Understanding the key market drivers that will underpin the development of an Insecticide Resistance Management Strategy for FAW

Final Technical Report

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Plant Health AUSTRALIA

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Disclaimer:

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Key noctuid insecticides mentioned throughout this report

Group	Brand	Active
1A	Lannate® L	225 g/L methomyl
3A	Dominex® Duo	100 g/L alpha-cypermethrin
3A	Talstar® 250EC	250 g/L bifenthrin
3A	Decis® Options	27.5 g/L deltamethrin
3A	Trojan®	150 g/L gamma cyhalothrin
5	Success® Neo	120 g/L spinetoram
5 + 18	Intrepid® Edge	300 g/L methoxyfenozide + 60 g/L spinetoram
6	Affirm®	17 g/L emamectin
6	Proclaim®	44 g/kg emamectin
6 + 4A	Skope®	32.5 g/L emamectin + 218 g/L acetamiprid
22A	Steward	150 g/L indoxacarb
22A	Avatar® Evo	303 g/kg indoxacarb (300 g/L s-indoxacarb)
22A + 15	Plemax®	320 g/L indoxacarb (240 g/L s-indoxacarb) + 80 g/L novaluron
28	Vantacor®	600 g/L chlorantraniliprole
28	Altacor®	350 g/kg chlorantraniliprole
28	Coragen®	200 g/L chlorantraniliprole
28 + 4A	Durivo®	100 g/L chlorantraniliprole + 200 g/L thiamethoxam
28	Fortenza®	600 g/L cyantraniliprole
28	Belt®	480 g/L flubendiamide
31	Vivus Max	Nucleopolyhedrovirus of *Helicoverpa armigera*
31	Fawligen	Nucleopolyhedrovirus of *Spodoptera frugiperda*

Pest abbreviations used through put this report

FAW	Fall armyworm (*Spodoptera frugiperda*)
GVB	Green vegetable bug (*Nezara viridula*)
Heliothis or Helicoverpa	*Helicoverpa punctigera / Helicoverpa armigera* complex
RBSB	Red banded shield bug (*Piezodorus hybneri*)
RGB	Rutherglen bug (*Nysius vinitor*)

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1. Executive summary

The arrival of Fall armyworm (*Spodoptera frugiperda*) (FAW) into Australia in 2020 has triggered a significant increase in insecticide application in some crops / geographies as managers implement strategies to protect crops from economic damage.

Frequent insecticide applications targeting FAW is leading to a concern that this may accelerate selection for insecticide resistance in this species. Additionally, due to considerable cross over between products, regions and timing of insecticide applications for *Helicoverpa* management, there is concern that increased spraying for FAW may also accelerate resistance selection in *Helicoverpa* and other noctuid moth species.

A well implemented resistance management strategy can delay or prevent resistance. Plant Health Australia commissioned this report to understand the multi region and crop issues that would need to be considered if developing an insecticide resistance management strategy (IRMS) for fall armyworm.

To evaluate the need and understand likely design features for any IRMS, it is important to first understand the current pest impact by location in key crops; infestation timing and intensity of impact; current management approaches that are working (or not) and the extent of selection pressure for resistance/risk to specific insecticides or modes of action.

This report summarises desktop research and more than 50 depth interviews conducted in 2022 with agronomists and researchers from southern NSW to northern Western Australia, operating across a wide range of horticultural, coastal and broadacre grains crops. Recommendations to enhance current management approaches have been presented, along with considerations for any potential future IRMS. Due to the diverse cropping systems and geographic regions covered by this research, significant regional analysis is also provided to assist with regional tailoring of management and resistance management responses. Areas of further research and/or extension required have also been identified.

Distribution of fall armyworm – FAW have rapidly dispersed across northern Australia and are now a key pest in host crops throughout coastal Queensland, Northern Territory, and northern Western Australia. In these regions, populations are present for most of the year, however life cycles take significantly longer during winter months.

In the majority of New South Wales and Queensland cropping areas away from the coast, FAW are currently subsiding almost completely over winter and start to rebuild in spring. Many reported peak FAW activity in December and January.

Key host crops – Sweet corn and maize are clearly the key host crops of FAW in Australia. While both are attacked at all growth stages, the primary stages requiring protecting are young plants (up to approximately V4-6 growth stage) as excessive damage can lead to plant mortality; and then again during early cob formation (especially tasselling to silking).

In high value sweet corn there is zero tolerance for crop damage. As a result, the number of insecticide applications is frequently high. Sweet corn grown in Queensland over summer reported (by far) the most frequent use of insecticides targeting FAW.

High FAW pressure in maize and the subsequent insecticide program required in a relatively 'low value' crop has already seen a significant reduction in maize being grown as a rotation crop by many growers.

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While only grown in small areas and certain specific locations, those managing capsicums in Queensland or grass pastures (particularly establishing Rhodes grass or some millet species) reported major FAW pressure which required regular treatment.

Vegetative sorghum was also reported to host FAW, although typically this only required insecticide intervention when grown in close proximity to maize. Once sorghum heads appear, several reported that FAW disperse, presumably looking for a more attractive host crop.

Outside of the crops listed above, FAW generally only requires insecticide control in other crops where pressure is extreme – which is frequently due to a high incidence of maize or sweet corn in the immediate vicinity.

Management approaches

Planting date – Several reported that early spring or late winter planting of maize was a useful avoidance strategy, resulting in successful crop establishment before the main FAW pressure arrives. However this did not always suit local agronomic practices.

Insecticide use – Following the arrival and rapid dispersal of FAW, several 'emergency use' permits were issued to allow users to legally apply a range of insecticides in a wide range of crop situations. Typically these permits were issued at application rates and crop use situations that mimic currently registered uses for control of *Helicoverpa spp*.

Subsequent research has shown that for indoxacarb (in particular), the rate required for acceptable control of FAW is significantly higher than the current maximum label rate for *Helicoverpa.* In other situations, some products where a permit exists are largely ineffective on FAW (e.g. synthetic pyrethroids and to a lesser extent organophosphates) as resistance was present in FAW populations before arrival. Review of current permits is required, and some should discontinue.

In broadacre crops, chlorantraniliprole (as Vantacor® or Altacor®) was consistently identified as a preferred insecticide for FAW. Commonly this position appeared to be a carryover from *Helicoverpa* experience where the knockdown efficacy, length of residual control, selectivity to key beneficials and comparative cost per hectare (in broadacre grains) has positioned chlorantraniliprole as the best 'value for money' proposition when targeting *H. armigera*. Several agronomists who were taking this position of chlorantraniliprole as the 'best' against FAW had little firsthand experience with other insecticides against FAW. Where there was firsthand experience, it was often relative to indoxacarb (which is generally the main alternative to chlorantraniliprole in broadacre grains for *H. armigera* – but as mentioned above, is significantly weaker on FAW).

In horticulture, chlorantraniliprole (as Coragen®) does not appear to hold the same strong market dominant position as in broadacre crops. This is likely to be a factor of a lower application rate being used (for both *Helicoverpa* and FAW) and less of a price advantage relative to competitors. Typically the lower application rate in horticultural crops for *Helicoverpa* has been able to be supported as the retreatment interval is more frequent.

It should be noted that the application rate for chlorantraniliprole against FAW on USA labels is significantly higher than rates on Australian permits (especially for horticultural crops). In discussion with registrants, it is likely that Australian chlorantraniliprole rates will be increased as emergency use permits are transitioned to full label claims.

Emamectin (as Affirm®) does not appear to be widely used in broadacre for FAW. This is likely due to the perception of shorter residual than other products such as chlorantraniliprole, while also being more expensive. However, those who had tried it in vegetative maize reported generally good levels of control, which is supported by recent efficacy trials. In horticulture (as Proclaim®), emamectin was often mentioned as a primary tool for *Helicoverpa*, and now FAW, as generally the shorter intervals between applications in rapidly growing crops negates the length of persistence advantage of chlorantraniliprole.

Spinetoram (as Success®) is predominantly used in horticultural crops for *Helicoverpa* and western flower thrips (WFT). While it is considered expensive, it is used for WFT due to lack of other effective options. Adding emergency use for FAW has provided good control of FAW where the product is already being used in rotation for other pests. In broadacre crops, the price per hectare has generally seen spinetoram not consider at all, despite many understanding that it is one of the better performing insecticides against FAW.

Synthetic pyrethroids and organophosphates were initially tried against FAW, but (mostly) this has been abandoned due to lack of performance. However the carbamate insecticide methomyl is still occasionally used in specific situations.

In sweet corn, most appear to be using all effective insecticide options in heavy rotational frequency, yet still experiencing heavy damage in times of peak pressure. There appears to be little to no opportunity to reduce the frequency of use of any particular insecticide until either more modes of action are available and/or alternate and effective non-insecticide management strategies are introduced.

<u>Insecticide application</u>

Most advisers interviewed understood the important of insecticide coverage, especially in large canopy crops such as maize and sweet corn, but many were unsure of the level of coverage currently obtained. Some reported application of insecticides via overhead (pivot) irrigation (i.e. chemigation) with generally good results.

Several sought more information on improved insecticide application.

<u>Traps and monitoring</u>

Physical crop monitoring was identified by all as critical for early detection of FAW. However this is time consuming, and therefore expensive. This is often hard to justify in low value broadacre crops and/or crops where growers have not needed to pay for monitoring previously.

Agronomists are interested in the potential of pheromone traps to identify the presence of FAW. Ideally managers would like these traps able to substitute for the need for in-crop scouting - with insecticide applications being scheduled based on trap count numbers. This is especially the case in regions or crops where FAW pressure is typically low, as currently these situations are consuming a large amount of agronomist time and often detect nothing, but the crop still needs to be scouted 'just in case' FAW are present.

Failing this, value is still seen in using traps if they could signal the 'arrival' of FAW into the district, and thus avoid the need for earlier monitoring of crops before FAW are present.

Unfortunately it was commonly reported that there was frequently very poor correlation between FAW pressure observed in crops and what was detected in the currently available traps, so in many situations agronomists are losing interest in this as a support technology.

<u>Baiting</u>

Many are interested and several have tried, the concept of applying a bait (commonly Magnet®) plus methomyl insecticide in strips through the paddock as a 'lure and kill' strategy for adult moths. This allows a broadspectrum insecticide such as methomyl to be applied to only a small area and thus be less disruptive to beneficials.

A small number of managers interviewed saw ongoing benefit of this approach, generally when applied in conjunction with other broadcast insecticide treatments. However a larger sample suggested that this technique works best when pressure is low – but in this situation most growers would elect to do nothing and wait until numbers breached established thresholds. Once FAW numbers are over threshold, there was often low confidence in the bait being able to 'replace' a broadcast insecticide application.

<u>Viruses</u>

Most interviewed had experience with nuclear polyhedrosis virus (NPV) (e.g. Vivus® Max) to target *Helicoverpa armigera* in a range of crops (especially sorghum). Several had tried Fawligen® which is a different NPV specially targeting FAW, but generally have not achieved results similar to their experience with Vivus on *Helicoverpa*.

Vivus is very effective on medium to larger *Helicoverpa* and, once infected, these larger larvae can often be found clinging to foliage and oozing virus from their bodies, which then becomes a source of ongoing infection in the crop. In contrast, Fawligen is only effective on small (less than 3rd instar) larvae so is best applied to young crops where direct contact of small FAW can be achieved. Those that are killed drop off the crop and are no longer seen. The result is that typically Vivus can be applied once at the start of head initiation in sorghum and often provide ongoing protection from that point forward. While Fawligen in maize often requires multiple applications with excellent coverage (e.g. best applied through chemigation techniques).

Some agronomists, particularly on the Atherton Tableland and in some parts of coastal Queensland and New South Wales reported evidence of native metarhizium virus infecting FAW. This was generally correlated to periods of very high humidity. There was considerable interest in further understanding the impact of native viruses and the potential for 'sprayable' applications.

<u>Beneficials</u>

There was generally a high level of interest in and concern for maintenance of natural beneficials. Most advisers want to use 'soft' insecticide treatments where possible, but almost all sought more information on which species are most important for FAW management, to assist in guiding their insecticide choice.

Resistance management strategies

Almost all interviewed were conscious of overuse of insecticides leading to selection of resistance. In broadacre grains, this discussion was predominantly focused on the Group 28 mode of action (and chlorantraniliprole in particular), while in horticulture it was more generally across all modes of action.

When it came to specific implementation strategies or need for a formal strategy, almost everyone suggested that it would be extremely difficult, if not impossible to implement a FAW IRMS on a broad scale due to region differences in pest pressure and cropping systems, along with cross over of insecticide use for *Helicoverpa*.

As a result of the challenges identified and the lack of evidence of changes in sensitivity to the primary insecticides currently in use for FAW control, our staged recommendations for resistance management are:

Short term

1. Industry to invest in ongoing annual resistance testing in targeted regions for each important mode of action. This will detect early shifts in insecticide sensitivity and signal the urgency to adapt use patterns. This information should be made public each year. Without ongoing industry commitment to this, there is arguably little point in developing further resistance management strategies.
2. The market seeks improved understanding on the best management approach for FAW, incorporating both insecticide and non-insecticide tactics, dynamic spray thresholds for all key crops and application advice. A lot is already known (largely gathered through trial and error) about what is working for FAW. But rarely does any individual understand the collective knowledge across the industry. There is strong evidence of some insecticide applications being applied prophylactically in case FAW populations rise rapidly. This appears to be especially happening where the agronomist lacks the confidence to be able to bring the population back under control. Delivery of 'best management practice' industry extension is likely to see an immediate reduction in insecticide applications if users gain more confidence in workable management strategies. Such extension should be prioritised, acknowledging that there are still data gaps (especially around thresholds and beneficials).
3. There is opportunity to improve product labelling to place greater emphasis on the number of permissible applications and the timing between subsequent applications, from a resistance management perspective. Historically the number of labelled applications has often been guided by residues in produce, however many users perceive that this is resistance management advice.

Medium term

4. Monitor for sensitivity changes to key modes of action and be prepared to initiate a more restrictive IRMS if changes in sensitivity occur. Implementing an industry wide IRMS for FAW is likely to require cross industry / RDC / State integration and require significant financial investment to develop, implement and extend the information to users. To be successful, this will require a commitment to ongoing annual funding to keep the strategy current and front of mind of users.

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2. Key findings

Fall armyworm (*Spodoptera frugiperda*) (FAW) was first detected in far north Queensland in early 2020 and immediately started to disperse both to the south and west. Within 2 years of arrival in mainland Australia, FAW had been detected across tropical Australia and as far south as Perth in Western Australia and almost to the New South Wales (NSW) / Victorian border on the eastern seaboard.

In far northern Australia, FAW is now established as a 12 month of the year pest where sensitive host crops are being grown. Lifecycle generation is rapid over summer months (i.e. less than 30 days), while lifecycles extend over winter in relation to temperature.

In sub-tropical regions south of approximately the Tropic of Capricorn, FAW numbers were reported as declining over winter months, often being quite low in early spring. As temperatures start to rise, lifecycles shorten. Peak FAW numbers are reported to occur from late December through January and into February. Several agronomists in sub-tropical regions reported that FAW populations appear to disperse / reduce from February. It is not yet understood if this is perception or reality, or the reasons for this, should science validate this observation.

Testing has confirmed that the population of FAW arriving in Australia already contained a high frequency (44 to 199-fold) resistance to synthetic pyrethroids (SPs), which is most likely due to enhanced metabolism (Bird, Hopkinson, & Grundy, Resistance update - mites, aphids, helicoverpa, mirids and SLW, 2021). This was confirmed by several field failures where SPs were initially tried as a control solution early in the outbreak. This same research indicates that there is some minor, but significant, resistance to Group 1 insecticides (organophosphates and carbamates) i.e. 11-fold tolerance to methomyl.

This understanding of current resistance and a desire to prevent/delay resistance to newer insecticides, has driven industry to consider the need for resistance management strategies for FAW. It is also acknowledged that in many crops, insecticides will also be applied to control caterpillars of other noctuid moths (especially *Helicoverpa*) plus other pest species. So any resistance management strategy focused on FAW will also need to consider other associated pests and potentially also non-host crops for FAW.

In addition to rapid dispersal across the landscape, the reported host range of FAW is also very wide. FAW are known to prefer monocotyledon crops from the order Poaceae, however there are several reports in the literature where a wide range of broadleaf species can also host FAW.

To understand the extent FAW impact crop production and the potential risk of selection for insecticide resistance, Plant Health Australia (PHA) commissioned Independent Consultants Australia Network (ICAN) to develop this report to understand the key crops and locations where FAW is having the most impact on agricultural production; what insecticides are currently being used, how often and to what effect; what strategies are working, or not working; and how do mangers perceive future control strategies that are likely to be required, including how insecticide resistance management fits into production plans.

To achieve this, ICAN undertook desktop research complemented by over 50 individual depth interviews of experienced agronomists, advisers and researchers. Interviews were concentrated in Queensland and northern NSW to align with where the majority of FAW impact is currently being experienced. A small number of interviews were also conducted in the Northern Territory, northern

Western Australia and southern NSW, reflecting the smaller area of 'at risk' crops grown and/or lower levels of pressure being experienced from FAW in these regions.

This report will assist to inform the need to consider development of a resistance management strategy for FAW and, should a strategy be required, provide background information of the key regional and crop considerations that will need addressing.

Crops of primary concern

<u>Sweet corn and maize</u> are strongly the preferred host for FAW. All maize varieties appear very attractive to FAW. The key important crop growth stages being:

- Establishment to V4-6 – heavy FAW populations at this time may kill young plants, or severely retard agronomic development.

  Many advisers were then prepared to accept 'some' level of vegetative feeding by FAW from around V6 to V10-12 growth stage, however it was emphasised that sufficient green photosynthetic leaf area had to be maintained to ensure later growth rates were not compromised
- V10-12 to tasselling – Most wanted to ensure FAW populations were low at this stage, as yield expectations were being set and protection of the tassel was important for pollination. (Vegetative leaf number is a guide only, with reproductive commencement varying slightly with variety. Generally tasselling in sweet corn commences approximately 2-3 leaves earlier than gritting corn)
- Silking – Almost everyone interviewed recognised that silking was a critical stage for cob protection. Larvae of FAW (and *Helicoverpa*) can feed on the silks and utilise the silks as an easy entry point into the young cob, however FAW were also regularly reported as entering cobs from both the sides and bases as well as from the top
- Those growing maize varieties for silage were slightly less concerned about cob protection, placing more emphasis on biomass protection.

Several of those growing maize for grain noted that, where maize can be planted early (i.e. late winter to early spring) in sub-tropical regions (plus the Atherton Tableland), then early FAW pressure can often be 'manageable' when complemented by effective insecticide applications. However, when planted in the November/December planting window, crops may be 'decimated' by FAW and for some growers, this has already driven a switch to early planting dates. Whereas for others where early planting does not suit, they have largely already moved away from growing maize in this later planting window. Several advisers mentioned that the gross margin for maize was challenged by more financially attractive crops even before the presence of FAW. However with the new normal of several insecticides being required, this was reported as a tipping point for several. Typically advisers were suggesting that if it is possible to still grow maize with 2 (or possibly 3) insecticide applications, then some growers are likely to continue growing maize for grain where there are individual reasons for doing so. Most believed that this was only likely to be possible with an early planting date in higher pressure areas such as the Atherton Tableland.

In tropical regions and especially in sugarcane production systems, maize for grain may be grown over winter as part of a 12-18 month 'break' between cane crops. Typically there will be a summer pulse crop either before or after (or both) the maize crop, before returning to cane. In these regions, winter sown maize is being severely damaged by FAW and advisers reported that some growers are persisting with maize but applying more frequent insecticide applications, while several have already dropped maize from the rotation in 2021 and are still determining what a 'new' rotation may be.

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Consistent feedback from agronomists was that prior to the appearance of FAW, establishing maize crops were only rarely (if ever) checked for insect pests, while vegetative maize would never be checked. Crops 'may' have been checked for *Helicoverpa* during early cob set.

Sweet corn is the main crop of concern. Three primary factors drive this.

- Like all maize varieties, sweet corn is very attractive to FAW. Some suggested that sweet corn is even preferentially targeted by FAW over gritting varieties when grown next to each other
- There is zero consumer tolerance for cob damage. It was mentioned that should *Helicoverpa* enter the cob, they would generally only feed on the cob tip, so it was still possible to cut off the tip and utilise the remaining cob into pre-packaged sweet corn for the supermarkets. However, FAW will feed all the way down the cob, making the whole cob unsaleable. There were reports from Bowen that even with extensive insecticide application, there can be still up to 10% losses at harvest
- Customers demand fresh sweet corn 52-weeks per year. To meet this demand, larger growers supplying supermarkets need to have northern & southern production regions (typically Bowen and the Lockyer Valley for east coast and Carnarvon and Perth for west coast) and need to continuously plant blocks every few days and harvest almost every day. As a result, they do not see an opportunity to use planting date as a management tool.

These factors result in growers spraying sweet corn between 6 and 10-12 insecticide applications per crop (with up to 15 occasionally reported). Insecticide plus application costs are often in the range of $1000 to $1500 per hectare.

<u>Capsicum</u>. While not a widely grown crop in terms of hectares, where it was grown all advisers interviewed reported similar experiences in that neonate FAW preferentially target the stem of very small capsicum bells, making a small and almost undetectable entry point. Once inside the bell they can continue feeding and developing through their instars, usually without any externally visible symptoms until close to harvest where the bell prematurely changes colour and is rotten on the inside.

For these reasons, most managers in high pressure FAW regions are currently instigating a robust insecticide rotation (as often as 3 days between applications) from flower initiation to harvest.

<u>Tropical grass pasture</u>. In tropical regions, some tropical grass pastures were being hit hard by FAW. In particular, freshly planted Rhodes grass and some millet species were reported to be heavily attacked, particularly during emergence. Prior to FAW, these pastures were typically never checked or treated for insect pests.

<u>Sorghum</u>. Where sorghum is grown in proximity to maize or sweet corn it may come under heavy pressure from FAW spillover. In the establishment phase, this may sometimes require insecticide application to ensure plants are not killed. Once in the vegetative stage, most were reporting that 30-40% (some even suggesting 50%) vegetative damage can be sustained without significant damage to grain yield, so several are not spraying vegetative sorghum despite heavy loss of leaf tissue.

Similar to maize, where crops were grown for grazing / silage, more importance is placed on green leaf retention, which may result in additional early insecticide application, especially in high pressure coastal tropical regions.

Most interviewed reported that once sorghum heads start to emerge, generally FAW appear to disperse – presumably looking for a more attractive host. This is the growth stage where traditionally scouting commences for *Helicoverpa*.

<u>Summer pulses</u>. Soybean, mung bean and peanuts occasionally require treatment for FAW, however this is generally only occurring where they are being grown in close proximity to maize / sweet corn, or in very high pressure FAW regions (which by default are usually areas with significant planting of maize / sweet corn).

While direct insecticide applications for FAW may not be high in these crops, they are important to consider as soybean and mung bean in particular will regularly receive 1-3 insecticide applications for *Helicoverpa* +/- sucking pests, and generally these insecticides will be from the same mode of action (MOA) group and often being applied at similar timing to FAW applications in other crops.

In summary, our research found that maize and sweet corn were the primary economic host crops for FAW. In regions where these crops were being grown, spillover pressure into sorghum and occasionally onto other summer crops was a common observation. FAW populations are also sustained in several summer pastures and tropical grass crops and weeds. Where these crops are grown in isolation from maize / sweet corn, there may be only the occasional need for insecticides targeting FAW, particularly if these crops can be grown outside of peak FAW numbers.

For other horticultural crops (outside of sweet corn and capsicum), ginger has been identified as another key host of FAW. However ginger is only grown on very small areas in Australia and our research did not cross any advisers with direct experience in ginger production. Green peas / snow peas are not regularly grown in any volume in northern climates, however a single adviser mentioned that FAW may be found in these crops. While cucurbits (pumpkins, melons) may be treated for a range of caterpillar pests, which may occasionally contain some FAW.

A few advisers in far north Queensland mentioned that FAW can sometimes be found in tree crops (in particular avocado) but also mentioned that these crops are regularly sprayed for other caterpillar pests and those products are also likely to be controlling any FAW that may be present.

Other than crops specifically mentioned, we did not encounter additional crops that were requiring specific and regular management for FAW. Some crops such as sugar cane or rice have also been suggested to be primary hosts for FAW, but agronomists interviewed were generally not experiencing problems in these crops – with the exception of crops that are very weedy (in particular barnyard grass was mentioned as a host weed species).

