pheromone trap catches amongst the six trap locations (A) and the collection dates (B). Bars are standard error of the mean.

RapidAIM (Nancy Schellhorn, pers comm 2025) promotes the deployment of multiple traps in a grid across a management unit. Our initial results support the need for this approach to allow for the variation seen in trap locations over time.

Visual representation of the egg mass distribution during the trial (Figure 6) shows a trend towards higher frequency of egg masses on the western side of the trial. A non-random distribution indicates that a structured sampling plan is required to reliably determine the level of infestation of FAW (Binns & Nyrop 1992). Currently there has been limited assessment of in-crop distribution of FAW eggs and larvae in crops and consequently there are no guidelines for crop monitoring to assist growers and agronomists. More work to determine if edge effects are characteristic of FAW infestations, and appropriate sampling strategies would be of value to growers and agronomists engaged in making management decisions for FAW. An effective sampling strategy for FAW must be developed in conjunction with existing strategies for other key pest species e.g. *Helicoverpa*, *Nezara viridula*, and natural enemies e.g. egg parasitoids, larval parasitoids, predators.

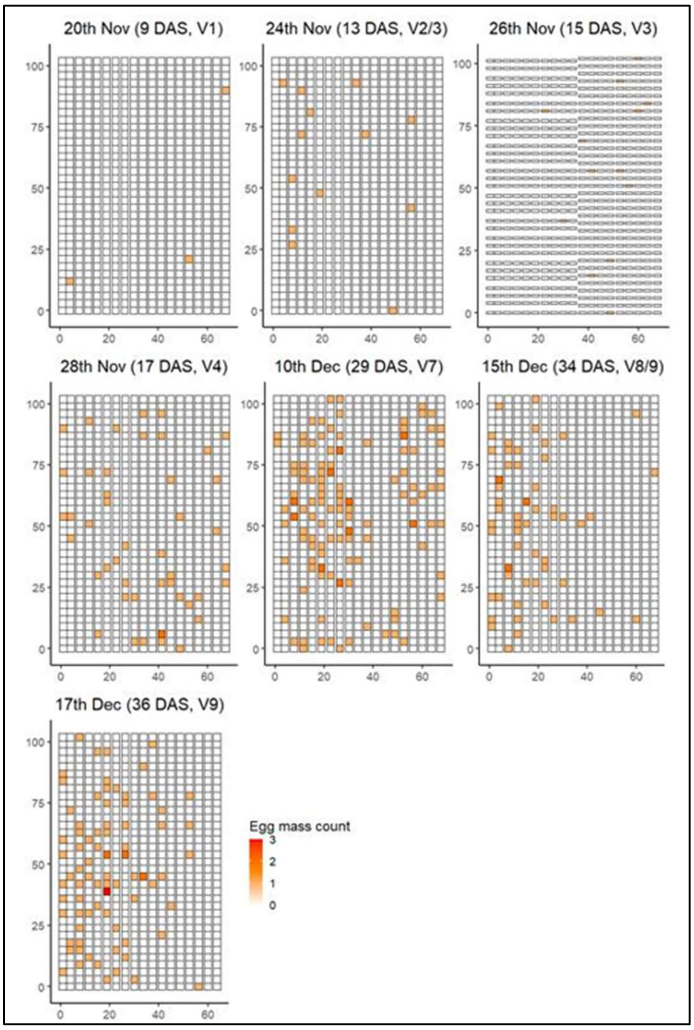

Figure 6. Heatmaps showing the distribution over time of egg masses per plant. Crop stage in brackets. DAS = days after start of the trial

When we examined the relationship between moth trap catches and the density of white egg masses across the trial we found no relationship (F=0.5, df=(1,6), p=0.511). Moth trap catches and white egg mass density for each sampling occasion is presented in Figure 7.

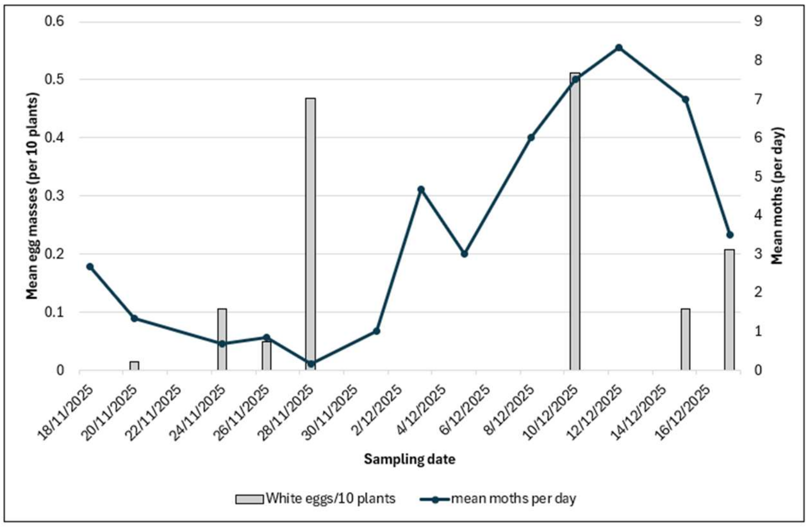

Figure 7. There is no relationship between FAW moth trap catches overnight and oviposition (white egg masses) the following day. Note the different y-axis scale for moth and egg mass data.

Conclusions and recommendations

These trials set out to test whether pheromone traps that attract male FAW moths could be a useful addition to a grower's monitoring program, to support management decisions about if and when to treat a crop.

The initial trial in Bowen showed that the manual bucket trap and automated RapidAIM trap catches were strongly correlated. This means that growers can use either option with confidence. The automated traps clearly provide the convenience of providing data without having to visit the trap. Strategically placed manual traps that can be visited daily, or regular intervals, would provide the same information.

In the second trial, at Gatton, multiple traps were placed around the trial block and provided the opportunity to see just how variable trap catches could be over a relatively small area. This finding is consistent with studies on pheromone trapping with other noctuids. These data indicate that multiple traps provide a more robust and reliable view of FAW activity in the vicinity of the crop.

A weak relationship was found between trap catches and the density of white egg masses in the Bowen trial, but no such relationship was found in the Gatton trial.

More data from a variety of fields with varying FAW activity, over longer observation periods, would provide the opportunity to examine more thoroughly the relationship between trap catches and in-field infestations. Gridded arrangement of automated traps at different scales on farms would also be useful approach to further testing the question of pheromone trap value, and the appropriate density of traps that may be necessary to provide an effective indication or forecast of FAW risk.

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