Understanding host crops and where FAW is doing damage has particular relevance to minor use permits for FAW, as several permits are currently in place to support insecticide use in crops where FAW are not reported as a pest of major concern.

Key insecticides

It became very evident through this research that initial management strategies employed for FAW by advisers, started with those that have been tried and tested for *Helicoverpa* management in northern Australia. Advisers are typically applying the same insecticides, at the same application rates and via (mostly) the same application techniques. While there are some similarities between these pest species, it was apparent that many *Helicoverpa* management practices are in need of modification when treating FAW.

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This was reinforced by industry initiating a large number of minor use permits for FAW, with almost all of these picking up use rates and use patterns verbatim from those currently recommended for control of *Helicoverpa*. For many users, this creates an expectation that 'what works for *Helicoverpa* should also work for FAW'.

With regard to specific insecticides:

Pyrethroids and organophosphates were trialled in the first year of FAW in Australia, generally with poor results (especially with pyrethroids). Most use of SPs has been discontinued due to very high levels of resistance. A strong recommendation from this report is that those holding minor use permits for use of pyrethroids against FAW should consider if the advice they are providing to users is sound. Not only does it appear the pyrethroids are likely to be ineffective and therefore unlikely to protect growers' crops, but their use is also likely to negatively impact overall insect management by decimating natural beneficial populations.

Carbamates - There are still some applications of methomyl being applied in specific situations – in particular when used in conjunction with an attractant (e.g. Magnet®) in 'lure and kill' applications; or sometimes when a very short withholding period insecticide is required close to harvest.

Chlorantraniliprole – In broadacre crops, Vantacor® (and previously Altacor® before rebranding in 2021) has developed a market leading position as the preferred option for control of *Helicoverpa* in several summer crops. For many, this is a value proposition of efficacy, length of residual control, relative safety to key beneficials (in particular *Trichogramma* which is an important parasitoid of *Helicoverpa*), a large range of registrations in most key crops, and the relative price versus competitor insecticides.

For these reasons, it appears that several agronomists interviewed are of the (strong) opinion that Vantacor is also their first-choice insecticide for FAW. Several appear to have taken this position with very little first-hand experience with other options. Many appear to be almost unwilling to consider other options, especially where other options are more expensive.

In broadacre crops, Vantacor has historically been applied mainly to protect the grain from damage from *Helicoverpa*. By default, this generally means application when the crop has largely finished vegetative growth. In this situation, the extended residual of chlorantraniliprole is a key feature. However, in many FAW situations, insecticides are being used to protect early foliage growth. At this application timing there will be rapid crop growth dilution of any insecticide applied, so the key advantage of a long residual from chlorantraniliprole is less likely to be relevant at vegetative application timings.

Coragen® is the leading chlorantraniliprole brand for vegetable uses (including sweet corn and capsicums). In this segment, Coragen did not appear to have the same market dominant position as Vantacor has in broadacre crops. This is likely to be a result of;

- The chlorantraniliprole application rate for *Helicoverpa* and other caterpillars (and now FAW on permit) is 20 gai/ha in vegetable crops, as opposed to 24, 33 or even 54 gai/ha in various broadacre crops
- These horticultural crops are likely to be sprayed more frequently, so hence users are not as focused on length of residual from a single application
- The relative price of Coragen versus its direct competitors, compared to Vantacor versus its direct competitors.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

In the USA, chlorantraniliprole is registered for use against FAW at approximately 50 to 75 gai/ha. This is significantly higher than the application rates on Australian minor use permits (and registered rates against *Helicoverpa*).

Several agronomists interviewed were using Vantacor as two back-to-back applications and generally they were reporting improved control from this use practice. Where consecutive applications are applied in close succession, it could be predicted that this is likely to improve control. Technical opinion is required from entomologists with regard to the value of improved efficacy from consecutive applications, with efficacy benefits weighed against the increase in resistance selection pressure from multiple applications. This is required for all insecticides, not just chlorantraniliprole.

There is likely to be improved efficacy from increasing chlorantraniliprole application rates for FAW. It is believed that this may occur for some use patterns as permits are transitioned to label claims. In broadacre, the associated cost increase with higher application rates may also result in some users being more prepared to consider other effective alternatives.

While it was not widely known by most agronomists interviewed, a cyantraniliprole seed treatment is being developed for intended use in maize, sweet corn and sorghum. This is expected to assist with protection against FAW and other pests in the initial few weeks after emergence. Resistance management guidelines associated with Group 28 insecticides are likely to require a significant generational gap, and most likely a requirement for 1 or 2 insecticide applications from a different MOA, between cyantraniliprole use as seed treatment and other foliar applied Group 28 insecticide. This may have significant management implications and require modifications to some current programs in crops using the seed treatment.

<u>Indoxacarb</u> – In both northern broadacre crops and horticulture, indoxacarb (Steward® in broadacre or Avatar® Evo in horticulture, or one of the many generic brands) is often the positioned as the first-choice rotation partner for *Helicoverpa* where chlorantraniliprole is not used. This experience against *Helicoverpa* appears to often be resulting in indoxacarb also being tried as the first-choice rotation partner for FAW. Several mentioned that performance was not great against FAW, but in some situations (especially under heavy pressure) it continues to be used, as users perceive that they are doing the right thing by rotating modes of action.

Recent bioassay screens on Australian FAW field collected populations (Bird, Hopkinson, & Grundy, Resistance update - mites, aphids, helicoverpa, mirids and SLW, 2021) showed that "Indoxacarb was 28-fold less toxic on *S. frugiperda* compared with *H. armigera*." This calls into question the efficacy of applications made at the *Helicoverpa* application rate and most likely explains the poor field performance reported. No agronomists interviewed specifically mentioned that they were aware of this research, but some (but certainly not all) had seen comparative trial results suggesting that indoxacarb is not the most effective choice for FAW.

Several minor use permits are in place for many crops that support the use of indoxacarb at these *Helicoverpa* application rates. Holders of these permits should consider if the advice they are providing to users by supporting these permits is sound – in particular, does the need to have an additional MOA permitted for use in those crops outweigh the risk of poor insect control and hence potential for crop loss, or the increased selection pressure that may arise for sub-lethal applications?

A small number of broadacre advisers have already identified the relative weakness of indoxacarb on FAW relative to *Helicoverpa* and were already trying to position their growers to focus indoxacarb into pulse crops where *Helicoverpa* is generally the main pest, leaving chlorantraniliprole for maize, (and sorghum if required) where FAW is more likely. A single horticultural adviser reported using Plemax® (indoxacarb + novaluron) instead of straight indoxacarb in fruiting vegetables when still wanting to use a Group 22A insecticide. They believed that the addition of novaluron (Group 15) provides significantly better efficacy against FAW and a preferred resistance management outcome (noting that there is no specific permit for Plemax against FAW, but it is registered for *Helicoverpa* in this situation and both species are likely to always be present).

Spinetoram – While permits are in place for use of Success® Neo in key broadacre crops, there was effectively no use of spinetoram identified in broadacre situations. This was largely due to price per hectare, however many attempted to justify their non-use by claiming that spinetoram is too damaging on microhymenoptera.

It is noted that Corteva are currently progressing a registration of Intrepid® Edge (spinetoram + methoxyfenozide) for FAW in key broadacre crops (maize, cotton, pulses). While both of these actives are known to be effective on FAW, at the time of publication of this report the application rate and cost per hectare in these crops has not been disclosed.

In horticulture, Success Neo is frequently used in some vegetable crops. While very effective on *Helicoverpa*, the primary justification for use in these crops is in situations where Western Flower Thrips (WFT) is also present. For crops such as sweet corn and capsicum, it was common that Success Neo was already being used in a program (for WFT). So for several, the only change may be an increased frequency of use when under continual FAW pressure.

Emamectin – When historically used in cotton for *Helicoverpa*, Affirm® was generally positioned as an early season application targeting very small instars. At this stage, rapid growth dilution means that no product gave extended length of residual protection. The legacy of this is that, in the view of some, Affirm in broadacre is considered to be a product for knockdown of small *Helicoverpa* and has relatively short residual. For these reasons, other products have often been used for *Helicoverpa* in broadacre and Affirm has often 'not been needed'.

In vegetable crops, emamectin as Proclaim® is used more frequently and is generally considered one of the primary rotation options for both *Helicoverpa* and diamondback moth.

Bird et. al. 2021 demonstrated that against FAW, emamectin was the most active insecticide (on a gai/ha basis) of those evaluated. In horticulture, Proclaim appears to be well entrenched in rotations for FAW management in key crops. While in broadacre, only a very small number of advisers mentioned that they had tried Affirm – however, those who had used it appeared committed to continue with it as a rotation partner with Vantacor (despite a higher price / hectare).

Nucleopolyhedrovirus (NPV) – NPV specific to *Helicoverpa* (e.g. Vivus, Gemstar) have been used effectively in Australia for several years in many crops and especially in sorghum, where often a single application at early head development is adequate to provide season long protection, with the virus self-replicating in the crop provided environmental conditions are suitable. These NPVs are specific for *Helicoverpa* and have negligible effect on FAW.

Following the arrival of FAW, emergency use permits were issued for Fawligen and Spodivor® Plus. Both are a *Spodoptera frugiperda* specific NPV. With one exception, Fawligen was the product mentioned by advisers.

Applications of Fawligen need to be well timed to target first and second instars only, as efficacy declines significantly from the third instar. It can often be difficult to detect FAW egg rafts or hatchings and then have growers apply the product on time to meet this critical application window. Additionally, under high pressure situations, there is often a wide range of FAW instars present simultaneously. Further, it is often extremely hard to find dead first and second instars as they fall off the plant, never to be seen again. This can sometimes appear like Fawligen has been unsuccessful, if live, larger larvae are found.

With Vivus against *Helicoverpa*, dead larger larvae can often be found in the canopy oozing virus spores. This is the source of ongoing infection in the crop. With Fawligen, dead larvae are very small and often drop to the soil and produce a very much smaller viral load upon death. This may be a reason for the reported lack of in-crop virus replication, and therefore the need for continual re-application.

Application coverage is reported as very critical for performance of Fawligen. Users who are having most success appear to be applying with very high water rates targeted directly over the row in small maize / sweet corn with spray directed to run down into the whorl. On larger plants, most success appears to be when applied via chemigation (application via overhead irrigation).

Users who have replaced a traditional insecticide application with a Fawligen application were generally reporting that timing and application of Fawligen was more challenging, efficacy not as strong (particularly on any larger instars) and of no significant cost advantage. So many have dropped this from their program. Those who were continuing to advocate its use were often applying frequently under high pressure situations, and generally as a mix with a conventional insecticide.

<u>Lure & kill strategies</u> – Several were attempting to use lure & kill strategies (e.g. Magnet® as the attractant plus methomyl as the insecticide) as a population reduction strategy. This involves running strips of the attractant + insecticide throughout the crop at 30 to 70m intervals which attracts the female moths to feed on the bait, and hence ingest the insecticide. The general principle is that this allows a different mode of action insecticide to be used via this technique that wouldn't traditionally be applied as a broadcast application. For many, this was methomyl which is considered too damaging to beneficials to be applied as a broadcast spray.

Magnet + methomyl is positioned as providing 4-5 days population reduction before needing to be reapplied, however this is in the absence of rainfall or overhead irrigation which will wash it off the treated surface. Much of sweet corn and maize is grown under overhead irrigation systems which makes it difficult to time applications between irrigations.

Most who have used this technique reported that they could find a significant number of dead moths that were attracted to the bait. However several mentioned that where FAW pressure is low (and where this strategy is likely to be most effective), the general grower response is to prefer to 'do nothing' until FAW exceed thresholds. Where this technique was tried on above threshold populations as a 'replacement' for a conventional insecticide application, it was often mentioned that pressure quickly overran the bait – hence several that sought to use this as an insecticide replacement strategy have moved away from it.

Those who continue using a lure and kill strategy, generally reported that it is being used in conjunction with traditional insecticides, and in particular having a dedicated nozzle dribble out the Magnet + methomyl from one end of a convention boom applying a broadcast insecticide application. These users often commented that efficacy improves as strip spacing narrows, however this raises cost.

There can also be some 'collateral damage' to beneficials in close proximity to the bait that also decide to feed on it, which increases as strip spacing decreases.

QM FAW is an alternate attractant to Magnet which was supplied to some users during 2021 and early 2022, although does not have a specific permit for use against FAW so it is believed that supply has been temporarily suspended at the time of this report. Those than had compared QM FAW to Magnet consistently reported QM FAW as a better attractant for fall armyworm.

Using an alternate insecticide to methomyl in a lure and kill strategy that is less harmful to beneficial populations e.g. spinetoram was suggested.

Scouting & pheromone traps – The need for through scouting and early detection was mentioned by almost everyone interviewed.

In horticultural crops, scouting is already happening as a matter or course and most believed that this would be adequate to detect FAW and enact management systems. Where pressure is extreme there is arguably less importance placed on scouting, as the decision to spray will be simple.

Cotton and broadacre pulse crops are relatively thoroughly scouted so this is likely to pick up any FAW, however these crops are not primary hosts of FAW.

Those agronomists currently looking after maize, sorghum and tropical grass pasture in particular, commented that they have not traditionally been regularly scouting these crops for insect pests, or at least not at the crop stage where FAW are damaging. If crops are checked, it has generally not been at the frequency, or to the level of detail, recommended by entomologists to be confident in early detection of lower-level threshold populations.

This requirement for early and more frequent scouting was reported as problematic, as the agronomic system in these crops is not currently set up for intensive scouting. Generally growers are typically not paying for this service, and advisers who are currently doing it are reporting that the model is unsustainable, as they do not have the time required to scout the area of crops in detail, especially without being financially compensated. As many of these crops are of relatively low value, there is little desire for growers to pay for additional scouting for FAW. Of particular concern was the time required to scout these crops where 'nothing' is found, or similarly the time required to scout a wide range of other secondary crops that only 'occasionally' hold FAW populations and are as a result 'mostly scouted for nothing'. For these reasons, advisers fitting this demographic were all interested in how other similar agronomists were being compensated for this service.

Scouting strategies employed in broadacre crops varied. Some were providing full scouting and being partially compensated by margin on insecticide sales. Others were pushing scouting back onto the grower, acknowledging that this is likely to provide less accurate information for decision making (but also for some this was seen as a way to abdicate responsibility where scouting is otherwise less frequent than recommended by entomologists). Others were needing to base decisions on observations of damage only, as this was considered much easier/faster information to collect.

However, most interviewed had hoped, or were still hoping, that pheromone monitoring traps would be the answer. Ideally, they were looking for a pheromone trap to inform the level of pressure in crops. If traps can identify egg lays, a Fawligen or Magnet + methomyl application could then be timed to coincide with neonate hatching.

Often crop pressure was very poorly correlated with data from pheromone traps, with high levels of crop damage often reported in the absence of significant moth capture in traps. Despite this poor correlation, most still saw a position for traps if reliability could be improved to at least indicate the presence of FAW into the area, with this information used to signal time to ramp up scouting levels in the crop. The key value of this is that time isn't 'wasted' checking crops when no FAW are likely to be found.

Beneficials – The majority of broadacre advisers interviewed were very interested to understand which native beneficials are likely to suppress FAW populations, and in what frequency they are required. This is an important short-term research question to be answered.

Many advisers base their insecticide selection at least partly on the perceived impact on beneficial species – however this is mostly in relation to beneficial species known to be important for *Helicoverpa*, and specifically *Trichogramma*. However, when pressed, most advisers indicated that they have no evidence that *Trichogramma* are assisting much with FAW, or of numbers of *Trichogramma* building following (in response to) increases in FAW populations. Further, several mentioned that they had tried commercial *Trichogramma* releases and were generally of the opinion that any benefit was not supporting the cost of these releases.

Several suggested that *Cotesia* and general predators like shield bugs may be more important for FAW.

A few suggested that 'local' beneficials are perceived to better adapted for survival within the region of release than commercially reared species from other geographic regions.

In horticultural crops and specifically for sweet corn and capsicums where our interviews were concentrated, while there was a general desire of advisers to be 'soft on beneficials', the frequency of insecticide application in these crops and the range of different modes of action being applied on short rotation, meant that most did not see that beneficials were having a chance to establish. Further, as there is zero tolerance for any physical damage to marketable produce, there is less acceptance of time for beneficial numbers to build in response to insect pressure.

Native fungal pathogens – There are several native fungal pathogens that are known to be effective against *Helicoverpa*, sucking bugs and grasshoppers under certain environmental conditions (e.g. *Beauveria spp*. and *Metarhizium spp*.).

Advisers from the wet tropics consistently mentioned that native *metarhizium* (believed to be *M. rileyi*) can often be found in advanced maize crops and sometimes this is perceived as providing adequate ongoing suppression of FAW that may negate the need for further insecticide application after silking. Anectodical experiences suggest that, for the fungus to build and persist, conditions need to be warm and humid. Several suggested that you can find it in young maize crops, however it was only when crops reached full canopy and developed their own enclosed micro-climate, that fungal load built to levels that provided useful suppression of FAW.

Some advisers in the South Burnett and Northern Rivers also reported finding significant levels of *metarhizium* in early 2022 in maize, however it should be noted that conditions were extremely wet (i.e. flooding) during this period.

There was high interest by several to understand more about how this native fungal pathogen could be integrated into a management package. Additionally several were interested in the concept of being able to deploy a sprayable formulation to be able to introduce the *metarhizium* into crops. There was some mention that sprayable *metarhizium* formulations are available overseas, while in

Australia, BASF currently sells a product called Green Guard®. However it is understood that the majority of commercially available formulations are using *M. anisopliae* (and not *M. rileyi*).

There is some work underway at QDAF Mareeba to further understand these pathogens.

Application – Several advisers interviewed mentioned the importance of good application for optimal insecticide performance. Most did not have particular confidence in what constituted optimum application settings to recommend to their growers, apart from 'more water is better'.

Many were interested in acquiring more knowledge in this area, with some suggesting the need for dedicated training. This includes:

- Strategies to apply to young plants, especially maize, sweet corn and sorghum i.e. water rates, nozzle number and orientation to get insecticide deep into the whorl
- Strategies for application to full canopy maize and sweet corn
    - Is a high clearance ground rig or aerial application better?
        - What set up is required for each?
        - How much water / ha is needed by air? (as this drives application cost)
    - Do either give optimum coverage of the plant at locations where control is required?
    - Do drones have a place where paddocks are too small for planes and/or planes are not available?
- Water-run application where product is applied via overhead irrigation
    - How does efficacy compare to a conventional application (spray rig or plane)?
    - What irrigation rate is optimal?
    - Label updates are required for several key insecticides to cover this application method.

In several situations, it appears that poor control, possibly arising from incorrect product choice or application rate, or incorrect timing, may be passed off by the agronomist as 'poor application'.

Within the main body of this report we present some recent application research from QDAF Kingaroy which starts to address some application questions. This has yet to be widely disseminated to industry. Substantially more application research is required and in particular work targeted to large canopies is desired. These preliminary studies were done on small maize plants. However, these initial studies with semi-commercial application equipment are already highlighting challenges with application that are only likely to become more severe when dealing with larger canopies.

In particular, a single study where field crops were treated and leaf samples used for a laboratory bioassay the market standard (Vantacor) performed extremely well when applied to soybean, however the same tank of insecticide applied via the same sprayer on the same day resulted in a very poor result on maize. This appears to suggest that there may be large differences in insecticide leaf retention and/or uptake between crop species. Should this be confirmed, this may be very important for product efficacy and how products are applied.

FAW insecticide resistance management strategy (IRMS) – The primary intent of this research project was to understand market dynamics, key host crops, and current management strategies that would inform the need for an IRMS. And should a strategy be required; this information will assist in its development.

To achieve this objective ICAN initially matched area of likely host crops with main production areas, (utilising Australian Bureau of Statistics data) and overlaid this with expected FAW distribution. This was then used to then direct field interviews. Two to seven interviews were conducted per key region, with interview numbers reflective of FAW pressure and concentration of host crops. This allowed a regional overview to be constructed to account for geographic variation that may be required for any IRMS.

In addition to refining regional management practices, we also sought adviser views on the need for resistance management strategies for FAW, and how these could be implemented. Almost without exception, there was considerable concern associated with the overuse of Group 28 chemistry as it had largely become the first-choice insecticide for *Helicoverpa* in a wide range of crops and is now also positioned as the first choice for FAW.

When 'resistance management strategies' were mentioned, there was an immediate assumption that this would involve some form of non-use application window for Group 28 insecticides. This was met with hesitation by the majority. While they understood the intent of a use exclusion window, there was significant concern that could be summarised as follows:

- In crops that are regularly being sprayed multiple times (in particular sweet corn and capsicum), a window which removed the use of any product at any time of the year would immediately result in other products being used more frequently to compensate.
    - This places additional selection pressure on those products that can still be used
    - This may also force some users into applying the remaining products more frequently than their label permits (with significant implications for quality assurance programs) or force users to abandon the strategy if they 'run out' of other options. Several mentioned that they can already be in this situation with all tools currently available to them.

  For growers of these crops, to contemplate an IRMS where a mode of action is completely excluded for an extended period of time, it is likely that this may only be considered where the total number of applications per crop could be reduced to significantly less than 6-8 per crop (assuming there are only 4-5 viable modes of action available and one of these would be restricted from use). Currently this is not seen as possible in these high-pressure vegetable crops that are regularly being sprayed more frequently.

- In several broadacre crops grain crops in the north, chlorantraniliprole (Vantacor) is perceived as a much better value for money proposition for control of *Helicoverpa* than all other insecticides, with this market dominant positioning now also moving across to FAW applications. This is driving users to want to use Vantacor in preference to other options.

  There is currently a *Helicoverpa* IRMS strategy which proposes a mid-summer application break of Group 28s. Several wanting to grow summer pulses during this time are currently just ignoring the existing strategy as it is perceived as 'voluntary' and 'does not allow them to use their preferred product when they want to use it'. Those who justified their non-support of the strategy, cited 'not being aware of the strategy', or that 'other insecticides are too damaging to beneficials' – but then they frequently also separately reported that they are adding a broad-spectrum partner for sucking bug knockdown.

What was clearly evident from this research was that any IRMS proposing a non-use window will be difficult to construct, as the timing of crops grown and when both *Helicoverpa* and FAW are present often does not align. At best there will need to be regional strategies to attempt to address some local needs. This makes the strategy more confusing to implement. There are also many different regions to consider that cross 3 State and 1 Territory boundaries.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Very importantly, this will require a large and ongoing commitment to extension resourcing should an effective outcome with high end user compliance be the expected outcome. Additionally this strategy will cross several RDCs and crops, which may make ongoing funding challenging.

The best known current IRMS example is from cotton where the strategy attempts to cover all key insect pests, but in a single crop. This can be used to showcase the industry commitment likely to be required. While the cotton IRMS has been extremely successful, this is a single crop; planted in a relatively tight window; in a small but profitable and progressive industry; and has a large and well-resourced technical panel and extension network with excellent communications channels to and within its research, adviser and grower networks.

The horticultural diamond back moth strategy for brassica vegetables and the grains *Helicoverpa* strategy for summer crops have attempted to address a more regionally diverse strategy for a single pest but have generally only been partially successful. Some of this relates to the complexity of implementation, while the lack of extension resourcing for ongoing strategy roll out and reinforcement of messaging is also likely to be a factor.

Using these other IRMS as examples, the decision to implement a product non-use window has generally been made after an initial shift in sensitivity is noted to a specific insecticide group. This highlights the critical importance of industry commitment to regular, ongoing and permanent resourcing commitment to resistance testing at a frequency that will detect small shifts in sensitivity very early. This alone will be a significant funding commitment due to the number of regions, crops and times of the year where sampling would be routinely required. Without this commitment to industry funded resistance testing, it could be argued that there is little point in developing an IRMS in the first place.

In the opinion of the authors, making regular resistance test results available to advisers is the single most important recommendation contained within this report. Most professional advisers will make their own decision to reduce applications of a particular product if it is demonstrated that the product is coming under resistance pressure, even in the absence of a resistance strategy directing them to do so.

While we have identified several challenges with implementation of an IRMS that requires a non-use window, it may be ultimately required for FAW. However we perceive this as a medium-term priority for development.

More urgently, we have identified two strategies that are likely to reduce overall insecticide applications, which by definition should reduce the need for a more complex strategy.

The first of these is to dedicate significant extension resources to communicating FAW best practice management. Across agronomists interviewed, most are still forming their FAW management strategies and much of this is being done by trial and error or picking up the experiences of others in similar situations. With exceptions, there is a general lack of understanding of FAW lifecycle biology; appropriate planting dates; insecticide choice; insecticide rate; spray set up; use of beneficials and how to integrate chemical and non-chemical strategies to best manage this and other insect pests. Many advisers understand some of these topics, but very few interviewed were considered to understand all of these. However collectively, there is a large body of evidence and experience being assembled.

Regional entomologists are assisting with some dissemination of best practice, however most do not appear to have adequate time or resourcing to make this a primary function of their existing role.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

There is a strong and urgent need to roll out a widespread training program on FAW to many regions across northern Australia and we see this as the most beneficial short-term strategy to improve FAW control in several crops. This would be expected to reduce some level of current overuse of insecticides by dropping applications that are ineffective, while giving users more confidence in a best management program which is likely to reduce the current 'risk mitigation' response of spraying 'just in case' the FAW become a problem that can't be managed.

The second short to medium term strategy that may also reduce selection pressure and therefore delay the need for a formal window based IRMS, is to improve the wording of resistance management statements on product labels. Very frequently agronomists reported that growers are much more likely to comply with use direction on the label in terms of total number of applications per crop and frequency of those – and much less likely to take notice of a stand-alone 'voluntary' IRMS.

Some companies supplying Group 28 insecticides have already started to include specific directions for resistance management on their labels. With several of the technical managers of insecticide companies interviewed suggesting that they are considering doing similar on upcoming labels. Currently much of this is being done individually by each company, and it appears that there is scope for greater industry leadership and engagement with industry entomologists. It is likely there is an opportunity to better coordinate label statements to provide consistent advice to users which is seen as likely to result in increased rotation of insecticides.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

3. Recommendations

Advisers seek substantially improved understanding of agronomic management strategies to manage FAW. This includes

- FAW behaviour
- Prediction systems / tools to enable presence of FAW to be detected in low value crops or in low pressure environments, without the need for intensive field scouting
- In-field identification of neonate and early instars
- Significantly improved understanding of which beneficials are important for FAW management and strategies to optimise them
- Action thresholds for each key crop – particularly in lower pressure regions and crops.

Without being confident of the management tools and implications, most agronomists are likely to resort to more frequent insecticide application than may be required – which is likely to be both financially unattractive to growers and also increase resistance selection pressure, not just to FAW but also to other insect pests present in these crops.

There is likely to be value (especially to growers) of media communications of case studies and testimonials to document examples where a switch to an earlier planting window for maize or sorghum (late winter/spring) has resulted in a much more favourable outcome, than planting in a more traditional December / January planting window. Most advisers (from central Queensland and south) reported that management of maize and sorghum was significantly easier, crops were under less pressure, sustained less damage and insecticide costs were much lower when planting was constrained to the early spring window. While many advisers recognise this and have already commenced adoption to an earlier planting window, there are agronomic reasons (as detailed in the body of this report) why this is not straight forward. So media communications may help assist growers see the benefit of considering a change in planting date for more at risk crops, especially maize.

Some current emergency use permits are not providing best practice and should be surrendered or modified.

A summary of permits for FAW control are included as Appendix A.

Several of these permits were initiated at the start of the FAW outbreak and hence little was known at that time with regard to the crops likely to be targeted and the effectiveness of the insecticides. However, in the eyes of the user, there is an expectation that if a permit is in place, then it is considered a ‘recommended’ control and ‘should’ be effective.

In the opinion of the authors, some of these permits are unlikely to deliver best practice, while some others may not be required at all where the crop does not host FAW.

Of primary concern

- Rates of chlorantraniliprole may be lower than optimal for adequate control of FAW (especially in horticultural crops). In several situations, Australian permit rates are less than half USA registered rates for FAW.
- Recent bioassay trial work (Bird, Miles, Quade, & Spafford, 2022) suggests that FAW sensitivity to indoxacarb is approximately 30-fold higher than rates required for *Helicoverpa*. So this calls into question permits for indoxacarb that utilise *Helicoverpa* use rates
- Australian FAW populations have been shown to have very high resistance levels to synthetic pyrethroids (when used without the inclusion of a synergist such as piperonyl

butoxide). Bird et. al. demonstrated that control of 10 Australian FAW populations ranged from 0-15% when treated at the *Helicoverpa armigera* reference dose for alpha-cypermethrin. In addition to the use of pyrethroids not controlling FAW, they will also be decimating natural beneficial populations and thus reducing the effectiveness of other control strategies. We would recommend that permits for pyrethroid use targeting FAW be surrendered immediately, while those permits that also contain a range of active ingredients be modified to have the pyrethroid component removed. Permits involved PER85447; PER89279; PER89295; PER89425; PER89403.

To facilitate IRMS objectives, there is a need for continual, regular and seasonal resistance testing of FAW to all key insecticides from all major geographic markets identified in this report. This is a large and ongoing financial impost on industries; however it is essential to be able to pick up changes in sensitivity and then have the opportunity to adjust management strategies appropriately to reverse, or slow down, progression towards insecticide failure.

Without a commitment to ongoing resistance testing, it is questionable if there is value in developing an IRMS strategy in the first place.

Should budgets be constrained, we would argue that the minimum position should be to prioritise these ongoing and regular regional resistance tests and publish the raw data. Even in the absence of additional resources to further improve management outcomes, develop a formal strategy or to extend adoption messaging, the simple publication of resistance frequencies per region and how this is changing over time will assist the vast majority of advisers who will use this information to adjust their own management strategies, even without a formal IRMS.

There is industry-wide need (and desire) to reduce selection for insecticide resistance in FAW. Across almost every region surveyed, there was understanding of the need for strategies to reduce selection for insecticide resistance. (The exception was the Northern Territory and some regions where forage crops were the focus, where the low scale and diverse nature of crop production led some interviewees to question if an IRMS was either needed or could be made to be effective in that region).

Most interviewed immediately considered a IRMS to mean some form of mode of action window-based restriction is likely to be the delivery tool. However, there was widespread concern as to how this could be implemented in three particular areas:

- In horticultural crops such as sweet corn and capsicum, the current frequency of insecticide applications is resulting in all key products being used almost to the maximum permitted labelled frequency, while still incurring unacceptable levels of damage. Therefore any IRMS that places limitations on any single product will most likely directly result in corresponding increased selection pressure on the remaining products
- In these same horticultural crops, customer demand forces growers to plant/harvest daily or weekly for as much of year as the environment allows. As a result, on any given farm, there will almost always be adjacent crops at different and overlapping growth stages. This makes a window-based IRMS focusing on crop growth stage extremely difficult to implement, and would force windows to be based solely on calendar dates
- In broadacre crops, the planting windows across geographies and between crops within a single geography do not align, so a window-based strategy may work for one crop in one

region, but not for additional crops in that region; for different regions; or where the same insecticides are used for other pests that are present at different times.

For these reasons, most agronomists interviewed were supportive of the need for an IRMS, but were challenging how a window-based strategy could be practically implemented, adopted and still be effective in meeting the desired objective.

Information within this report has been developed to assist in identifying the key host crops, management strategies and regional considerations required to be considered when formulating such a strategy.

In the opinion of the authors of this report, working towards a published window-based IRMS that formally restricts use of certain products from certain times of year should arguably become a medium-term industry goal, and may not be required until there is evidence of a change in sensitivity shift to one or more of the key insecticides (hence the essential recommendation above to continue to fund resistance testing to be able to pick up these changes and still have time to react).

However, we would consider that there are more urgent short-term priorities required to be addressed that should take precedence over a desire to publish and communicate a window-based IRMS in the first instance (and especially if budget is not available to fund everything simultaneously).

The first priority activity is to better understand FAW behaviour and develop robust, best management approaches using a full toolbox of biosecurity, surveillance & monitoring, chemical and non-chemical tools. Once best management strategies are compiled, there is need for a coordinated extension of these strategies. Within this roll out, there will be opportunity to highlight the importance of resistance management and how best management strategies can work towards this objective. Arming users with better management strategies is highly likely to have the immediate effect of reducing insecticide use in almost all situations – as almost every agronomist interviewed reported that they are most likely applying insecticides more frequently than 'may' be needed, due to the fear that if FAW are allowed to establish then they do not feel that they have the confidence, or tools available, to manage these populations without significant losses to their growers.

Within this best management FAW training, several advisers were seeking updated resistance management training and upskilling on insecticide modes of action and how to optimise these.

Further, due to a lack of best-practice information, we identified several situations where managers may be making poor management choices. This leads to poor efficacy, additional cost to growers, often the need to retreat and potentially increases selection for resistance if FAW are being exposed to a treatment that provides sub-lethal results. Often these management decisions are being made in good-faith, commonly using strategies that have been effective in the past on *Helicoverpa* where there is a lack of specific knowledge of how these same strategies will work on FAW. Additionally, there are several industry supported emergency use permits for FAW that are arguably not providing users with what is now considered to be best advice, or implying to some (by their existence) that growers should be treating for FAW where there is little evidence that FAW is even present in some of these crops.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

> The second priority, as we see it, is to develop product label directions that provide specific directions in terms of number of applications and their frequency. This has already been initiated by some individual suppliers of Group 28 insecticides, however this is being done individually by only some suppliers and could be improved in terms of consistency and wording, while also being applied to all insecticides in a standard format. Consensus from those interviewed in this report would suggest that label directions are more likely to achieve attention and compliance than a 'voluntary' separate stand-alone document, and especially should the stand-alone IRMS be published once and then not supported with on-going extension and reinforcement.

Should these shorter-term strategies above not manage to reduce frequency of application and hold insecticide resistance, then a window-based strategy may ultimately be required.

A formal window-based strategy will require significant planning and resourcing to develop and, once developed, ongoing resources allocated for implementation and extension. Key to any successful strategy is an ongoing commitment to update and communicate changes (as a minimum biennially) as new resistance information comes to hand, or new solutions become commercially available.

In the first instance, it is likely that a cross-sector panel will need to be assembled to digest the risk of resistance and where (which crops, which geographies) this strategy would be focused. Market intelligence contained within this report provides initial background and identifies sweet corn, capsicum and maize are the priority crops in terms of FAW pressure, while grain and forage sorghum may also require inclusion in the initial scope, as while damage is usually minimal unless pressure is very high (usually linked to maize crops being grown nearby), sorghum is grown over a much larger area. Consensus is required to consider if other horticultural crops, or potentially summer pulses should be also included. Or the strategy expanded to also included *Helicoverpa* and other noctuids (noting that for each additional crop or pest included, there is an exponential level of considerations and interactions required to be addressed).

Once scope has been agreed, there would then need to be a technical panel assembled to review current known resistance and develop draft strategies (assuming multiple regional strategies are needed).

These draft strategies will then require road-testing with regional agronomists and grower focus groups to obtain buy-in (and provide opportunity for last minute feedback and adjustment).

Once strategy document(s) are finalised, local communicators / champions will then then be required to roll out the strategy to growers within the region and to keep the strategy 'alive' in subsequent years. The regional champions may require technical training and/or support from entomologists. In horticultural regions there are generally grower groups and/or industry development officers who may be in a position to champion this, however in forage crops and summer grains these networks do not currently exist. This may therefore require a more traditional media-based communication strategy supported by training of agronomists to support dissemination of the strategy. In order to gain grower buy-in it is recommended that resistance management training would also be delivered at this time. (Many, and especially younger industry participants, may not have knowledge of cotton or vegetable brassicas in the 1990s where *Helicoverpa* and Diamondback moth respectively were almost impossible to control due to herbicide resistance).

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

A website will be required to host the strategy, with the website owner chartered with budget and responsibility to provide relevant and ongoing promotion.

The crops and geographies of primary focus for FAW cross the grains, horticulture, cotton, grazing and emerging industries. So a complex multi-crop strategy is likely to require several RDCs as stakeholders. Engagement of state-based entomologists will be required across 3 states and 1 territory. Budget for development, roll out and ongoing and continual resistance testing and strategy updating / extension will be required.

Two examples that highlight the complexity of developing and updating resistance management strategies are worthy of mention to highlight the level of resourcing required.

WeedSmart https://www.weedsmart.org.au/ is a single industry (broadacre grains) initiative dedicated to promotion of messaging around herbicide resistance management, although it does not venture into development or communication of specific resistance management strategies. Instead just focuses on the underlying principles of resistance management in weeds. This initiative is resourced by approximately 8-9 part-time staff on an ongoing basis, while calling on a significant industry network of in-kind support from a very wide range of industry experts and advisers.

The Australian cotton industry has their own internal industry committee (Transgenic & Insecticide Management Strategy (TIMS) https://cottonaustralia.com.au/stewardship). This 20-person panel is supported by 3 additional technical panels of about 12 each focusing on insecticides, GM crops and herbicides plus a continual investment in resistance testing for key insecticides to key pests. This investment in strategy development is backed up by significant extension resources including in excess of 10 dedicated Cotton Australian regional staff; 14 regional Grower Associations and approximately 18 CottonInfo extension specialists which all assist in delivering extension messaging.

Both of these examples host a wide array of different resistance management communications on their respective websites.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

4. Project Background

Fall armyworm (FAW) (*Spodoptera frugiperda*) is a rapidly spreading global pest.

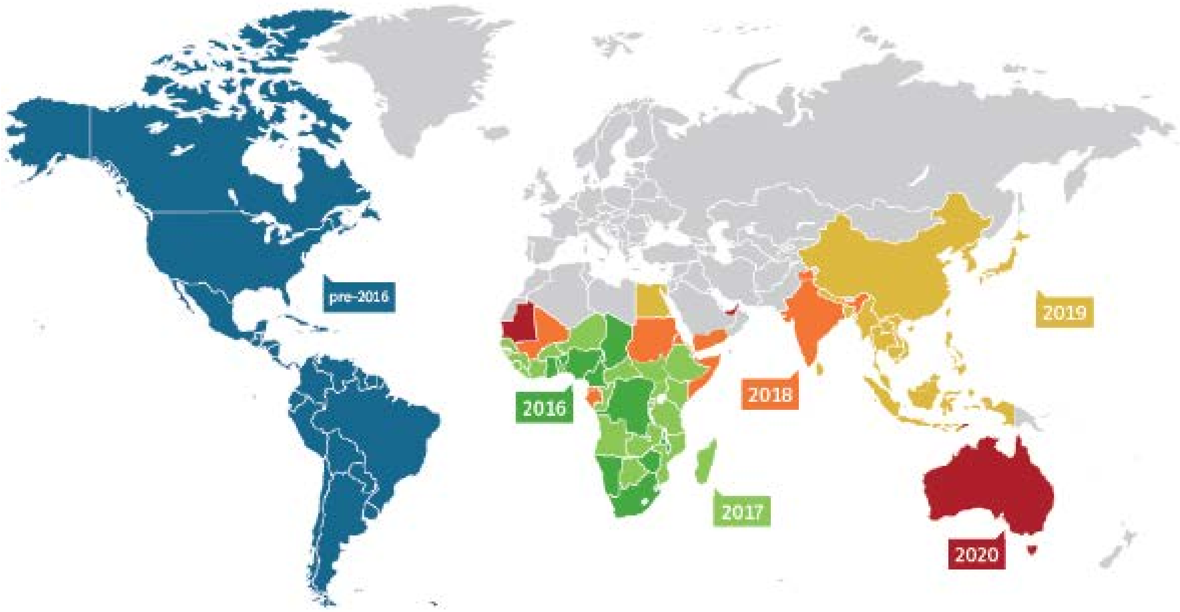


Figure 1 Geographic distribution of fall armyworm as of May 2020

Attempts to 'eradicate' FAW after arrival in a country have proven to be unsuccessful. This is due to FAW being highly mobile (adult moths can travel 100km in a night and over 1000km in their lifespan); they are very polyphagous (able to feed and reproduce on a very wide range of host plants); and often when they enter a new district, populations establish before they are identified by growers (FAO, 2019).

Entry into Australia was first detected in far north Queensland (Bamaga) in mid-February 2020, believing to have entered the continent via moth flights from Asia. By April 2020 (less than 2 months after initial incursion) FAW had spread across northern Australia as far west as Kununurra in WA.

It is known that the preferred host for FAW is maize / sweet corn / sorghum (Queensland Government, 2021). However, FAW may also cause economic damage to a wide range of both grass and broadleaf crops including C4 grass pasture / rice / sugarcane / peanuts / lucerne / cotton / wheat and various vegetable crops (du Plessis, van den Berg, Ota, & Kriticos, 2018). FAW is expected to be present year-round in many tropical / sub-tropical environments, while at more southerly locations in Australia, populations are expected to reduce in winter and then rebuild again over spring and summer, with populations expected to be at most damaging levels in mid to late summer.

While a fully integrated management program of tactics is likely to be required to manage FAW, the judicious use of insecticides across a wide variety of host crops is expected to continue to be an important pillar underpinning control.

Insecticide management is further complicated by the fact that:

- FAW populations entering Australia in 2020 were already resistant to certain insecticide modes of action
- Some insecticides that are effective against FAW are not registered in all host crops

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

- Insecticides have differing selectivity to beneficial predators and parasitoids (natural enemies/beneficials), and the importance of individual natural enemies changes between crop types
- Insecticide use targets a range of insect pests. The use of insecticides targeting FAW needs to be considered in context with other insecticide management programs in the crop and the region of use
- A significant increase in insecticide use targeting FAW is likely to place further resistance pressure on key insecticides.

Experience both in Australia and more globally has shown that frequent use of insecticides can lead to the development of resistance to that mode of action in a wide variety of crop x pest combinations. FAW populations are known worldwide to be able to rapidly select for insecticide resistance.

In Australia, there are several examples whereby the implementation of an effective insecticide resistance management strategy (IRMS) has been shown to delay resistance to key insecticide groups. Or, in some cases, even reverse resistance trends. Typically, resistance management strategies that are effective rely on:

- Regular and thorough scouting to detect pest presence
- Only applying any insecticide when pest populations exceed an economically damaging threshold
- Not re-spraying a spray failure with the same mode of action, where resistance is a possible reason for the failure
- Encouraging users to regularly rotate insecticide modes of action, often by recommending application windows whereby specified insecticide mode(s) of action cannot be used at specified times. In other situations, consecutive applications of the same mode of action are recommended to be avoided
- Encouraging the activity of natural enemies via use of the 'softest' effective insecticide mode of action to beneficials, or use of non-insecticide means of management where options exist.

Development of an effective IRMS should be underpinned by resistance monitoring in key geographic locations. Ideally the resistance strategy is continually adjusted based on trends in resistance levels i.e. as resistance to a particular mode of action starts to increase, these increases are communicated with decision makers and end users, then changes are made as appropriate to the IRMS – often involving further use restrictions being placed on that mode of action.

CropLife Australia publishes resistance management strategies for pests of high risk of developing insecticide resistance. In some instances, these strategies have been developed by CropLife Australia, while in other instances the CropLife strategy may default to a more detailed industry specific strategy. Key CropLife strategies relevant to this project can be found in Section 5.1 of this report.

The current CropLife Australia strategy for fall armyworm is found at https://www.croplife.org.au/resources/programs/resistance-management/various-fall-armyworm-spodoptera-frugiperda-draft/ (CropLife Australia, 2021). This strategy is designed to cover several geographies and crop segments, so hence is somewhat general in nature.

As growers become more accustomed to managing FAW in Australia, it is anticipated that there will be the requirement to develop additional, and possibly regionally based, IRM strategies for key host crops. For FAW, this task will be complicated due to the wide host crop range which includes several fresh fruit & vegetable crops which are grown at different times of the year in different regions (to ensure continuity of supply to supermarkets). Therefore, for practicality, several regionally based IRM strategies may be required (and possibly even crop x region strategies). However, any 'customisation' of strategies to suit local needs will need to be balanced against the overall science underpinning an effective IRMS that is likely to require limiting the use of some insecticides at certain times when some growers may wish to use that mode of action.

To facilitate development of regional IRMS strategies, detailed market research is required to understand the major host crops x geographic region; when these crops are grown within the region; current insecticide use patterns for FAW and other pests; predicted FAW pressure; how FAW is likely to change existing insecticide use patterns; and if the adoption of increased insecticide use targeting FAW is likely to significantly impact beneficial populations resulting in 'flaring' of other insect pest species.

This report summarises desk top research and agronomist/research interviews undertaken in 2021/2022 to understand existing crops x region x insect pest occurrence for the identified important host crops for FAW. Current insecticide use patterns for FAW (where FAW are already present) were collected, along with insecticide use targeting other noctuid moths, as this understanding will be required in development of regional IRMS to manage FAW in association with other key pests. Where FAW is not yet entrenched, we also sought to explore the 'expected' change to insecticide use. Our research also identified any successful IRM strategies that are already in place locally for either FAW or associated pests.

5. Methodology

To design effective insect resistance management strategies, it is essential to understand existing crops x region x insect pest occurrence for the identified important host crops for FAW.

To achieve this aim, we utilised desk top research, augmented by interviews with regional agronomists and entomologists to explore current insecticide use x crop x region.

Initial desktop research was first implemented to understand crops x region and any relevant IRMS already in use. This was then followed by a series of depth interviews with leading agronomists in key geographical regions, plus leading entomologists in each state, to understand:

- Pest spectra present in key crops at important times of the year when FAW is likely to be present
- Current insecticide use patterns in these crops, including any noticeable changes where FAW is already present
- Current management strategies in place for other noctuid moths with likely implications for management of FAW
    - Will existing IRMS for other pest species need to be modified in the presence of FAW?
    - Are predicted changes likely to have noticeable effects on beneficial populations?
- Within each region, are there current insecticide resistance concerns to particular modes of action?

The information contained within this report should serve as the basis for required background information to underpin the development of national, regional or crop segment specific IRMS plans that may subsequently be developed under future investment projects. When IRMS plans are being formulated, the importance of engagement with affected industry stakeholders at a regional level cannot be underestimated.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

5.1. Fall armyworm lifecycle and expected distribution

Fall armyworm does not have a diapause stage in its lifecycle. Therefore, where environmental conditions (particularly temperature) are suitable, and there is an ongoing feed source, it is expected that FAW will become a resident pest, affecting host crops all year round in environments where temperature and food sources allow. This is likely to be the case across many growing regions in northern Australia, and hence these regions have been prioritised for this research project.

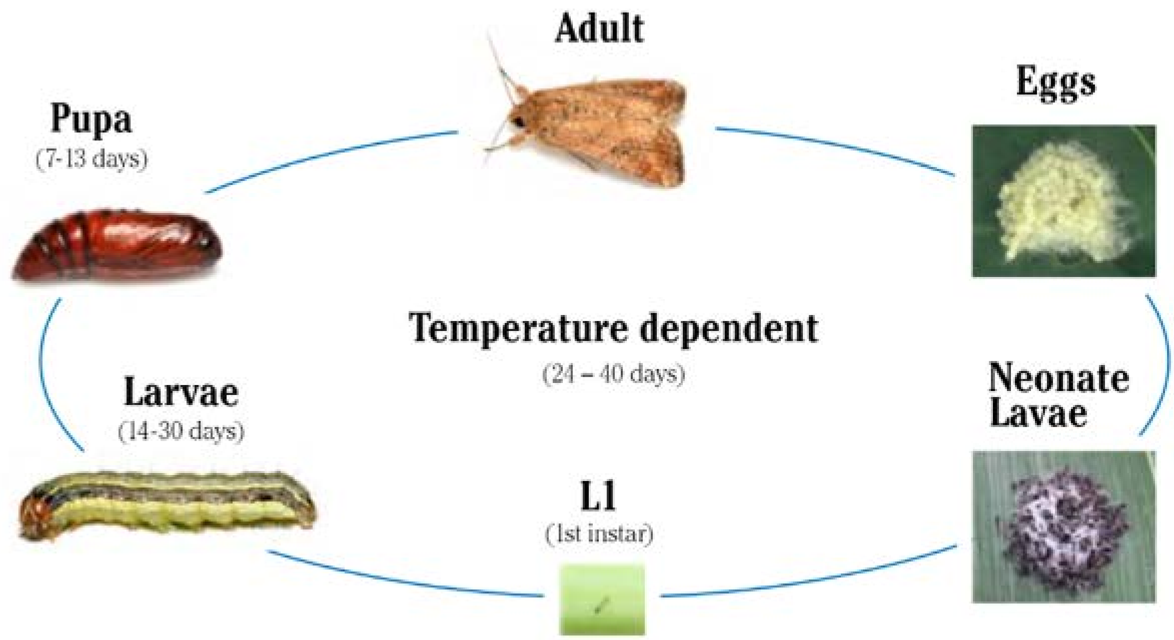


Figure 2 Fall armyworm lifecycle (Rural Business, 2020)

With an average lifecycle of around 30 days over summer conditions, it is likely to therefore likely that there can potentially be at least 3 generations within a 110–120-day maize crop.

Research from a range of studies where FAW is endemic, suggests that the minimum temperature for FAW to complete their lifecycle is somewhere between 8.7 and 16.9°C (du Plessis, van den Berg, Ota, & Kriticos, 2018).

Where temperatures fall below this for extended periods FAW is not expected to become locally resident with populations declining during winter months but building again the following year as a result of migration from the north under warmer conditions.

Modelling undertaken by the CSIRO in 2020 predicts that distribution of FAW is likely to be as follows.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

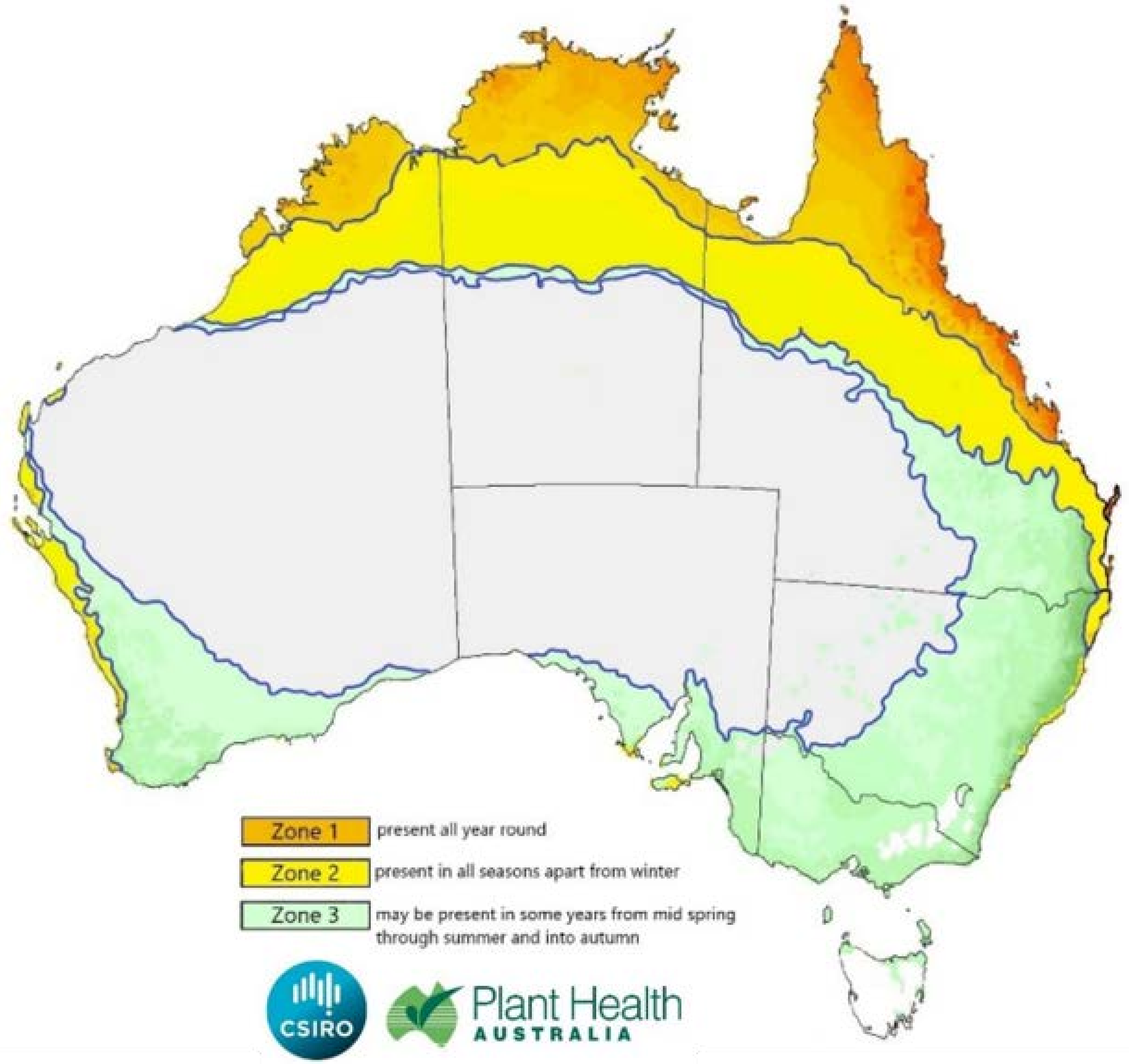


Figure 3 FAW risk prediction map showing zones where there is FAW risk all of the time, most of the time or some of the time. (Kearns, et al., 2020)

While this is the 'predicted' distribution of FAW, it will be important to continue to update this information as more practical experience is gained. For example, some continual FAW pressure appeared to be maintained across winter 2021 in the Lockyer Valley and Bundaberg (currently marked as yellow), while the South Burnett and eastern Darling Downs are currently marked as green on the map above, however FAW behaviour is more akin with yellow designation. Additional information is included https://thebeatsheet.com.au/fall-armyworm-tough-it-out-during-winter/

5.2. Fall armyworm x Crop x Region

Due to the diversity of host crops for FAW and rapid spread since first entering Australia in 2020, ICAN initially proposed the following mix of fifteen (15) sub-regions x core crops for depth review. We noted that the full potential geographic impact of FAW may extend further than these crops/regions - however we believed that these crops x region would encompass the majority of primary economically relevant hosts for FAW.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Table 1 Intended regional and crop breakdown for this project

State	Region	Code	Crops							
			Maize / sweet corn	Sorghum	Sugar cane	Rice	Cotton / pigeon pea	Summer pulses	Chickpea	Vegetables
Queensland	South East Qld	SEQ	X							X
	Darling Downs	DD	X	X			X	X	X	
	Wide Bay / Burnett / Bundaberg	WBB	X	X	X			X		X
	Central Highlands / Dawson Callide	CQ	X	X			X	X	X	
	Bowen / Burdekin	BB	X	X	X			x		X
	Atherton Tableland	AT	X		X	X		X		X
New South Wales	Northern Rivers NSW	NR	X		X			X		
	Gwydir/Namoi	G/N		X			X	X	X	
	Riverina & SNSW	RIV	X			X	X	X		
Northern Territory	West Arnhem	ARN	X	X						X
	Douglas Daly / Katherine	DD/K	X	X			X	X		
	Barkley tableland	BT		X			X	X		
Western Australia	Ord River / Kununurra	ORD	X	X	X	X	X	X	X	
	Carnarvon / Broome	CAR	X							X
	Geraldton	GER								X

Following further desktop review of crop areas grown by region (see Section 4) it was decided that the small area of crop grown and low number of agronomists in some targeted regions, demanded that both the Northern Territory and northern Western Australia should be condensed into two regions. So hence a final grouping of 11 sub regions was addressed via field interviews.

Table 2 Breakdown of the final 11 regions in which interviews were conducted in this project

		Crops								
		Maize	Sweet corn	Sorghum	Sugar cane	Rice	Cotton	Summer pulses	Chickpea	Vegetables (not sweet corn)
Qld	SEQ		X							X
	DD	X		X			X	Mung	X	
	WBB	X	x		X			Soy / Peanut		X
	CQ	X		X			X	Mung	X	
	BB		X	X	X	X		Soy		X
	AT	X			X					X
NSW	NR	X						Soy		
	G/N			X			X	Mung	X	
	RIV	X				X	X			
NT	all						X			X
WA	all	X	X				X	Soy / Mung	X	X

SEQ = South-Eastern Queensland; DD = Darling Downs; WBB = Wide Bay Burnett; CQ = Central Queensland; BB = Bowen/Burdekin; AT = Atherton Tableland; NR = Northern Rivers; G/N = Gwydir and Namoi Valleys; RIV = Riverina; NT = Northern Territory; WA = Western Australia.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

5.3. Interviews conducted

The following tables provide a summary of agronomist locations and other industry representatives who provided input into this research, primarily as a result of depth interviews conducted as part of this project. The names of agronomists have not been included as anonymity was negotiated in exchange for frank and open discussion.

Table 3:Location and number of agronomists / advisers interviewed

Queensland		
Southeast Qld	SEQ	2
Darling Downs	DD	5
Wide Bay / Burnett / Bundaberg	WBB	4
Central Highlands / Dawson Callide	CQ	3
Bowen / Burdekin	BB	6
Atherton Tableland	AT	4
All northern region crop segments		1
New South Wales		
Northern Rivers NSW	NR	2
Gwydir/Namoi	G/N	4
Riverina & associated irrigation areas	RIV	1
Northern Territory		3
Northern West Australia		3

SEQ = South-Eastern Queensland; DD = Darling Downs; WBB = Wide Bay Burnett; CQ = Central Queensland; BB = Bowen/Burdekin; AT = Atherton Tableland; NR = Northern Rivers; G/N = Gwydir and Namoi Valleys; RIV = Riverina

Additional commentary was sought from key industry suppliers and researchers.

Table 4: Insecticide suppliers interviewed

Corteva	Kate Daly, Rob Annetts
Syngenta	Ken McKee
FMC	Greg Cornwell
AgBitech	Phil Armitage

Table 5: Researchers interviewed

QDAF	Melina Miles, Hugh Brier, Subra Subramanium, Ian Newton, Richard Sequeira
DPIRD	Helen Spafford, Dusty Severtson
NSW DPI	Mark Stevens, Lisa Bird

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

6. Crops and area grown

In order to understand the range and extent of host crops for fall armyworm, ICAN interrogated the Australian Bureau of Statistics (ABS) published crop areas by geographic region.

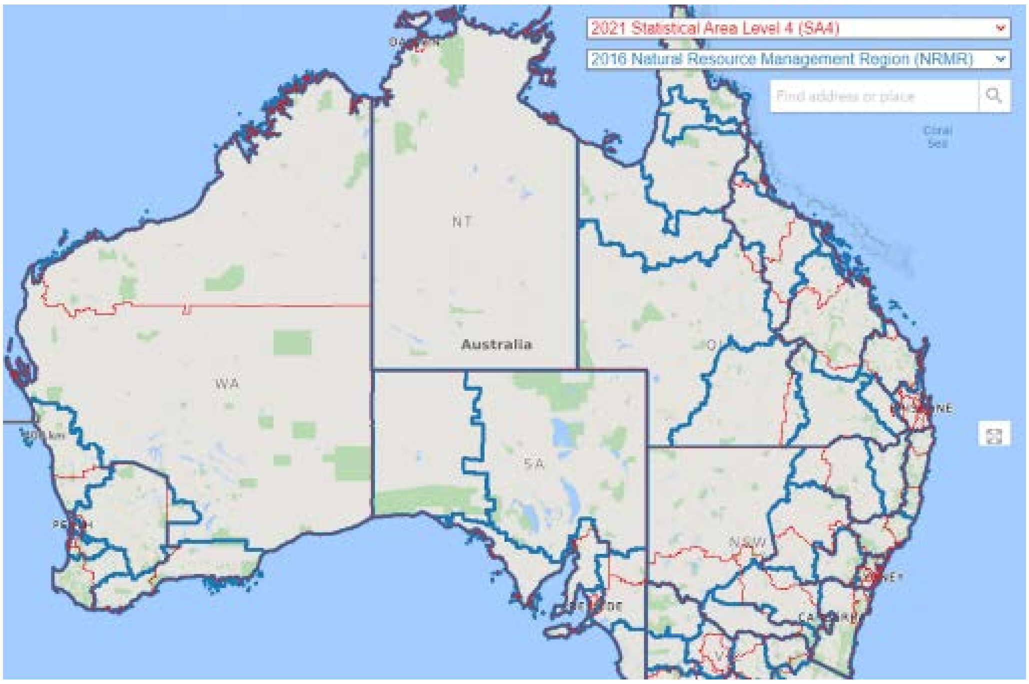


Figure 4: ABS agricultural land area usage data split by either Statistical Area Level 4 (SA4) [red] or National Resource Management Region (NRMR) [blue] boundaries.

For the areas of geographical interest to this project we elected to use NRMR boundaries for NSW, Qld and the NT, while for Western Australia SA4 boundaries more accurately accounted for key geographies of interest, so hence these were used. The table below is a summary of the ABS geographic regions used to compile Tables 7 and 8.

Table 6: ABS geographic regions used in this report to compile crop area data presented in tables 7 and 8.

State	Region	Region code	Data used
Qld	South East Qld	SEQ	NRM Qld – SEQ
	Darling Downs	DD	NRMR Qld – Condamine + Qld – Murray Darling Basin
	Wide Bay / Burnett / Bundaberg	WBB	NRM Qld – Burnett Mary
	Central Highlands / Dawson Callide	CQ	NRM Qld – Fitzroy basin
	Bowen / Burdekin	BB	NRM Qld – Nth Qld Dry Tropics
	Mackay / Proserpine	MP	NRM Qld – Reef catchments
	Atherton Tableland	AT	NRM Qld – Terrain NRM
NSW	Northern Rivers NSW	NR	NRM NSW – North Coast
	Gwydir/Namoi	G/N	NRM NSW – North West
	Riverina & associated irrigation areas SNSW	RIV	NRM NSW – Murray + NSW – Riverina
NT	West Arnhem	All NT	NRM NT – Northern Territory (ABS report NT as a single geographic unit)
	Douglas Daly / Katherine		
	Barkley tableland		
WA	Ord River / Kununurra / Broome	ORD	SA4 WA – Outback - North
	Carnarvon / Geraldton	CAR	SA4 WA – Outback - South

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Data below in Table 7 is from the 2019-2020 year, which is the latest ABS reporting year available at time of writing this report. However, it is noted that this year was significantly below average rainfall for many target areas, in particular most of Queensland and NSW. While total area per crop was down on average, it still provides guidance to the geographic locations of importance to this project. Shaded areas in the table have been used to direct project resources towards the priority region x crop combinations for this study.

Table 7 Area of selected Agricultural Commodities reported by ABS, 2019-20 year. (Australian Bureau of Statistcs, 2021)

		Crops (ha)								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	SEQ	522	1 801	522	6 171				10	11 514
	DD	3 432		54 781			4 225		72 907	2 185
	WBB	4 680	184	6 036	43 658		239		367	6 481
	CQ	7 088		59 578	911		9 791		59 266	123
	BB	436	2 814	20 694	81 976	637	53		36 423	7 469
	MP	552		953	111 271				1 812	89
	AT	227	3	42	133 081					959
NSW	NR	106	27	7	21 608	55				544
	G/N	1475		32 786			36 236		43 080	13
	RIV	6 712	5	1 702		4 074	13 333		8 264	3 328
NT	all		2			123	300			1 062
WA	ORD	4 934		264	2		190		543	903
	CAR	50	210						5 143	462
Aus total		**37 730**	**6 225**	**204 113**	**404 168**	**5 007**	**69 886**		**309 151**	**98 921**
% Aus total		**80%**	**81%**	**87%**	**99%**	**98%**	**92%**		**72%**	**36%**
Shaded area % Aus total		**71%**	**78%**	**82%**	**97%**	**94%**	**92%**		**70%**	**29%**

- Area of maize and sweet corn are lower by comparison to some other crop segments. However, as this is the preferred crop host of FAW, these identified segments require prioritisation
- The area of sugarcane grown in Mackay / Proserpine is significant, however we elected not to direct project resources to this region as it is the only significant crop of interest grown within the region and impact and response to FAW on sugarcane is likely to be similar to other wet tropic geographies
- Summer pulse crops of interest to the project include crops such as pigeon pea, mung bean, soybean, peanuts. These crops are grouped and reported in ABS statistics as either 'Other Pules' or 'Other oilseeds' (depending on the crop in question), so it is not possible to obtain accurate hectares. In the table above we have colour coded cells in the summer pulse column where total hectares reported are significant and ICAN's existing market intelligence indicates that these target summer pulse crops will feature prominently
- While the area of target crops grown in the NT and WA are low by other comparisons (noting some of these industries are in their infancy), it is an important segment to understand for noctuid management in northern Australia. Previous history demonstrates that failure to manage noctuid pests in these regions has resulted in complete industry collapse.

For comparison, Table 8 compares crop area for the 2016-2017 year, which was a more 'climatically average' year across northern Australia. Crop mix x region is generally similar although often greater in total area, reflecting the more average rainfall conditions and availability of irrigation water supply in that year.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Table 8 Area of selected Agricultural Commodities reported by ABS, 2016-17 year (Australian Bureau of Statistics, 2018)

		Crops (ha_								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	SEQ	760	3836	547	3 772		100			10 553
	DD	18 763	1002	158 958			176 219			5 143
	WBB	5 562		2 495	60 975		635			5 007
	CQ	7 144		53 628	860		24 318			
	BB	1 051		31 310	85434	4	1 828			7 957
	MP	36			133 723	54				265
	AT	1 996		158	140 930	60				1 172
NSW	NR	1 348	17		21 484	290				551
	G/N	4 221		101 351			227 743			24
	RIV	15 353		1 098		81 451	38 815			6 309
NT	all	394		112		71				1 549
WA	ORD	1 639		624						1 210
	CAR		54							817
Aus total		**67 771**	**9 044**	**367 920**	**453 470**	**82 204**	**518 589**			**110 645**
% Aus total		**86%**	**54%**	**95%**	**99%**	**100%**	**91%**			**37%**
Shaded area % Aus total		**77%**	**54%**	**94%**	**93%**		**90%**			**24%**

- In 2016-17 chickpea was included in the broader 'pulse crop' category and hence isn't able to be separately determined.

7. Current IRMS encompassing noctuid moths

The immature life stages (instars / caterpillars) of insects from the Noctuidae family are often very damaging to agricultural and horticultural crops. This very large family of moths includes (amongst many others) *Helicoverpa*, *Spodoptera* (armyworms), *Agrotis* (cutworms) and *Plutella* (diamondback moth) genus.

Fall armyworm is unlikely to occur in target crops as the only pest species for consideration. For preferred hosts such as maize or sweet corn, it is conceivable that FAW may become the dominant pest, and therefore a future IRMS strategy applicable to these crops may primarily be based around management decisions for this species. However, in many other 'summer crops', FAW may only be a secondary or tertiary pest problem, so IRMS strategies are likely to also need to consider other pests such as other noctuid moths that may also be present in the crop; or potentially be even more complex and encompass all pest species, especially where the impact of an insecticide targeting one pest may have impact on other pests or beneficial species – for example the cotton industry IRMS (see below).

Additional complexity arises where there is a wide range of host crops within the same geographic region. To be most effective, an IRMS which limits use of certain insecticides at specified times, would ideally apply to all key host crops grown in a region at a particular time i.e. there is at least a minimum of one generation that does not receive any application of the insecticide in question in that region.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

However, this has the potential to generate 'conflict' in some situations, which may lead to lower levels of adoption.

As an example. The chlorantraniliprole 'window' for use in 'grains' and 'cotton' according to the current IRMS for these crops does not align. The cotton window opens on November 1 or December 15 depending on the region, while the grains window for this same product effectively is closed from mid-November to mid-January (and longer in the north). With the high adoption of insect-tolerant cotton, there is little need for chlorantraniliprole in that crop, so in some regard the current chlorantraniliprole window in cotton is somewhat irrelevant, as the insecticide is rarely if ever used. In grains, the current window allows for use in chickpeas in spring, but then effectively prohibits any use at all in spring-planted summer pulses such as mung beans and soybeans (although the window may open again for some very late planted mung beans in some regions). For this reason, several agronomists mentioned that they and their growers are not considering the 'grains' IRMS at all where summer pulses are an important part of the program. Further, when it comes to managing FAW, most reported that peak FAW pressure (across all host crops) is late November to January, where the chlorantraniliprole 'window' in grains is currently closed.

There was very strong feedback from those interviewed that a resistance management strategy for chlorantraniliprole was needed, however the feedback was even stronger in that if any strategy restricted a product from use where it has the best biological and/or 'value for money' fit, then that strategy is less likely to be supported and adopted by the industry.

With the diversity of grains and horticultural crops; the spread of planting dates required and the different timing of pressure from different noctuid moths, consensus indicated that this will make a window based IRMS extremely difficult, if not impossible, to implement in many regions. This has become exponentially more difficult since the arrival of FAW, as crops such as maize and sweet corn now become driver crops, whereas in the past when *Helicoverpa* was a primary driver of resistance planning, so these smaller crops were rarely considered outside their respective industries.

At best, there would need to be several versions of a window-based strategy for each of the main production zones, which takes into account the local crop mix and the important periods of high pressure. Although having many different versions of a window-based strategy has the potential to add confusion, and will require a very large, and ongoing, extension budget to gain grower acceptance and drive adoption.

In this report we also have considered other resistance management strategies outside of a 'window' based approach.

7.1. Existing strategies

CropLife Australia provides general strategies designed to manage resistance across a range of priority pest targets and crops. https://www.croplife.org.au/resources/programs/resistance-management/insecticide-resistance-management-strategies-3-draft/ Typically these CropLife strategies only focus on a single crop in isolation, for a single pest species, and are not developed regionally – so they are considered more as general principles to follow, rather than a detailed management strategy. However, they will still be important to consider when developing a FAW IRMS.

Amongst the insecticide strategies that have been developed by CropLife Australia, the following have been identified as important to take into consideration when developing a detailed strategy to manage fall armyworm.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Various Fall armyworm
https://www.croplife.org.au/resources/programs/resistance-management/various-fall-armyworm-spodoptera-frugiperda-draft/

Sweet corm Helicoverpa armigera
https://www.croplife.org.au/resources/programs/resistance-management/sweet-corn-heliothis-ear-worm-2-draft/

Sorghum, maize, summer & winter legumes *Helicoverpa*
https://www.croplife.org.au/resources/programs/resistance-management/sorghum-maize-summer-grain-legumes-cotton-bollworm-heliothis-2-draft/

Cotton All pests
https://www.croplife.org.au/resources/programs/resistance-management/cotton-all-pests/

Tomato Helicoverpa
https://www.croplife.org.au/resources/programs/resistance-management/tomato-heliothis-tomato-budworm-draft/

Brassicas *Plutella xyostella* (diamondback moth)
https://www.croplife.org.au/resources/programs/resistance-management/brassica-diamondback-moth-3-draft/

Canola *Plutella xyostella* (diamondback moth)
https://www.croplife.org.au/resources/programs/resistance-management/canola-crops-forage-brassica-diamondback-moth-draft/

Other strategies

In addition to the CropLife Australia strategies mentioned above, there have been some industry sector specific resistance management plans developed for key pests.

Cotton

The most developed and probably most known and adopted strategy is the cotton industry IRMS.
https://stage.cottoninfo.com.au/sites/default/files/documents/IRMS%20CPMG%202020.pdf

This strategy was originally developed in the 1980s as a response to high level insecticide resistance to *Helicoverpa* in cotton (in particular, but not limited to, the synthetic pyrethroids). The strategy has been updated annually and now includes the full range of cotton pests (not just *Helicoverpa*). New insecticides and genetically modified cotton varieties have been added as they came to market.

Very importantly, the strategy is underpinned by annual resistance testing across the entire cotton growing region. Where this testing results in a noticeable shift in increased tolerance/resistance the application window for that mode of action will be constrained in the strategy. This then forces users to seek alternate control options, and thus reduces selection pressure on the mode of action of concern – which in several cases has demonstrated the desired intent to slow or even reverse the incidence of resistant individuals in the population. This commitment to resourcing ongoing resistance testing and continual updating of the strategy, combined with ongoing extension and significant peer group pressure, is arguably the reason why this strategy has stood the test of time.

Following initial success against *Helicoverpa*, the strategy was expanded to include sections on managing resistance in mites and aphids, and later other sucking pests such as mirids and silverleaf whitefly. In more recent years, the 'pest' component of the strategy has been removed and the current strategy just focuses on application windows for individual active ingredients, regardless of the pest being targeted.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Two slightly different versions of the strategy are published – one for central Queensland where there is no diapause in *Helicoverpa*, and the other for the remaining cotton growing regions.

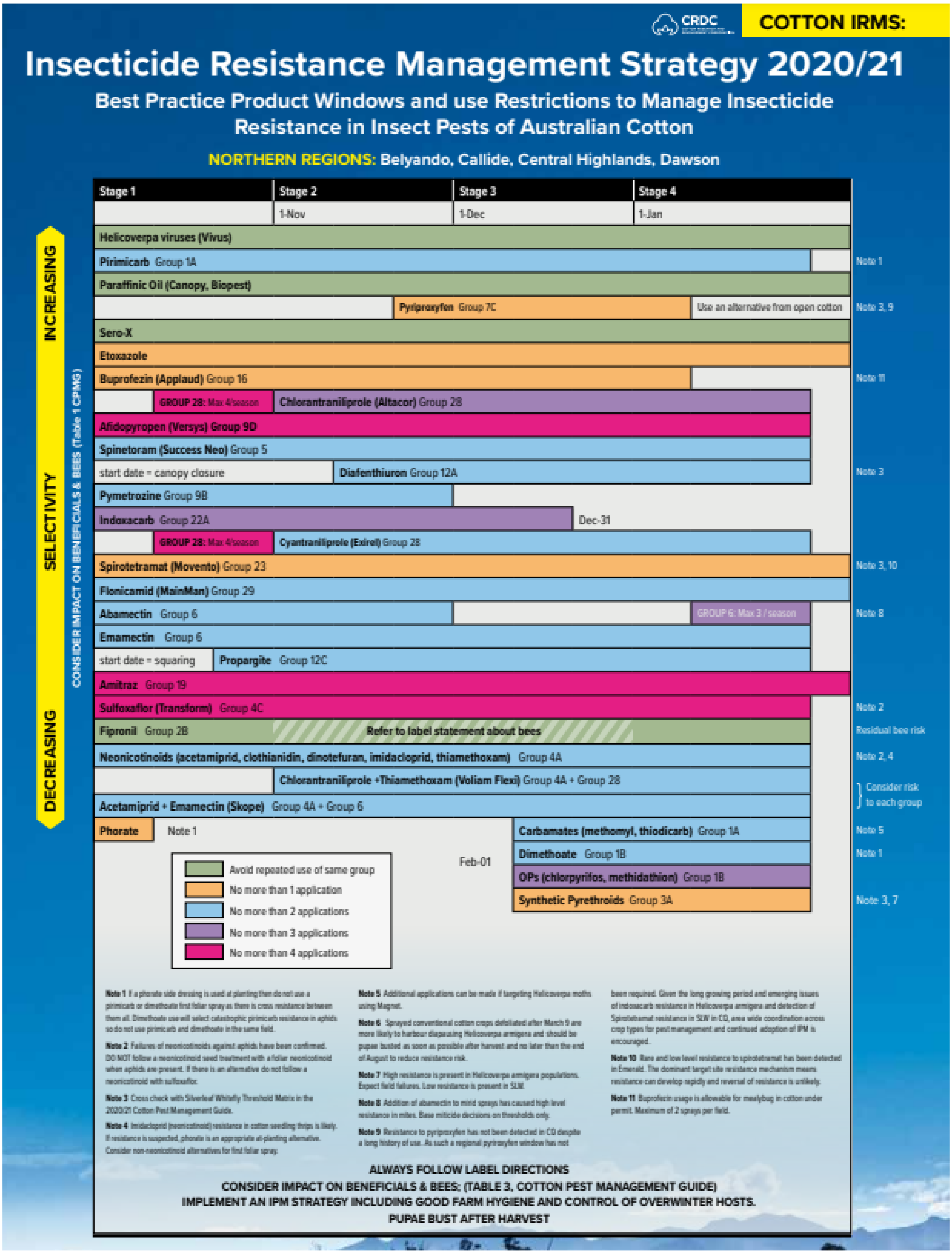


Figure 5 Australian cotton IRMS 2021 – northern regions (Cotton Research and Development Corporation, 2021)

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

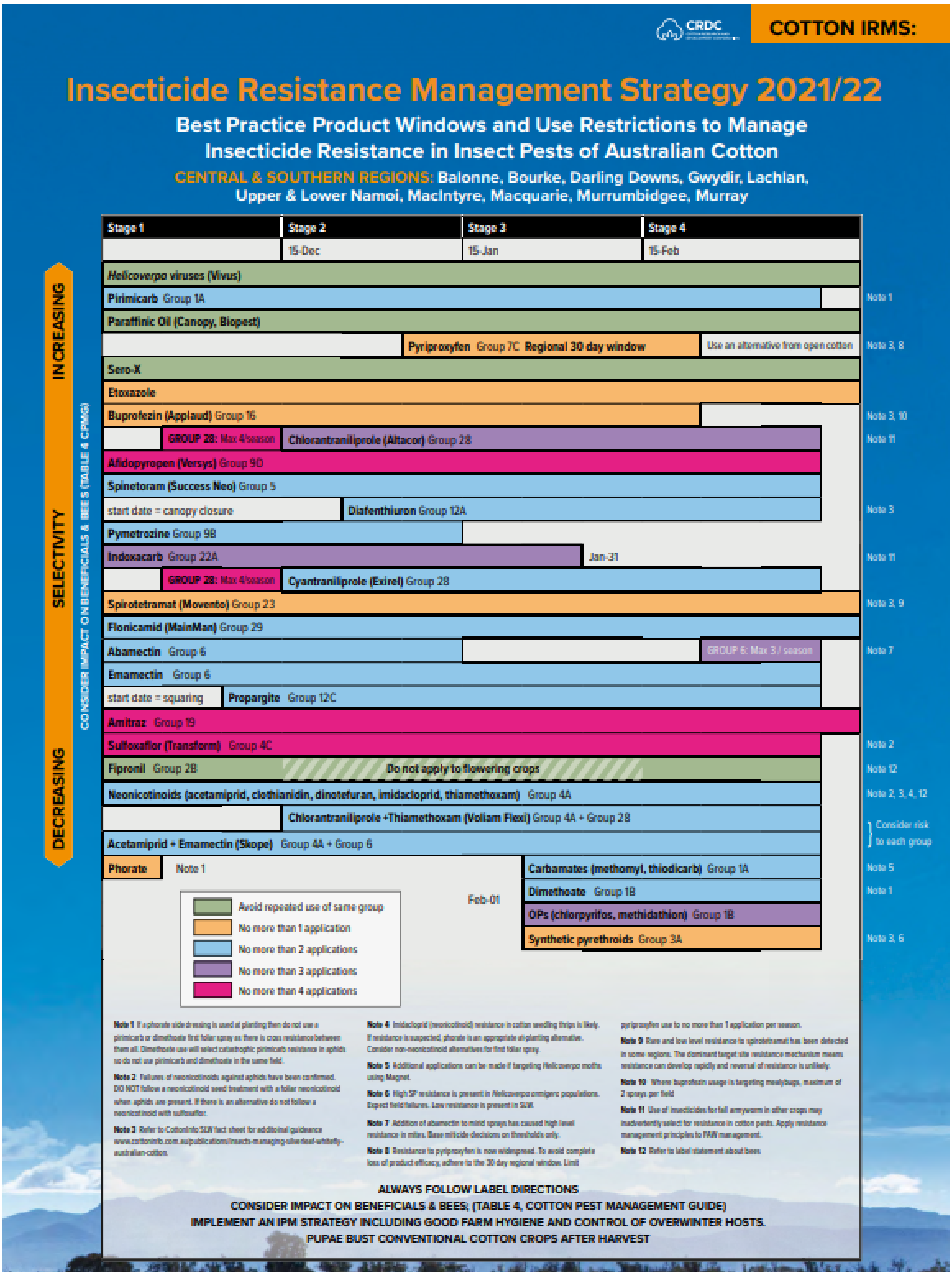


Figure 6 Australian cotton IRMS 2021 – central and southern regions (Cotton Research and Development Corporation, 2021)

These base 1-page strategies are backed up by detailed information on scouting & monitoring information on each major insect pest of cotton; integrated pest management guidelines and extensive information re the impact of different insecticides on beneficial species as part of the annually updated CRDC Cotton Pest Management Guide publication https://www.crdc.com.au/sites/default/files/pdf/Cotton%20Pest%20Management%20Guide%202021%20LR.pdf .

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Prior to the development of this strategy, the Australian cotton industry identified widespread *Helicoverpa* resistance (and high-level product failures) to synthetic pyrethroids, organophosphates and carbamates which occurred across a relatively short timeline from the early 1980s to mid-1990s. In addition, aphid and mite resistance to several sucking pest insecticide groups was also identified within this timeframe. In the approximately 30 years since introduction of the strategy there has been no further complete loss of any insecticide mode of action, with resistance to some modes of action partially reversed during that time frame – evidence of the success of the strategy and the industry compliance that is associated with its use.

Other industry-driven IRMS exist, however generally these have not had the same level of industry buy-in and adoption as the cotton strategy. Reasons for this are several:

- Crop areas are often regionally diverse
- There is less peer group interaction in many of these crop segments, and hence less peer group pressure to ensure that everyone complies with the strategy
- In some markets, (particularly vegetables) there is strong marketplace competition between growers, and hence a high level of reluctance to share information. Many are looking for areas of competitive advantage and are unwilling to share this where it has been gained
- In crops where only a single insecticide application is expected during the crop lifecycle, there is no opportunity to 'rotate' modes of action
- In some situations, crops are of much less value (on a $/ha basis) which may encourage the use of the 'cheapest' control option
- Internal communications within the cotton industry are excellent and augmented by;
    - the relatively small number of cotton growers,
    - the existence and influence of regionally located cotton grower / irrigator groups in key valleys, and
    - by the fact that almost all cotton production is aided by the input of a professional cotton adviser, who are relatively few in number and who are well coordinated and easy to direct consistent messaging to.

<u>*Helicoverpa* in grains</u>

Helicoverpa are a common pest of sorghum, pulses, sunflower and canola and, on occasion, will attack cereal crops. In southern grain regions (southern NSW to Western Australia) typically the population is dominated by *Helicoverpa punctigera,* arising from moth flights in spring that originate in central Australia and move into crop regions with prevailing winds. As these populations reinfest each year from unsprayed areas, they are typically susceptible to the major insecticide modes of actions. Typically, growers would only budget on a single application in most years, often targeting larvae of multiple sizes with a single application. As there is minimal resistance, there is little incentive to move away from 'cheap, broad-spectrum' insecticides such as the synthetic pyrethroids (especially where a single application of these products can control a range of larval sizes). Noting that there can be some exceptions: such as growers who are concerned about early applications of broad-spectrum insecticides which have the potential to damage beneficial populations and may result in flaring of secondary pests such as aphids; or some localised regions where some *H. armigera* may be endemic and require a different management approach.

Across much of the northern grains region (specifically from the Liverpool Plains to central Queensland) it is more likely that *Helicoverpa* populations may be a mix of both *H. punctigera* and *H. armigera* in winter grain crops. Depending on winter and early spring build-up of *H. punctigera* in central Australia and the channel country, early season pest pressure (spring or early summer) may have *H. punctigera* as the dominant pest over *H. armigera*. Prevalence of *H. armigera* increases from south to north and from west to east, often also increasing in the period between September and December. Most winter crops sprayed for *Helicoverpa* infestations south of ~ Dubbo NSW, are generally targeting *H. punctigera* only, while most in Queensland will be assuming *H. armigera* is present.

As the season becomes later, it is typically expected that the percentage of *H. armigera* within the population will increase. *H. armigera* are generally believed to be more resident, with populations in temperate regions going into diapause over winter and then re-emerging from the soil in spring as temperatures warm. In central Queensland and more 'tropical' regions, populations will not diapause over winter, but generational lifecycle times do become longer in winter. As a result of being a 'local' population, resistance genetics tests are typically carried from one season to the next, with many *H. armigera* populations having a level of resistance to several different insecticide modes of action. Additionally, as these northern geographies have warmer springs (when winter crops are filling grain), it can be possible to require more than one insecticide application per crop for winter pulses. Susceptible summer crops will be regularly under pressure from *H. armigera* for their entire growing season, although economic impact is often limited to predominantly the period from flowering through to pod fill.

To address resistance in *H. armigera*, industry has developed an IRMS targeting this pest in grain crops. https://ipmguidelinesforgrains.com.au/important/uploads/GRDC_RMS_Helicoverpa-Armigera.pdf Additional background supporting this strategy can be found at https://ipmguidelinesforgrains.com.au/important/uploads/Science-Behind-the-RMS-for-Helicoverpa-armigera-NIRM-2018.pdf

This strategy effectively just focuses on a single pest species (*Helicoverpa*) and when initially developed, attempted to align with the cotton strategy where it is most applicable, to assist growers and agronomists that will be implementing both strategies. However, since development of the grains IRMS, there have been further changes to the cotton IRMS and changes to use patterns of insecticides in grain crops – so there is arguably less current alignment between strategies (in particular the positioning of chlorantraniliprole).

The grains strategy was published in 2018 and has not been modified since. This has been somewhat possible due to the lack of 'new' insecticides for grain crops since it was first published – although noting the use of chlorantraniliprole has expanded significantly since this strategy was developed. The availability of resistance information by mode of action collected primarily from the cotton industry investments is likely to also apply to grain crops grown in many of the same general geographic regions (with some additional sampling occurring from non-cotton regions of high pressure). This has allowed the grains industry to somewhat reduce their need to support ongoing resistance testing required to maintain an effective IRMS.

The lack of availability of chlorantraniliprole for summer pulses under the existing IRMS was mentioned by several agronomists interviewed in this project as a reason why the grains industry IRMS has relatively poor adoption. Additionally, some agronomists interviewed mentioned that they 'remember' a grains IRMS being produced, but as they have not seen continual extension communication and reinforcement, it has largely been forgotten.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

> *Authors note: to be effective, any IRMS developed for fall armyworm will require an ongoing extension commitment, and budget, to keep the strategy current and up to date. This should take the form of:*
>
> - *Annual resistance testing against key insecticide groups, across all key geographies of concern*
> - *Annual technical revision by the research community of windows and usage restrictions, resulting from the outcomes of resistance testing*
> - *Scheduled budget to update the strategy to add any new insecticides and make revisions as needed.*
>
> *Without a process (and budget) to continually and routinely test key insecticide groups for changes in resistance levels, and the subsequent commitment from both researchers and industry to both restrict use windows as sensitive shifts are detected and communicate these changes (via an extension program), then it could be argued that there is little point in going to the trouble of developing a 'one-off, set and forget' IRMS for FAW, as the current CropLife FAW resistance strategy probably already meets this need.*
>
> *Commitment to annual testing and updating of the strategy for FAW will be complex, especially considering the wide geographic spread of host crops and the fact that different industries are likely to place differing levels of importance (and hence budget commitment) to this initiative.*

Horticulture

IRMS appear to work best when there is a relatively synchronised planting date across the landscape (for example, the cotton strategy mentioned above). This allows those designing the IRMS to consider the best technical fit for a product and place it in an application window that will balance the technical strengths of the product; expected resistance levels at that time of year or crop growth stage; impact on beneficials likely to be present at that time; and use of that product in relation to other alternate modes of action.

For many horticultural growers targeting the fresh produce market, it is common to spread planting dates to extend harvest over the longest possible period for their geographic location. This keeps produce on the supermarket shelf for many additional months and reduces gluts and troughs in market supply that distorts pricing.

Historically, when attempting to design an IRMS for these 'continual planting' situations, the approach has been to use windows based on a hard start/stop calendar date. As an example, the horticultural industry developed a two 'window' strategy for diamondback moth (DBM) (*Plutella xylostella*) to try and reduce yearlong insecticide use. While this strategy below was developed in 2009, it is still currently available on the AusVeg website (CropLife Australia, 2009).

A modified version was also developed for Western Australia. However, in the course of desktop research for this project, we were not able to find evidence that this WA version is still being maintained.

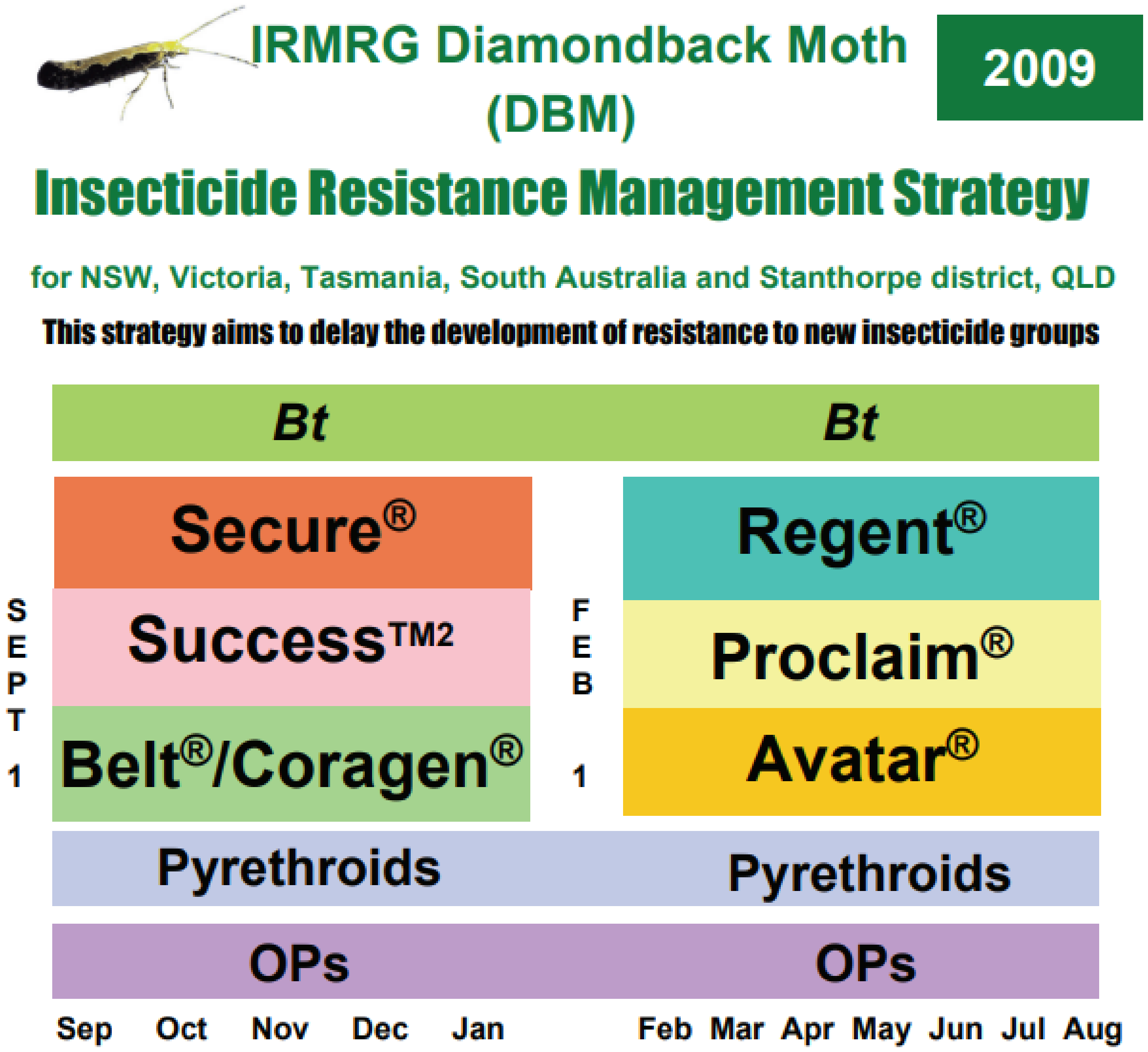
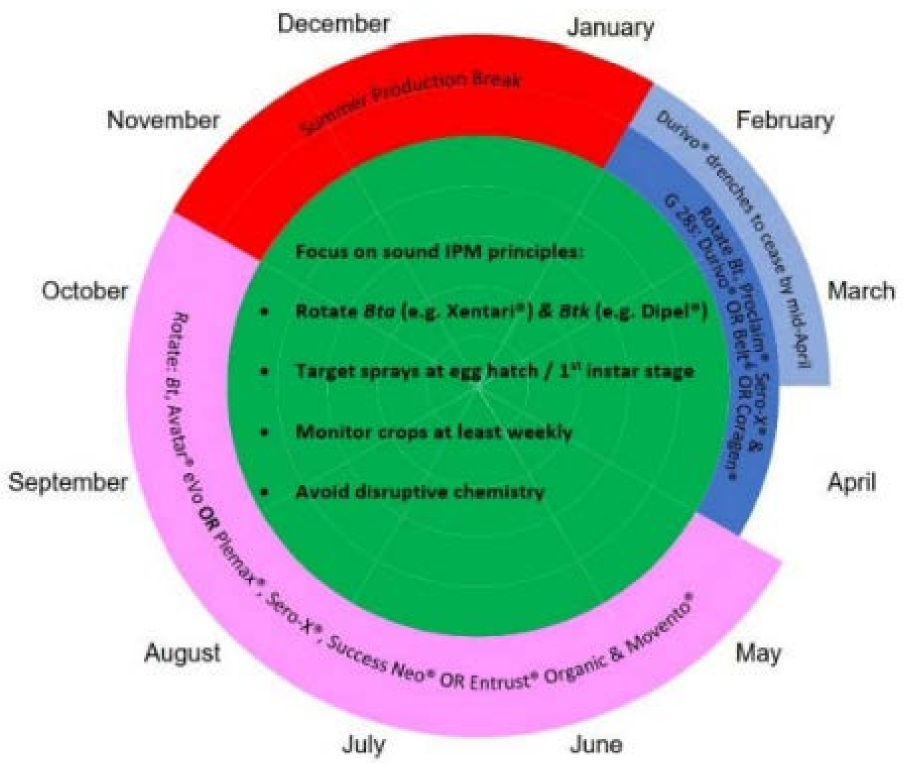


Figure 7 A two-window diamond back moth IRMS covering multiple geographic regions.

For insecticides in high demand, this type of strategy may mean that certain products are not to be used at all with some crops (should the growing period fall outside of the use window), or possibly the allowed application timing may not align with the crop growth stage for 'optimal' effectiveness. This strategy 'may' be practical if there are sufficient effective options available in each window to cover the number of insecticide applications required to protect that crop. However, where there are limited insecticide registered options available, or a key product is lost in a particular location due to resistance or regulatory withdrawal, then users can be forced to go outside of the recommended strategy in order to ensure short-term insect control and hence not compromise the marketability of their crop for a goal of longer-term industry steward ship for resistance management.

More recently, the Lockyer Valley in southeast Queensland has expanded on this basic diamondback moth IRMS to develop a more detailed version of the two-window strategy for this key pest.



Caution: Regent® (G. 2b) may be used in warmer periods for crop 'clean up' however this chemical should be used with caution due to its disruptive nature.

Summer Production Break

- A summer production break is recommended from November through to January to reduce the Diamondback moth population and minimise exposure to available chemicals

Focus on sound IPM principles

- Rotate *Bacillus thuringiensis* (Bt) strains aizawai (e.g. Xentari®) & kurstaki (e.g. Dipel®) as the primary form of chemical control

First Window Insecticide Rotation - February to April

- *Bt* (G. 11 strains *Bta* & *Btk*). Bts form the primary control strategy
- Proclaim® (G. 6)
- Sero-X® (G.NA)
- Durivo®* (G. 4A & 28) OR Belt OR Coragen®** (G. 28)

* **Durivo® drenches to cease by mid-April**

** **Do not apply any Mode of Action to more than 50% of the life of the crop**

Second Window Insecticide Rotation - May to October

- *Bt* (G. 11 strains *Bta* & *Btk*). *Bts* form the primary control strategy
- Avatar® eVo (G. 22a) **OR** Plemax® (G. 15 & 22a)
- Sero-X® (G. NA)
- Success Neo® OR Entrust® Organic (G. 5)
- Movento® (G.23) with Hasten™ spray adjuvant (1st instar larvae only)

Figure 8 Diamondback moth (DBM) IRMS for the Lockyer Valley, Queensland (Lockyer Valley Growers, 2021)

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

This somewhat more detailed strategy attempts to provide growers with direction for insecticide choice x time of year x crop growth stage for a crop such as brassica vegetables which may be growing anytime within a nine-month production window. While this strategy is for one pest in one crop group and in one location, the majority of the products included in this strategy are also effective on and registered for *Helicoverpa,* both in brassicas and the other main crops grown in that region. So where this strategy for DBM is adopted, it is also likely to reduce selection pressure for *Helicoverpa* (as opposed to no strategy at all and open use of any product).

However it needs to be noted that this strategy departs from a more traditional IRMS 'window' based strategy which preferably looks to confine application of a single mode of action to only 1 insect generation per year / crop, with no applications of the same MOA to successive generations.

Many/most of the insecticides underpinning the DBM strategy in the Lockyer valley are the same insecticides that will also be primary tools for managing FAW in sweet corn, which is another equally important vegetable crop in this region. While brassica vegetables typically take a production break over summer in this region, this is usually the <u>key</u> timing for sweet corn production (and FAW pressure) in this district. Feedback is that sweet corn crops grown during this period will require at least two applications of most insecticides from both 'windows' – with the consequence being that growers will be currently using all of the main insecticides for >9 months per year for one pest or the other, with considerable overlap between the two.

This highlights that the arrival of FAW, and the required insecticide applications associated with it, will not only put pressure on resistance selection with FAW populations, it is likely to also add considerable selection pressure to other pest species – DBM in this case, but also *Helicoverpa armigera* in many other geographies.

Development of a window-based, district wide IRMS to accommodate all crops grown in the Lockyer Valley into a single strategy is most likely going to very difficult and will require blocking of many products into a regimented window, with the result being substantially less flexibility and choice for growers.

This same challenge is expected to be present in several other regions that produce fruiting vegetables and sweet corn on an almost 12-month basis.

7.2. Current resistance in *Helicoverpa*

The Australian cotton industry typically undertakes the largest regular insecticide resistance monitoring program, so it is useful to look to this research to track insecticide resistance for the geographies where this is relevant. This cotton industry research covers much of inland central and southern Queensland and northern NSW, with some collections occasionally pushing into north Queensland or southern NSW. These surveys may not adequately reflect insecticide resistance patterns in key vegetable growing regions such as south-east and coastal Queensland, or in NT / WA.

While the cotton industry research also monitors resistance levels in two-spotted mites, aphids, mirids and silverleaf whitefly, it is resistance to *Helicoverpa* that is likely to be of most interest to this report, as frequently the same insecticides that are used for *Helicoverpa* control (in particular *H. armigera*) are also likely to be considered for FAW management.

A recent summary of *Helicoverpa* resistance was reported in the October-November 2021 edition of The Australian Cotton Grower (Bird, Hopkinson, & Grundy, Resistance update - mites, aphids, helicoverpa, mirids and SLW, 2021). For *Helicoverpa* they reported the following:

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Similar to previous seasons, screening for emamectin benzoate (Affirm®) and chlorantraniliprole (Altacor®) found no evidence of resistant individuals, indicating that genes conferring resistance to these insecticide groups remain exceedingly rare. While this is a positive result, these products are now under increased pressure due to fall armyworm (FAW), Spodoptera frugiperda, with Altacor in particular having become the 'go to' insecticide across a range of commodities where Helicoverpa are also a pest. Low levels of chlorantraniliprole resistance in H. armigera detected between 2014–19 show the potential risk for resistance development with the inevitable increase in spraying across industries (Figure 11).

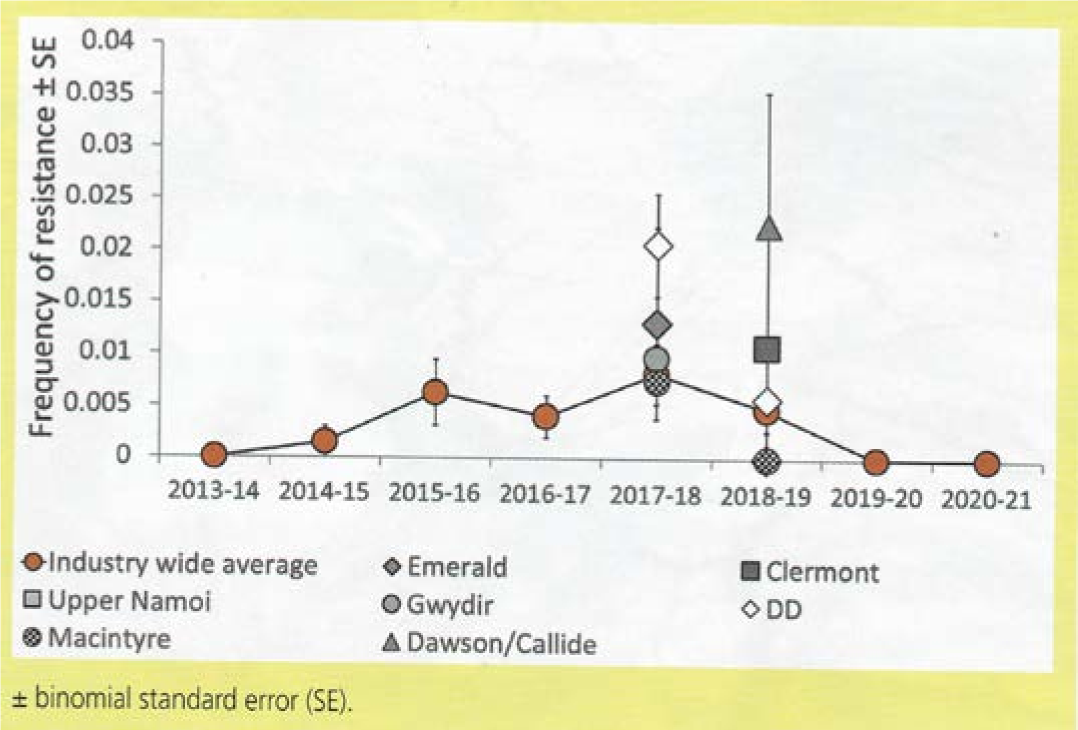


Figure 9 Annual frequency of H. armigera chlorantraniliprole resistance in all regions where resistance was detected compared to industry average.

Increased spraying for FAW may also explain minor increases for H. armigera resistance levels to indoxacarb (Steward®) during the 2020–21 season. The industry-wide average increased from 5.6 to 6.8 per cent (Figure 12) due to elevated resistance in the Macquarie region in NSW's central west.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

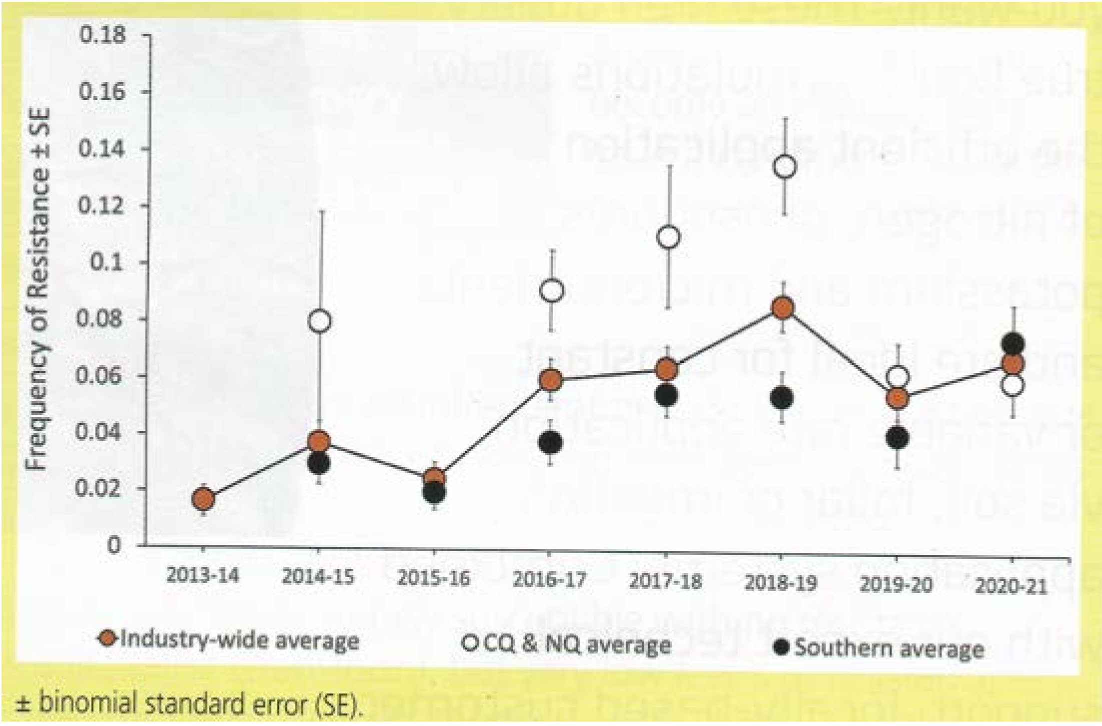


Figure 10 Annual frequency of H. armigera indoxacarb resistance in central Queensland (CQ) and north Queensland (NQ) compared with the industry and southern (southern Queensland and NSW) averages.

This represents the highest level of indoxacarb resistance recorded in NSW to date and was a significant increase from 2017 when resistance levels were between 2 and 4 per cent in the Macquarie region. In comparison, average resistance in CQ and NQ was similar to the previous year at 6 per cent with some variation between regions. Resistance in the Emerald and Dawson/Callide regions was lower than the previous year, while increasing slightly in the Clermont region. Although resistance increased in the Burdekin from 6.6 per cent to 11 per cent, it remained significantly lower than the peak of 16.7 per cent in 2018–19. These changes are more likely driven by indoxacarb usage in pulses (and more recently maize and sweetcorn for FAW) than in cotton. But indoxacarb remains an important product for non-Bt cotton and is a cornerstone product for many rotation crops grown within the cotton farming system. To avoid any worsening of this situation, it is recommended that usage across commodities be guided by the Helicoverpa Resistance Management Strategy (RMS). The strategy is based on best practice product use windows and restrictions on the number of sprays to minimise selection pressure across consecutive generations of H. armigera. Resistance management is also assisted by:

- *Regular monitoring of pests, natural enemies and spray efficacy to avoid unnecessary applications or detect emerging issues.*
- *Calibration of spray-rigs for effective coverage. Poor spray jobs can result in sub-optimal doses that might exacerbate resistance selection.*
- *Conserving natural enemies by using target-specific products to reduce the chance of resistant larvae surviving to pass on their genes.*
- *Avoiding repeated use of the same chemical group, particularly if there is a spray failure.*
- *Complying with all directions on product labels. Not only is the label a legal document, but it also has important information that can be used to maximise product efficacy.*

The Helicoverpa RMS can be downloaded from the GRDC website.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

7.3. Current resistance in fall armyworm

When designing an effective resistance plan it is important to also understand the effectiveness of insecticides that will be considered. Further efficacy evaluation against FAW is required under Australian populations, however results of some preliminary screening by NSW DPI in 2020/2021 were presented at GRDC Updates.

Table 9 Key finding from research into efficacy of several insecticides to FAW. (Miles & Bird, Fall armyworm update, 2021)

Product	Efficacy on fall armyworm
spinetoram & spinosad (e.g. Success® Neo, Entrust®; Group 5)	Similar level of toxicity (efficacy) in both *H. armigera* and FAW at all levels of the dose response.
emamectin benzoate (e.g. Affirm®; Group 6A)	Similar level of toxicity (efficacy) in both H. armigera and FAW at all levels of the dose response.
chlorantraniliprole (e.g. Altacor®; Group 28)	A similar level of toxicity (efficacy) at high doses in *H. armigera* and FAW. However, FAW was about 2 times less sensitive at the median lethal concentration (LC_{50}) of chlorantraniliprole.
indoxacarb (e.g. Steward®; Group 22)	Toxicity is significantly lower in FAW compared with susceptible *H. armigera* and probably represents a naturally higher tolerance to indoxacarb in FAW.
methomyl (carbamate; Group 1A)	There is a small but significant reduction in sensitivity to methomyl in FAW larvae compared with *H. armigera*. This is consistent with the detection of genetic markers for carbamate resistance in FAW. However, moths of FAW remain fully susceptible to methomyl.
synthetic pyrethroids (SPs; Group 3A)	FAW is 50-80 times less sensitive to alpha-cypermethrin and gamma-cyhalothrin compared with susceptible *H. armigera*. Based on our experience with *H. armigera* with similar levels of SP resistance, it is therefore highly unlikely that field rates of these insecticides will control FAW, even under optimal spray conditions. There is strong evidence to support metabolic (not target site) resistance to SP in FAW. Metabolic resistance is an important mechanism which is also known to confer very high levels of SP resistance in *H. armigera*.

This was summarised as follows (Miles & Bird, Fall armyworm update, 2021)

> *High levels of metabolic resistance to SP and presence of genetic markers for resistance to carbamates and organophosphates indicate that broad-spectrum insecticides are unlikely to provide effective control of FAW. Given the levels of resistance to broad-spectrums, growers are strongly advised to avoid using these chemical groups and instead consider adopting IPM strategies which help optimise the cost of controlling FAW by taking advantage of natural enemies present in crops.*
>
> *High levels of susceptibility to selective insecticides such as emamectin benzoate and spinetoram indicate these insecticides will be effective options for management. The Group 28 insecticide chlorantraniliprole is also likely to provide effective control. However, control may be marginal at rates below the full field rate of this insecticide.*
>
> *A natural tolerance to indoxacarb in FAW suggests this insecticide may not provide effective control in crops with high insect pressure. However, indoxacarb may be useful for achieving*

> *population suppression in low pressure situations and for providing an additional rotation option for resistance management.*
>
> *As with any insect pest, there is considerable potential for further selection of resistance in FAW to selective insecticides if usage increases. Overuse of selective insecticides could also threaten Helicoverpa resistance management if there is an increase in the frequency of sprays in crops where the two species occur together.*

A more detailed paper on relative insecticide efficacy and current insecticide resistance was provided by Dr Lisa Bird (Bird, Miles, Quade, & Spafford, 2022).
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0263677

FAW Resistance in
Australia_Bird et al. :

Within this report, comparative toxicity values (LC_{50} values) and discriminating dose of susceptible FAW populations was established, based on bioassays of 11 field collected FAW populations. For ongoing insecticide resistance testing, it is critical to establish these values before extensive exposure to insecticides. Once these values have been determined, subsequent populations can be tracked against these initial values, as a way of detecting shifts in sensitivity.

This study also compared toxicity to a known 'susceptible' population of *H. armigera*. Values presented in the table represent the increase in dose rate required to control these 11 FAW populations, relative to the 'susceptible' *H. armigera* standard.

Table 10 Relative toxicity of selected insecticides to fall armyworm in Australia

Insecticide	LC_{50} μg/mL (variability range)	Discriminating dose for FAW μg/mL (based of $LC_{99.9}$ values)	Toxicity ratio† (range) versus 'susceptible' H. armigera
Emamectin	0.023 (1.7-fold)	0.19	3-fold (2-3)
Chlorantraniliprole	0.055 (2.3-fold)	1.0	3-fold (2-5)
Spinetoram	0.098 (1.6-fold)	0.75	1-fold (1) i.e. equivalent
Spinosad	0.526 (2.4-fold)	6	1-fold (1-2)
Methoxyfenozide	1.143 (3.3-fold)	12	4-fold (2-7)
Indoxacarb	3.789 (5.7-fold)	48	28-fold (11-63)

† LC_{50} *S. frugiperda*/LC_{50} *H. armigera*

While this information is essential in establishing baselines for future resistance management, these data are likely to be useful in assisting with understanding of relative field performance and potential application rates required.

It is understood that efficacy via a bioassay on an artificial diet could yield very different results to field applications. Leaf uptake, translocation and persistence, both on the leaf and inside the leaf, will vary with the different chemistries, their formulations, any adjuvants used and plant and environmental factors. However, this research can still highlight important differences between products. Figure 13 compares the current FAW 'permit' rate for various crops, with the overlaid discriminating dose from the NSW DPI work above.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

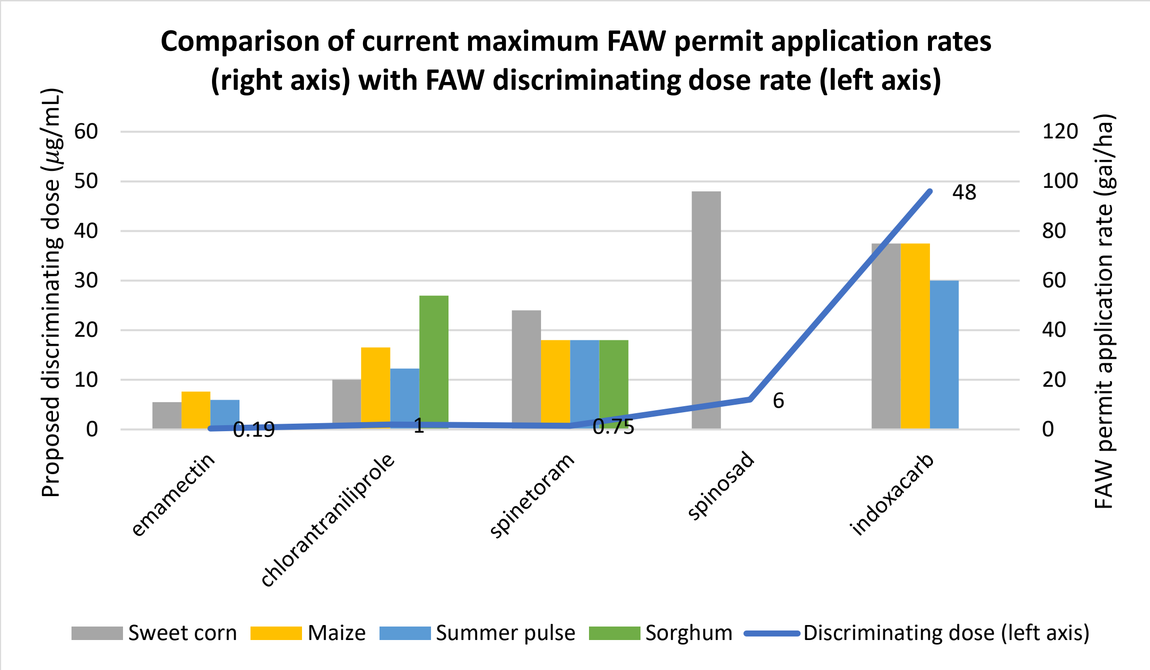


Figure 11 Comparison of FAW permit application rates and FAW discriminating dose rate

While these two axes are different units of measure and cannot be directly compared, it can be seen that this analysis appears to at least partially explain field experience.

Most agronomists interviewed suggested that emamectin was generally performing adequately on FAW (providing application timing was correct).

Chlorantraniliprole is being used the most frequently for FAW control, however this is generally reflecting better value-for-money compared to alternatives, rather than a major efficacy advantage. Although, we did identify some agronomists that commented that the 20 gai/ha rate for sweet corn 'was not as robust/long lasting as emamectin', however when the chlorantraniliprole rate was increased to 33 gai/ha and above for maize or other summer grain crops, it was often reported to deliver superior results to emamectin, especially in length of residual persistence. Melina Miles (pers. com.) indicated that the Australian permit rates were considerably lower than USA registered rates (50-75 gai/ha in maize) for the same pest. Geoff Cornwell also indicated that FMC are planning on a label update to increase chlorantraniliprole rates for FAW. Assuming this occurs, this is likely to both increase the robustness of the treatment, while also potentially addressing the 'value-for-money' proposition which may see users more willing to consider alternate options. Both would be a good resistance management outcome.

Spinetoram was mentioned by some as a comparative alternative to chlorantraniliprole in terms of efficacy at applied rates, however almost all were reporting that it is rarely being used due to the high price relative to other insecticides. The only market that appears to be using Success is the sweet corn or fruiting vegetable market, and even then, it was often 'only when other options have been exhausted first', or if the growers were already needing to use it for western flower thrip.

There is some current use of indoxacarb, primarily as a rotation partner for chlorantraniliprole and especially where *Helicoverpa* is also present. It is likely that indoxacarb has been initially chosen as the first rotation partner, based on this being the historical norm in many *Helicoverpa* market segments. However, this analysis (and feedback from those who have done side by side trials) would suggest that indoxacarb is likely a poor rotation option for FAW complex. With time and more practical experience, emamectin may well become the key first rotational partner for chlorantraniliprole, with indoxacarb being pigeonholed for *Helicoverp*a only (or *Helicoverpa* + sucking bug) market segments.

Methoxyfenozide in Australia is primarily positioned into the tree crop market segment, although does have registrations for *Helicoverpa* and *Spodoptera litura* in tomatoes, peppers (capsicum and chilli), egg plant and okra. Additionally there is a minor-use permit (PER84531 expires 31 August 2025) that covers use in sweet corn for "larval stages of Lepidopteran pests, including *Helicoverpa* spp." As FAW is a lepidopteran species, then this permit should also cover use in sweet corn targeting FAW. During the course of interviews for this project, we did not identify any sweet corn users that mentioned use of methoxyfenozide, although at current pricing and relative use rates, this may not be surprising (i.e. the application rate for Lepidopteran pests in vegetables or sweet corn is 5-7 times higher than the standard rates used in tree crops, which is the primary market segment for methoxyfenozide (and hence priced accordingly).

It is noted that Corteva have applied to the APVMA for registration of Intrepid Edge, "a 300 g/L methoxyfenozide and 60 g/L spinetoram suspension concentrate insecticide for use on chickpeas, mung beans, soybean, cotton, sorghum and maize to control various pests including Heliothis and fall armyworm." At this point of time application rates and relative pricing is not understood, however USA application rates for caterpillar complex (including FAW and *H. zea*) are equivalent to approximately 450-600 mL/ha o the Intrepid Edge formulation in cotton (135 + 27 gai/ha to 180 + 36 gai/ha), while maximum use rates are up to 900 mL/ha in maize (270 + 54 gai/ha) for the same formulation.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

8. Non-chemical FAW considerations

While the context of this report was focused on developing strategies to manage overuse and selection pressure for insecticides, it is important to also consider the role of non-chemical management tactics that may be able to be implemented.

8.1. Monitoring and surveillance

In regions where FAW is likely to be an ongoing pest, growers will need to become familiar with FAW identification (especially egg lays and early instars) in order to be able to enact management strategies before larvae become intrenched and more difficult to control.

Several useful resources are available that show how to identify fall armyworm.

QDAF
https://thebeatsheet.com.au/key-pests/fall-armyworm/faw-identification/
https://thebeatsheet.com.au/wp-content/uploads/2020/06/Armyworm-larvae-May20.pdf
https://thebeatsheet.com.au/detecting-faw-in-sorghum-and-corn/
https://thebeatsheet.com.au/wp-content/uploads/2020/06/Schutze-FAW-Webinar-13th-March-2020.pdf

NSWDPI - Two stage lab-diagnostics
https://www.youtube.com/watch?v=ozZAEg2fXkY&list=PL4zlvcUKKUmViy1yl-4bdcerUW5Y-RTUo&index=2

Western Australia
https://www.agric.wa.gov.au/fall-armyworm-western-australia?page=0%2C3#smartpaging_toc_p3_s0_h3

For sub-tropical and temperate regions, where FAW are only likely to build in damaging numbers through summer, surveillance networks incorporating the use of pheromone traps are likely to become extremely important each season in being able to flag the first arrival of moths into the district. A permit for use of currently unregistered pheromone lures has been issued by the APVMA (PER89169 expires 28/2/23).

While pheromone traps are simple to assemble and components are commercially available (e.g. https://bugsforbugs.com.au/product/pheromone-lures/), identification of FAW from other moths that may also be trapped is likely to require expert laboratory identification. Resources on how to establish and use pheromone traps and identify catch include:

QDAF
https://thebeatsheet.com.au/key-pests/monitoring-for-pests-and-beneficials/pheromone-traps/
https://www.youtube.com/watch?v=2qIxD8iajqQ
https://thebeatsheet.com.au/wp-content/uploads/2020/06/MothIdentification-FAWpheromonetraps.pdf

NSW DPI
https://www.youtube.com/watch?v=ae8NIfri02Y&list=PL4zlvcUKKUmViy1yl-4bdcerUW5Y-RTUo&index=3

Western Australia
https://www.agric.wa.gov.au/sites/gateway/files/DPIRD%20Fall%20armyworm%20surveillance-trapping%20training%20manual_1.pdf

To assist growers, QDAF and NSW DPI maintain a trapping network of pheromone traps across their respective states to monitor recent FAW presence. At the time of writing this report, counts from these traps were being maintained on a weekly or fortnightly basis and published on the QDAF Beatsheet website https://thebeatsheet.com.au/key-pests/fall-armyworm/faw-pheromone-traps/ .

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

In NSW, fall armyworm was a 'notifiable' plant pest, which requires anyone who finds it to notify NSW DPI Biosecurity (Exotic Plant Pest Hotline 1800 084 881 biosecurity@dpi.nsw.gov.au https://www.dpi.nsw.gov.au/biosecurity/report-a-pest-or-disease). This additional level of reporting allowed NSW DPI to publish maps of both male moth detection (via the network of pheromone traps) plus actual detections from the field. (Figure 14). However, as per the NSW DPI webpage https://www.dpi.nsw.gov.au/biosecurity/plant/insect-pests-and-plant-diseases/fall-armyworm updated on 25 February 2022, it states that FAW is no longer a notifiable pest and no longer needs to be reported. This date also appears to be the last time NSW DPI published the distribution map of FAW.

Figure 12 Fall armyworm moth and larvae detection as at 22/2/22.
https://www.dpi.nsw.gov.au/__data/assets/image/0010/1371448/Fall-armyworm-detections-MAP-25-Feb-2022.jpg

Adama launched a commercial (fee for service) trapping and monitoring system https://www.adama.com/australia/en/trapview-network which automates the process of moth identification and reporting following capture in a modified bucket trap design. Currently this service is limited to commercial monitoring of pest species as shown in Figure 15. Use against other pests, including FAW, is reported to be in development.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

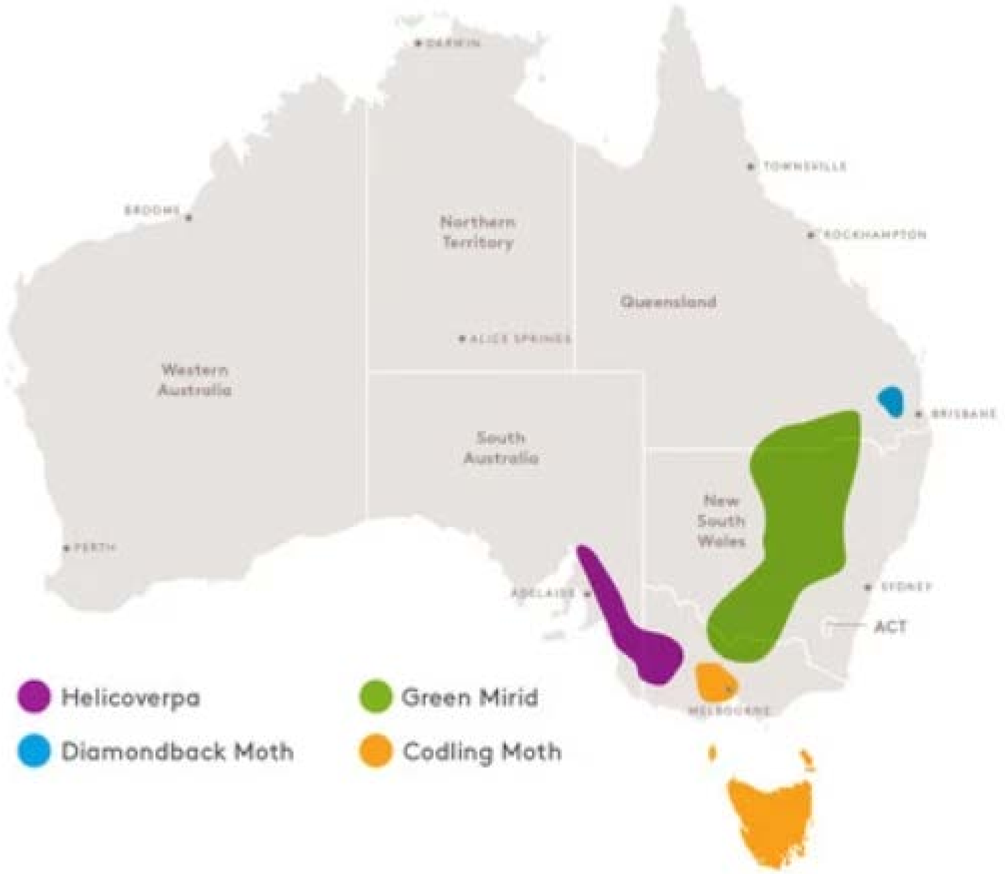


Figure 13 Adama Trapview network coverage (as of December 2021) https://www.adama.com/australia/en/trapview-network

The Food and Agriculture Organisation of the United Nations (FAO) maintain a 'global' website and app for tracking FAW detections https://www.fao.org/fall-armyworm/monitoring-tools/famews-global-platform/en/. However, at the time of writing this report (June 2022), data was limited to Africa and parts of South-east Asia and there were no entries for Australia.

8.2. Scouting for decision making

Implementation of any integrated management program relies heavily on understanding the magnitude of the population of the pest, along with any beneficials. Where crops are regularly scouted (e.g. twice weekly) this allows managers to monitor changes to populations over time and make selected insecticide interventions only when required. Knowing population numbers also influences choice of insecticide control selected.

For any pests where insect pressure has been high and the insect of concern is highly damaging to the crop, most growers have adapted to implement a scouting regime appropriate to the situation.

> For example, cotton crops are generally professionally scouted more than once per week. When *Helicoverpa* were the key target, this required manual checking of terminals. As *Helicoverpa* became less problematic and mobile sucking bugs became more important, the use of beat sheets has become more important.
>
> In pulse crops in northern regions, crops are regularly scouted for a range of caterpillar and sucking pests, at least from first flower – typically by intensive use of beat sheets. However, in the south where *Helicoverpa punctigera* are the primary pest and these are still 'easy' to control

> at any growth stage by application of a cheap, broad-spectrum insecticide, then scouting is far less intense, and a sweep net is more likely to be used.

These examples are provided to highlight that scouting will be adapted to reflect the problem faced and the associated cost of management decisions. However, there is also a tipping point, in that in situations where the pest is 'always' likely to be present in high frequency and will be causing substantial economic damage, then scouting may actually drop off and managers accept that programmed insecticide applications will be needed.

Where the recommended time required for intensive scouting is considerable and needs to be implemented frequently (i.e. weekly or twice weekly) to be effective, this will only be used widely where the benefit outweighs the cost.

Implications for FAW management

For some crops (examples include cotton and summer pulses), managers are already frequently scouting for existing pests and therefore FAW will be detected should they be present. Typically where this high level of scouting is present, growers will most commonly employ professional insect scouts / consultants and there is usually a financial structure in place that covers the cost of scouting. These professional scouts become very proficient in insect identification and the most appropriate sampling methods for each pest. Advisers interviewed that reside in this segment were generally indicating that they would be able to identify FAW when/if it arrived in the crop.

Likewise, most high value vegetable crops (including sweet corn and capsicum) are also monitored frequently – not just for insect pests, but also for disease management, nutritional status, and irrigation scheduling. Feedback from our interviews suggests that in the case of FAW, scouting will often be used just to detect the initial incidence of FAW in the crop. Mostly, after that point, the expectation in sweet corn and capsicum is that FAW will be present in damaging numbers and that a regular insecticide program will need to be implemented from first detection until harvest.

Advisers dealing with already intensively managed crops such as sweetcorn or capsicum did not raise the cost of scouting for FAW, as it is likely already addressed within their current business model with clients.

The majority of advisers interviewed that are working with maize for grain or silage, sorghum and improved pasture (mentioned in far north Queensland and northern WA only), raised the cost of scouting for FAW as a major consideration. In each of these cases, crops are either not being scouted at all for insect pests, or the time where they are currently being scouted for 'traditional' pests does not align with the extent or timing of FAW infestation.

> For example – it is highly unlikely that maize for silage was ever checked for insect pests prior to the arrival of FAW, while many maize crops for grain 'may' have had a single check around silking for *Helicoverpa*. These crops are now requiring weekly or twice weekly scouting from crop emergence.
>
> Likewise, forage sorghum is typically not checked for insect pests, while grain sorghum scouting for *Helicoverpa* only commences once the plant initiates a seed head, and then again possibly later where sorghum midge is also expected to be a problem. The key damage period for FAW is from establishment until the emergence of a seed head, which is typically when sorghum crops are rarely checked for insect pests. Early indications are that while some sorghum crops have suffered extensive damage in the vegetative stage, most advisers in most regions felt that

> spraying of grain sorghum for FAW is likely to be limited post 'establishment', with often the crop having the ability to grow away from vegetative damage in most situations. As such, the need for increased insect scouting may not eventuate in this crop in some growing regions, however currently these crops are being regularly scouted until agronomists build up enough confidence that spraying may not be needed.
>
> Grass pastures (and millet) have rarely ever been scouted for insect pests. For high production Rhodes grass pasture in northern Australia, advisers are now needing to regularly check these crops, especially during establishment. Extensive grass pastures for grazing are never checked and no insecticides are applied but may now be a breeding ground for FAW populations.

The implication of this is that, for effective FAW management, managers are now being required to regularly scout for FAW in crops where scouting was either very targeted to specific pest windows or was never done in the past. For many of these situations (particularly grazing / fodder market segments) growers have not historically had an 'agronomist' providing in-field advice at all on a regular basis. Additionally, the crop value of these markets is relatively low, so there is a general reluctance to pay for the required scouting. Several agronomists working in these crop segments were asking 'What are other agronomists doing?' – as they are reporting that many growers of these low input crops are already 'complaining' that the insecticide and application cost are too high and 'expect' that the reseller business should be providing the level of service required to support the growers greatly increased insecticide bill. While the reseller agronomists were conscious that the margin on product sales was not adequate to go from effectively no scouting, to potentially twice weekly in-field scouting over many months. Not to mention the physical time constraints to do this across the district they service.

FAW lay their eggs in rafts and often these may be deep in the whorls. So, especially under light pressure, it can be much easier to miss a single egg raft when scouting, compared to *Helicoverpa* where single eggs are laid more evenly throughout the canopy. It has been suggested by some that, to accurately understand FAW populations and dynamics, then destructive plant sampling is required i.e. cutting stems and whorls. The time and expertise required to do this by growers or their reseller agronomists is unlikely to be able to be justified in these 'lower value' crops and hence managers are looking for less labour-intensive scouting / sampling methods.

With time, if intensive scouting and destructive sampling is the only practical option underpinning FAW management in these crops, then it will force those growers who wish to continue to grow these crops to pay for the degree of sampling required (as currently happens in cotton and summer pulses). However, it could be predicted that the additional cost of regular scouting in concert with the increased insecticide and application costs, is likely to see a reduction in the financial attractiveness of growing these (relatively low value) crops and growers may seek alternative crop options. In many areas, our research has identified that a significant number of 'maize growers' have already dropped maize from their program, or in other instances reduced the area planted and/or confined planting to only 'lower-pressure' windows for FAW. This reduction in maize planting intention is already happening without significant increase in scouting costs being passed onto growers, as most agronomists indicated that they are still trying to 'work out' how they recover the time cost that they are currently investing in their growers' crops.

Additionally, due the physical time demands of thorough scouting, if the agronomist is required to spend significantly more time in the paddock, then they will either need to significantly reduce the number of clients they can service or employ more checking staff. This is driving many of these advisers to look for other, less labour-intensive methods of FAW surveillance.

There was a high interest by many operating in these crops in the concept of pheromone traps. (See following chapter for more detail). Ideally, they see the potential for pheromone traps to be used as a signal that 'FAW have arrived' and therefore they can avoid wasting time scouting crops when FAW are not present. Additionally, several were wanting to utilise the early detection via traps as a trigger to target Magnet applications at moth flights, or to time Fawligen applications to hatching neonates (without the need for intensive in-field sampling to determine application timing). Unfortunately the current traps and trapping network was considered to generally not meeting these needs of several, with many reporting that FAW are often well entrenched in the crop before traps detect FAW presence. This observation was reinforced by similar observations from several entomologists interviewed. Most wanted to see advancements in trap reliability / accuracy for these reasons, however if traps cannot provide the level of reliability and accuracy required to meet this objective, then they were perceived as being of little value by many.

Several are also relying on 'visual damage' or 'presence of egg rafts' as a key scouting mechanism (especially in low pressure environments). This is often the case where there is low confidence of being able to identify early instars of FAW from other caterpillars, as egg rafts or visual damage symptoms are often easier to differentiate - especially to less experienced advisers or those who are only 'occasionally' scouting FAW. This can also be the case where the area requiring scouting is too large relative to the manpower available, and agronomists have no choice but to react to visual damage.

Some advisers were seeking a way to be able to accurately differentiate FAW neonates from other caterpillar neonates without the need and time delay of sending them away for identification. Several agronomists mentioned a desire to have something similar to the old 'Lepton' test to be able to accurately confirm FAW in the paddock. In each of these cases, these requests were coming from regions with currently 'low' FAW pressure and these (experienced) agronomists were looking for certainty in field detection as this will have a significant bearing on subsequent management. In regions where FAW pressure was high, there appeared to be less desire for FAW identification tools, with most appearing to 'assume' that any neonates found will be FAW. Physical damage symptoms were cited as being very specific to FAW – often obviating the need to speciate under high pressure situations.

A few other agronomists questioned if drone or satellite imagery may be able to replace the need for in-field physical scouting.

8.3. Utilising pheromones & attractants

Throughout our research, pheromones and pheromone trapping and other 'attractant' strategies were frequently mentioned by most interviewed. The majority of participants were using, or had tried, either or both of trapping of adult male moths (surveillance is the goal), or 'lure and kill' strategies for female moths (population reduction is the goal).

Pheromone traps – typically these utilise a male attractant lure, housed in physical 'trap' containing a dichlorvos insecticide block, with moths being killed and collected inside the trap. Attractant lures have pheromones optimised to attract different species (although physical identification of moths is still required to separate FAW from some other species of bycatch). To meet short-term market need, specific FAW lures have been imported and can be used under an emergency permit (APVMA permit PER89169 which expires February 2023).

Those agronomists who were advocates of this system were generally using this as a surveillance tool to provide a 'heads up' the moths are moving into the area i.e. in early spring when populations have been reduced over winter and are starting to rebuild. This gives agronomists an indication that it is time to start physically monitoring crops more thoroughly.

However, when pressure increases in and around key crops, several agronomists reported that these surveillance traps do not provide much additional value when they are capturing a 'bucket full' of moths each week.

A small number of agronomists interviewed maintained and utilised their own traps (primarily located around young maize and sweet corn crops). Some others were 'managing' traps on behalf of QDAF and NSW DPI, who maintain a 'network' of regional traps. While others were not directly managing traps themselves but did take notice of the QDAF and NSW DPI published trap count information for their region.

Often respondents reported that in situations of lower pressure there can often be low correlation between trap numbers and actual field damage. So often these are used 'as a guide only'.

A number of agronomists, especially in southern Queensland, reported that they perceived that the lures used in 2021/2022 (no product names were mentioned) were not as effective at attracting male moths compared to the lures used in earlier seasons. In subsequent discussion with Melina Miles (QDAF), there had been a change in lure supplied during this past season, with the new lure chosen to be more specific to FAW. Therefore it is likely that total moths collected could be significantly lower (less bycatch), but the actual FAW capture should be the same. It 'may' be possible that some who were reporting that the new lure was not effective as the old lure may be basing this on observations of 'total' moth capture, and not specifically counting FAW.

One sweet corn agronomist, with considerable experience with traps, suggested that in many situations the frequency of traps needs to be substantially increased in many regions, and frequency of checking increased (to at least twice weekly) if people want to confidently use the trap information for management decisions.

Multiple agronomists and entomologists cited the mismatch that exists between field infestation and capture by moths in traps. It was common to have high levels of field infestation before any moths were found in traps. It is unclear if this has been rectified or not by the introduction of the new attractant used this last season. Either way, there is substantial mistrust amongst agronomists as to the value of pheromone traps as a guide as to when FAW start to become active in an area. Should the new attractant be shown to be more accurate in correlation with field populations then research validating this is required to be disseminate to rebuild industry confidence in trap data.

Lure and kill – This strategy involves the use of a sprayable 'attractant' (plant volatiles) to attract female moths and is applied in conjunction with an insecticide that has adulticide activity on the moths that feed on the attractant. Generally this 'lure and kill' mixture is applied as a large droplet (to help longevity of survival) and is either applied to the perimeter of the field, or in strips across the field.

The basic principle of this strategy is that by only applying to a very small percentage of the paddock area (and attracting moths to this area), then a different mode of action insecticide can be used - in particular, those that have broad-spectrum insect activity and likely to be too damaging to beneficials if applied as a full broadcast application. It is also targeting a different stage of the lifecycle. Typically a fast knockdown insecticide will be selected.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

The most common strategy reported in the interview was the use of Magnet (attractant) and methomyl (insecticide). Magnet is a “unique blend of plant volatiles” which was originally developed as an attractant for *Helicoverpa*, but a minor use permit (PER89398) for use against FAW has been issued (noting that this permit is due for expiry in June 2022). In several situations, agronomists reported adding a feeding stimulant e.g. Optimol which is a molasses-based product, designed to keep moths feeding for longer.

Recommended use patterns for Magnet when targeting *Helicoverpa* are to apply a strip every ~72m under lighter pressure, or with larger fields. While smaller paddocks, or those under higher pressure should be treated every 36m. Some advisers reported that growers were setting up boom sprays with a single, low-pressure line and nozzle to ‘dibble out’ Magnet + methomyl from one end of the boom spray, when treating the rest of the field with a conventional insecticide application. For others, this can be a stand-alone application i.e. via quad bike.

Generally, those advocating for Magnet + methomyl are not using it as a stand-alone management tool. Where used, it is often considered a complementary tactic to support other management strategies, as efficacy is generally not considered robust enough to be used as ‘replacement’ of a broadcast insecticide when under moderate to high pressure.

A common observation from agronomists interviewed was that while Magnet is good at attracting *Helicoverpa* moths and also appears to have some activity attracting FAW females, there can also be relatively high mortality of beneficial insects in close proximality to the strips. For a small number, this was a reason not to use. While a few also commented that, to be really effective, the distance between strips needs to be kept close, however this increase cost and results in more damage to beneficial populations.

Magnet product information reports that the lure and kill strategy should provide ongoing moth reduction for 4-6 days after application. Advocates of the technology often reporting that it is best used in conjunction with pheromone trapping to time Magnet + methomyl applications as moth flights are commencing (especially in lower pressure situations). However, in some high-pressure situations, a few advisers interviewed were applying almost on a calendar basis with other broad-spectrum spray passes.

One common downside of the lure and kill strategy that was reported is that application is not ‘rainfast’. So if there was rainfall soon after application then the treatment needs to be reapplied. This reduced the attractiveness of the system in high rainfall environments, or where crops are being grown under overhead irrigation. For some of those growing maize under pivot irrigation, there was interest in using the technique around (but outside) the pivot, although this application technique is not currently supported by the Magnet label.

QM FAW is an alternative attractant that was mentioned by some advisers. For those who have used it, there was general consensus that it was more effective in attracting FAW than Magnet. While the additional recommended application strategies (in particular perimeter paddock baiting) added further appeal to some agronomists, than the comparative Magnet product label. The Australian QM FAW label is attached below.

QM FAW label.pdf

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

QM FAW is imported from China by Agreva and exclusively distributed by E.E. Muirs & Sons. As of June 2022, QM FAW is not currently registered by the APVMA. During interviews in early 2022 there was supply chain confusion with regard to the need for registration of this QM FAW label, as “QM FAW does not technically ‘kill’ anything. So is a registered label actually needed?”

The current label recommends “Combine with an insecticide with adulticidal action registered for control of comparable noctuid moths such as *Helicoverpa* spp, *Spodoptera litura* or *Mythimna* spp.” Then further goes on to state “Compatible insecticides with adulticidal action suitable for ‘attract and kill’ applications include the following fast acting insecticides: thiodicarb, methomyl, chlorantraniliprole and spinosad. Slower acting insecticides such as spinetoram, abamectin and emamectin benzoate may be used in conjunction with fast acting insecticides in QM FAW to assist in resistance management but should not be used alone.”

To the best knowledge of the authors of this report, none of these insecticides mentioned above have a ‘registered claim’ for control of insect pests via the lure and kill technique on their individual labels. (However ‘lure and kill’ use rates and use patterns for methomyl, thiodicarb, spinosad and spinetoram are claimed on the Magnet label). As a result of this registration ‘confusion’, some advisers reported that QM FAW had been ‘withdrawn from sale’.

There were some reports of other ‘attractants’ being tested, however these were not yet commercially available.

Pheromone based mating disruption – During the course of interviews conducted, a small number of advisers mentioned the potential of using pheromones to disrupt mating behaviour of moths. This technology is currently used in some orchard crops as a management tactic for pests such as codling moth, light brown apple moth and oriental fruit moth.

The cost of this type of technology, should it be similar to orchard crops, is likely to make this impractical for broadacre use over large areas.

Further research – There was high interest from several advisers interviewed for further research and to refine optimal pheromone and lure and kill strategies to enhance FAW management and this should be an area of ongoing research investment. Hort Innovation have initiated investment in this space https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/as21000/ , while QDAF (Subramaniam pers. com.) and commercial attractant suppliers also have ongoing research underway.

For those agronomists who have used QM FAW previously, there was a desire to have this commercially available (and appropriately registered, should that be required), as they perceive that it is more effective than Magnet.

8.4. Damage thresholds for FAW

Action thresholds for insecticide intervention for any pest (including FAW) should only be enacted after populations reach economically damaging levels. Eliminating unnecessary insecticide applications reduces insecticide selection pressure while also reducing damage to beneficial populations and is a basic pillar underpinning many resistance management strategies.

As FAW is a relatively recent arrival in Australia there is little locally generated information on damage thresholds. The advice below is based on USA generated information.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Table 11 Best evidence thresholds for a range of crops based on USA data (Kearns, et al., 2020).

Crop	Threshold
Maize vegetative Maize whorl stage	>3 larvae per plant and/or 50% of plants show signs of fresh feeding >20% of plants at whorl stage with one or more larvae and/or >75% of plants with signs of feeding damage
Sweet corn tassel emergence	>15% of plants infested at tassel emergence
Sorghum vegetative Sorghum grain fill	>30% defoliation, or >2 larvae per whorl Economic thresholds (ET) can be calculated using the following formula: ET = (C × R) ÷ (V × N × 2.4), where C is cost of control ($/ha), R is row spacing (cm), V is value of crop ($/t), N is number of heads/m row, 2.4 is damage (g/larva)
Cotton	No established threshold
Soybeans vegetative Soybean budding-podding	>33% defoliation 3 larvae /m2
Pasture (hay production only)	18-27 larvae / m2

Additional information is available at https://thebeatsheet.com.au/key-pests/fall-armyworm/faw-management/

From field interviews conducted, the primary learnings were:

Maize - No particular thresholds were being utilised, just subjective assessment of population dynamics (number of FAW and any beneficials), paddock location, damage being caused and expected ongoing pressure.

- Several indicated that an insecticide would be applied “as soon as FAW are detected in the crop” i.e. almost operating on zero tolerance. These advisers were concerned about the ability to control larvae if they become entrenched and move past the first/second instar. This approach was particularly evident in known ‘high FAW pressure’ regions and particularly where the infestation was early in the crop, or there were other ‘susceptible’ host crops likely to follow, and the adviser was concerned that a few larvae could quickly build to very high levels over the coming weeks/months. Mostly, these advisers were desiring to choose a tactic with minimal disruption as their first application (Fawligen, Magnet + methomyl, Vantacor were common tactics).

  A strategy of going in hard early was also supported by at least one entomologist, who advocated that endogenous population development within the crop itself, was a key source of later season high levels of infestation. As such, early control measures were strategic in reducing later season pressure from an endogenous insect population developing within the host crop. These comments were made in relation to high-pressure maize crops on the Atherton Tableland. This entomologist also identified crop establishment and the silking/tasselling as the key/critical periods when high levels of control were required. The period from approximately four – six leaf up to around 12 leaves was seen as less critical to crop yield, during which time the crop could sustain high levels of damage with less impact on yield than damage at more critical times

- Some other advisers were more prepared to hold off immediate insecticide application and determine a management strategy following subsequent checks. (A few mentioned that it can take 4-5 days for beneficials to 'catch-up'). While there were exceptions, generally these advisers were operating in lower pressure FAW environments. There was also an underlying sentiment within this group that they know that this is the right approach, however there is still a high level of apprehension with their ability to 'pull up' damage should FAW persist. This will take time and several years of experience to build confidence
- One Darling Downs agronomist was very comfortable to work on the premise that their base management approach will be to not spray at all in maize and allow native beneficials to do all the work. With insecticide intervention only used occasionally where the situation was getting out of hand.

Sweet corn and capsicum – these are primary horticultural crops mentioned as being very susceptible to FAW damage.

- For sweet corn, this was particularly during establishment (emergence to V6) and then again from V10 to harvest.
- While for capsicum this was particularly from flower initiation to harvest.
- In both crops there is currently a zero tolerance for any FAW presence at these important growth stages. Most growers have sequential plantings so there are always some blocks on the farm at the key growth stages. Many in this demographic are managing FAW at a 'farm' level, rather than as individual blocks. Once FAW are detected, growers will effectively be calendar spraying (as frequently as every 3 days in some situations).

Sorghum – consistently it was reported that vegetative sorghum can carry high levels of FAW, however once the crop pushes out a seed head the FAW appear to lose interest and seek alternate hosts. This is in direct contrast to *Helicoverpa* where economical damage only occurs to the sorghum head.

- Primarily, sorghum damage from FAW is often of most concern during the establishment phase, with some reports of complete plant mortality under extreme FAW pressure. Such circumstances are mostly related to sorghum crops grown in close proximity to maize or sweetcorn, and especially in coastal environments, where spillover insect pressure from nearby more susceptible crop types is the primary cause for damage.
- Providing the sorghum crop has established, some agronomists questioned the existing thresholds above (>30% defoliation) and they were suggesting that 40% (or even 50% in the case of one adviser) vegetative defoliation appears to be having very little impact on yield. Further quantification was being sought to reinforce these observations.

  One agronomist was an exception, reporting FAW were attacking sorghum seed heads. However this was in north Queensland and in an environment of extreme FAW pressure from attractive host crops adjacent to the sorghum.

Summer pulses – most summer pulses appear to only require treatment for FAW when there was other 'highly attractive' host crops (maize, sweet corn, vegetative sorghum) in the immediate vicinity. No particular thresholds were being utilised, just subjective assessment of damage and expected ongoing pressure.

In the absence of spillover pressure from adjoining highly sensitive crops such as maize or sweetcorn, most interviewed felt that it would be unlikely for most summer pulse crops to be specifically treated for FAW, although they will be getting regularly sprayed during podding for *Helicoverpa*.

While direct damage from FAW is low, summer pulses are all getting regular applications of the same insecticide modes of action for *Helicoverpa* control, mostly at the similar timing to FAW applications. So it will be very important to also consider summer pulses in any resistance management strategy developed.

Pasture – no thresholds were being used from the agronomists interviewed, just subjective assessment of damage and expected ongoing pressure. Under high pressure situations damage can occur to all crop stages, although the most important timing for FAW damage appeared to be during establishment. One Atherton Tableland agronomist mentioned that it was common practice to plant millet with the Rhodes grass pasture, as the millet was much faster to establish and then 'protects' the slower establishing Rhodes grass seedling, however both of these species are getting hit hard in a high-pressure environment.

Cotton – no evidence of FAW establishing in Bollgard 3 crops were reported.

Sugarcane, rice, winter cereals & other vegetable crops – There was generally no major reports of significant FAW damage to these crops. It appears that other hosts are preferred. FAW were reported as having been found in a number of crops where spill over pressure from nearby more sensitive crops had occurred, but these populations did not persist or were not problematic. Some northern Queensland agronomists commented that if rice or sugarcane were 'dirty' with grass weeds (in particular barnyard grass) then they were much more likely to find some FAW in these crops.

8.5. Beneficials

Across agronomists interviewed, there was a desire to better understand the role and importance of natural enemies/ beneficial predators and parasites.

There was a general understanding of the principle of trying to preserve beneficials wherever possible, but a lack of understanding of which specific beneficials are important for FAW. Most accepted this lack of knowledge, as it is recognised that FAW is a new pest and hence little is known, although without knowing which are important, their presence cannot be factored into decision making.

Most interviewed were noting beneficials present at scouting and subjectively factoring this into their decision making. However, only one agronomist interviewed was quantitatively counting or using any pre-determined pest/prey ratios to inform insecticide application (and this was largely based on *Helicoverpa*). This lack of quantification is most likely a factor of not knowing which beneficials are important, and in what numbers. Several agronomists mentioned that they were counting beneficials and *Helicoverpa* prior to the arrival of FAW but have now dropped the beneficial counts due to the large numbers of FAW being found regularly and the lack of confidence that beneficials will be able to manage FAW numbers.

In maize in particular, but also vegetative sorghum and summer pulses under high pressure situations, there was considerable concern that delays to insecticide intervention to allow a 'lag time' for beneficial insects to build may result in unacceptable levels of crop damage. In lower pressure situations in maize or high-pressure situations in less sensitive crops, advisers were looking for additional research to understand this dynamic and the associated management risk. Without confidence to delay, they are much more likely to intervene with an insecticide.

Conversely, one senior and well-respected Downs agronomist known to avoid spraying wherever possible commented that in 2021/2022 he was able to manage most of his high yielding (14-19 t/ha) grain maize crops without any insecticide applications at all, just relying on natural beneficials. In his opinion, beneficials respond strongly to FAW if you don't spray. Even strips of Magnet + methomyl were too disruptive for him.

In sweet corn, and capsicums (particularly from fruit initiation) the value of the crop is too high to accept 'any' damage. Additionally, most agronomists recognised that the frequency of insecticide applications, coupled with the heavy rotation of modes of action, meant that it offered little opportunity for beneficials to establish in these crops. So typically beneficials are not being considered as a management tool, even where agronomists would 'like' to preserve them.

Several agronomists interviewed had tried commercial releases of *Trichogramma* wasps (known to be effective against *Helicoverpa*).

- General consensus ranged from 'not worth it' to 'not really sure, as it was hard to quantify in a dynamic system with many other tools being applied simultaneously.'
- Only 1 agronomist interviewed (Namoi Valley) appeared 'committed' to regular commercial releases of *Trichogramma* wasps as part of their ongoing management program (although this was targeting mixed FAW and predominantly *Helicoverpa* populations).
- Several commented that they are aware that emamectin and spinetoram are two of the more effective FAW insecticides, however they can be both damaging to microhymenopteran wasps. Therefore there was reported reluctance by some to recommend these insecticides on the assumption that microhymenoptera are likely to be important in managing FAW. This assumption requires conformation
- Following feedback from one experienced agronomist, the authors of this report uncovered a paper from Mexico (Jaraleno-Teniente, Lomeli-Flores, Bujanos-Muniz, & Rodriguez-Rodriguez, 2020) https://www.mdpi.com/2075-4450/11/3/157/htm that showed that *Trichogramma pretiosum* has some control (av. 29% parasitism), however this was variable with sometimes no parasitism being recorded. In this same paper they reported much higher levels of parasitism (av. 70%) with *T. atopovirilia.*

The native larval parasitoid *Cotesia* was commonly mentioned by several who suggested that it was possibly more effective on FAW than *Trichogramma*. Several also mentioned generalist predatory bugs (assassin, shield, damsel, pirate, big eyed), lacewings and spiders.

Those working in cotton were particularly concerned with regard to use of 'hard' chemistry flaring silverleaf whitefly and mealybug.

Further research – Hort Innovation have funded a current research project via QDAF to better understand FAW parasitoids in horticultural crops https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/mt19015/

There was a strong desire by most to better understand which beneficials are most important for control of FAW.

Several agronomists and entomologists commented that for natural enemies to be efficacious over time, they need to be adapted to the local environment. As such, a common comment was that natural enemies bred and reared in captivity from strains selected from outside the target region for release are often poorly adapted to survive and flourish in the environment in which they are released.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

8.6. Native metarhizium

There were several reports of native metarhizium fungus (believed to be *Metarhizium rileyi*) infecting FAW. Where this was occurring, experiences were typically very consistent

- Predominantly occurring in maize (mostly likely due to high FAW numbers and a large canopy to provide the right microclimate)
- It was always associated with warmer conditions (summer) but only when in conjunction with very high humidity / moisture
- Infestation levels build through the crop but are only significant at later grow stages
- There were a number of comments that it may be found earlier in the crop, but generally did not appear to persist until the corn had full canopy development.

Reports were predominantly from north Queensland crops, but there was also some evidence from the Lockyer Valley, South Burnett and Northern Rivers in early 2022, noting that these more southern regions had atypical (flooding) conditions at this time.

Some agronomists reported that infection levels in some blocks were adequate to not require further insecticide sprays in maize post an at-silking insecticide application. But each of these advisers were not (yet) confident that this could be considered a long-term management strategy i.e. they did not have the confidence needed to not consider spraying maize at all after silking and let *metarhizium* become the primary FAW control.

The potential for a sprayable *Metarhizium* formulation was of interest to several interviewed, and some mentioned that they believed that sprayable products are available in other countries. Dr Ian Newton (QDAF) mentioned that they have completed some bioassays with a South African sprayable formulation but “results conducted thus far have been relatively ineffective.” However it is known that sprayable *Metarhizium* products are subject to formulation stability concerns and often need to be stored and transported under controlled environmental conditions, so it was acknowledged that this may have impacted on the results.

8.7. Host-plant resistance in maize

A few agronomists interviewed suggested that anecdotal field observations indicated that some maize / sweet corn varieties appeared to have significantly better tolerance than others. These agronomists were interested in understanding if this is correct. If so, which are the varieties with the improved tolerance?

Internationally there has been some recent research to show that significant differences in varietal tolerance is possible.

https://www.cimmyt.org/news/announcing-cimmyt-derived-fall-armyworm-tolerant-elite-maize-hybrids-for-eastern-and-southern-africa/

https://www.sciencedirect.com/science/article/abs/pii/S0261219420301514?via%3Dihub

https://researchspace.ukzn.ac.za/xmlui/handle/10413/19480

Further research – Side by side screening of Australian maize and sweet corn varieties grown under significant FAW pressure would be of short-term and useful benefit to the Australian industry, to understand the magnitude of difference (if any) between varieties.

9. Current management approaches

In many situations, advisers interviewed were still developing their FAW management strategies. Strategies will vary with expected FAW pressure, time in the season and proximity to host crops. Chapter 14 of this report provides regional and individual responses and some rationale underpinning those decisions.

In this chapter we seek to summarise experiences that appear to be working for most advisers.

9.1. Use of broad-spectrum insecticides

When FAW first arrived, there were numerous mentions of growers attempting to gain control with broad-spectrum carbamate, OP and SP products, typically with poor outcomes due to insecticide resistance.

While there was the occasional exception, research conducted for this project would indicate that these broad-spectrum insecticides are now rarely used for FAW, however there is still some occasional use of methomyl in certain situations. The most likely rationale for the use of broad-spectrum chemistry is in the following situations:

- The value of beneficials typically decrease at later crop growth stages, and in some crops the attractiveness for beneficials decreases as crops start to dry down
- The withholding periods for some 'selective' insecticides may prevent late season applications close to harvest
- Broad-spectrum, fast knockdown insecticides may be applied to clean out all insects (including beneficials) in marketable produce just prior to harvest. This is more likely in some fruiting and brassica vegetable crops destined for fresh produce markets and supermarkets, as consumers have zero tolerance for anything 'alive' in their fruit and vegetables (including spiders and beneficials)
- In sweet corn and vegetables under extreme FAW pressure, some indicated that they may have 'run out' of the permissible number of selective insecticide applications on the label before the crop reaches harvest
- In sweet corn/maize, there were mentions that monolepta beetles can sometimes be in large numbers and feed on the silks and thus damage pollination. Silking is also a key time for FAW, so at least one agronomist was reporting that the combination of FAW and monolepta beetles would result in methomyl becoming the insecticide of choice at silking
- In some crops (especially pulses) sucking pests may be equally, or more, important
- Some crop segments do not have registrations for newer 'selective' products
- The crop value cannot justify more expensive treatments
- The withholding periods for milk production (dairy cattle grazing, where stock are grazing every few days) prevent application of some of the newer 'selective' insecticides.

Further research and extension – It should be noted that several agronomists interviewed, including some considered to be fully 'on-message' when it comes to using 'soft' insecticides to support beneficials, were seeking more information and best management practice on how to best use broad-spectrum insecticides, as they still have a viable fit in some of the market segments listed above. Several interviewed were somewhat critical of the 'research community' who appeared to not see any fit for broad-spectrum insecticides at all, and therefore appeared reluctant to even discuss potential use patterns.

Horticultural crops

9.2. Sweet corn

From interviews conducted, sweet corn (and to a lesser extent maize) is undoubtably the crop under greatest pressure from FAW and is also most likely contributing strongly to overall FAW pressure in the district.

In districts where sweet corn or maize is being grown in a relatively large scale, this is generally leading to heavy FAW pressure being experienced in adjacent crops, whereas in other regions without sweet corn or maize, these same other crops may not require treatment for FAW at all. For example, soybeans and mung beans are often being specifically managed for FAW in the Burdekin, where they are often only managed for *Helicoverpa* in regions without significant sweet corn / maize.

Sweet corn is considered so attractive to FAW that one agronomist managing areas of maize under low/moderate FAW pressure reported that they were planning to experiment with a row of sacrificial sweet corn interspaced across the grain maize block.

In Bowen / Burdekin and Broome / Carnarvon, sweet corn is mainly grown over winter but experiences FAW throughout most crops as temperatures are warm enough to support population development over winter. The Lockyer Valley and north of Perth provide alternate production over the summer months, again also a period of peak FAW activity. The intent is that between the north and south production zones there will be consistent and regular supply into the fresh markets for most of the year. New blocks are planted every few days and harvesting occurs almost daily, so there is no opportunity to use early planting, or blocking planting windows as a management strategy under current commercial supply strategies.

All agronomists reported that sweet corn will be attacked from emergence providing that FAW is present. One or two insecticide applications are often applied before the V6 growth stage. Some agronomists were prepared to accept some level of leaf damage between V6 and about V10, however others were concerned about loss of growth rate during this time.

From approximately V10 there is a strong desire to maintain protection of the last two main leaves before tasselling, as these are important to drive photosynthesis during grain fill. Tasselling is another important growth stage, along with silking to ensure optimal pollination.

When *Helicoverpa* was the major pest, protection of the silks was important, as small instars would use the silks to gain access to the cob. However, low level *Helicoverpa* pressure was often tolerated as they tend to only damage the tips of the cob after entering via the silks. While less than ideal, damaged cob tips can still be removed and the remaining cob sold in pre-pack markets.

FAW will enter through the silks, but then proceed to feed right down the cob and exit towards the base of the cob to pupate. Additionally, they can also enter directly through the husk. In either case, the whole cob becomes unmarketable. In addition to direct physical loss from feeding, penetration holes into the developing cob all fungal and bacterial infections often to arise.

For these reasons, most sweet corn growers appear to be effectively spraying on a calendar basis from about V10. Sweet corn grown under light FAW pressure may be able to be grown with as little as 6-8 insecticide applications in total per crop. However 10-12 applications are not uncommon and 14-15 have been reported under extreme pressure. Some advisers reported weekly applications across the farm for the duration of production.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Sweet corn is a very high value crop (gross revenue approximately $30 000 /ha) so can support use of 'expensive' insecticides applied frequently. One adviser interviewed reported that even growers spending $1000 - $1500 /ha on insecticide + application costs can be still losing an additional 10% ($3000 /ha) in crop damage.

With the frequency of applications required, most advisers are recommending a rotation strategy of all available modes of action. There is some individual preference in performance between modes of action but typically spinetoram (Success Neo) and emamectin (Proclaim) are being utilised to their maximum number of applications permitted on the label, although some attempt to avoid excessive application of Success as it is much more expensive than other options. Chlorantraniliprole (Coragen) is also being used and often to the maximum number of permitted applications, although at permitted application rate for FAW in sweet corn this is perceived by some to be less robust than the previously mentioned insecticides. While most realise that indoxacarb is comparatively poor on FAW some indoxacarb may also be used, especially in situations where *Helicoverpa* is the dominant target or where growers have 'run out' of other options.

Several reported that Fawligen, or sometimes a foliar Bt, may regularly be tank mixed with several of these applications above but rarely will be applied alone.

Control may often be also complemented by Magnet + methomyl applications.

Occasionally 'hard' chemistry may be applied to crops in late growth stages, especially where other options have already been exhausted.

Collectively, sweet corn agronomists understood that this strategy places a very high resistance pressure on all modes of action, and that consecutive generations of FAW are being exposed to every active ingredient. However there is no appetite for any strategy which would result in reduced levels of control. Enforcement of non-use windows would place additional pressure on the remaining modes of action, while also potentially forcing growers into more applications of certain products than their labels allow.

With the frequent rotation of insecticides there is little opportunity for beneficials to establish, so they are typically not considered in sweet corn.

9.3. Capsicums

While capsicum was only managed by a small number of agronomists interviewed, it was the other horticultural crop frequently mentioned as of high concern. All agronomists managing capsicum reported that small FAW instars will preferentially enter into the stem of the young bell and damage can be almost undetected or may appear as similar to mechanical damage (stem rubbing). Once inside the bell, they continue to feed and develop through the instars with little external symptoms evident. One agronomist mentioned that a slight colour change might be evident in affected bells. While another suggested that you can sometimes even find pupae still inside the bell, indicating that they have completed their full development undetected.

Due to the difficulty of preventing FAW from entering the bells, the general response from those interviewed is that FAW management in capsicum is basically a program spraying approach as soon as the plant commences flowering, which is maintained until harvest is complete. In Bundaberg, where the majority of capsicum is grown, an experienced agronomist suggested that a 3-day rotation of insecticides was needed to ensure FAW free produce at harvest. In early 2022, with extended periods of wet weather that disrupted spraying, they attempted to move to a 4-day rotation in some blocks, which was reported as unacceptable and resulting in too much damage.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Although he did indicate that rainfall soon after some applications may have also contributed to the poorer results.

Similar insecticides and rotation strategies to those used in sweet corn are also used in capsicum. Once on a program, agronomists are rotating continually between different modes of action.

- Generally Success Neo and Proclaim are considered the strongest on FAW
- A Bundaberg agronomist reported that growers were already using Success Neo for WFT prior to the arrival of FAW, so there was no change in the frequency of applications. However, in the Burdekin, one agronomist reported that some growers were preferring other options due to the price per hectare of Success Neo
- In Bundaberg, Proclaim was performing well. With the key agronomist claiming that emamectin appears to be able to kill advanced instar larvae that are inside the bell. He did not believe that emamectin would have enough systemic/translaminar activity to do this, but that is what they are seeing both in the paddock and in trial work
- Coragen and Belt (both MOA 28) are being used extensively. These appear to be the primary option in Bowen/Burdekin (as chlorantraniliprole in particular appears to be the preferred insecticide for FAW in almost every crop). While in Bundaberg it was reported that Coragen (in particular) was not as robust as Success or Proclaim and therefore used less – primarily due to the low rate of chlorantraniliprole on the FAW permit
- There were reports of indoxacarb being used when in rotation with the insecticides mentioned above. Agronomists were reporting performance was inferior to the others, however it was being used mainly due to a lack of alternate rotation options
- In Bundaberg, the agronomist interviewed mentioned that they were using Plemax (indoxacarb + novaluron) instead of straight indoxacarb. Plemax does not currently have any permits for FAW, however does have a registration for *Helicoverpa* in capsicum (and other crops). In his opinion (based on field efficacy and small plot trial work), the addition of novaluron resulted in Plemax being much stronger on FAW, with performance similar to Proclaim
- There was no specific mention of use of Fawligen or Magnet in capsicums.

From those interviewed, the Bundaberg agronomist had the most experience with managing FAW in capsicums – both from commercial operations and small plot replicated trial work conducted on behalf of registrants. In his opinion he rated Success Neo as 90% ("provided coverage is good and well timed"), with Proclaim or Plemax at 80%. Coragen was rated at 60-70%, with straight indoxacarb as "less than these others". Additionally, he mentioned that they will only use either Success Neo or Proclaim "on any FAW past the 2nd instar".

As per sweet corn, those interviewed understood the heavy selection pressure being placed on all modes of action, but without several additional and effective insecticides becoming available, there is little opportunity to enact any resistance management strategy which restricts any product any further than the number of label applications that are permissible.

Broadacre crops

9.4. Maize for grain or silage

While maize does not generally make up a significant area of crop under management for most agronomists, it was – by far – the crop of concern for broadacre agronomists interviewed when discussing FAW management.

A repeated trend through the interviews indicated that prior to the arrival of FAW, maize crops were rarely managed for insect pests (especially those crops for fodder / silage). Previously, when *Helicoverpa* did do some damage, this was generally only to the tips of the cob with these grains generally not an important contributor to yield. As a result, many maize growers are not set up for insecticide applications (access to high clearance sprayers or aircraft). Where maize is grown under overhead irrigation (pivot), several are now applying insecticides via the pivot.

Additionally, while maize for grain or forage is a high yielding crop, it is relatively low value. With the arrival of FAW, the combination of the cost of FAW insecticides, the damage still being experienced even when spraying and the cost of contract application where required, this has significantly reduced the attractiveness of maize growing throughout Queensland and northern WA. This has already led to a significant reduction in the planted area, as many growers are looking to grow alternate feed options.

Several reported that the financial attractiveness of maize was already challenged by other crops prior to the arrival of FAW, but maize was continued to be grown in some locations where there was a specific agronomic fit that it could fill.

Reasons for growing maize, and the FAW pressure being experienced, differ greatly across the regions interviewed. This can be summarised as follows:

<u>Atherton Tableland</u>
FAW pressure is all year long, with only the duration of winter lifecycles increasing slightly with cooler temperatures. Therefore the is no real opportunity to grow under a ‘low-pressure’ time of the year.

Maize grown for grain (locally adapted varieties, used primarily in dairy cattle rations).

- One agronomist, who manages the majority of area grown for grain, reported that if it is ‘drier’ in spring/early summer and growers can plant at the preferred timing, the crops can be at a more uniform growth stage across the district, and this makes district wide FAW management more effective (as was the case in 2021 planting). However, in 2020 there was a lot of rainfall in spring and planting was more spread out. As a result, FAW management was more difficult.
- There was one report that the local maize processor was considering a (small) price increase, as it was suggested that they were concerned about declining maize planting as a result of FAW.

There is also a significant area of maize grown for silage or green chop, which again services the dairy market. A significant area of this has traditionally been grown by beef cattle growers for sale to their neighbouring dairy cattle operations. This has been a very low input system, as generally it was contract planted, either rainfed or sometimes grown under a pivot and contract chopped. Many of the growers are primarily self-described as cattle or dairy producers. There were suggestions that several of these cattle or dairy producers are now considering maize to be ‘too hard to grow’ with the need for multiple insecticide applications.

There were some suggestions that dairy producers are needing to reconsider their dairy rations without heavy reliance of maize (grain or silage / green crop).

<u>Burdekin (with some similarities in the Ord, WA)</u>

While maize was not a high contributing gross margin crop, it has been a very important break crop in the ~12-18 months between sugar cane crops. Depending on when the cane was taken out of production, growers would typically grow 1 maize crop during 'winter' and 1 or 2 pulse crops (mung bean or soybean), either before or after the maize.

Similarly to the Atherton Tableland, FAW pressure is all year long, with only the duration of winter lifecycles increasing slightly with cooler temperatures. So maize crops will be under heavy FAW pressure whenever they are planted.

Agronomists reported that there has already been a significant number of growers move away from maize in their rotation. Several agronomists mentioned that they are still trying to determine what a new rotation may be.

- Sorghum does not like to grow over winter (when maize is traditionally grown in the Burdekin) and sorghum has lower $/ha return
- Some are experimenting with 3 back-to-back pulse crops, but realise that this is not an acceptable agronomic solution in the long term
- One agronomist was considering hemp and either a mung bean or soybean rotation for their cane break phase
- Others were still hoping to work out how to continue to grow maize with 2 (or possibly 3) 'strategic' insecticide timings, which may be an acceptable outcome for some growers.

Southern Queensland (Darling Downs, South Burnet, Fassifern Valley) & northern NSW

While some silage is grown, the majority of maize grown in these regions is for grain and the crop needs to be economically viable compared to other grain alternatives. Typically crops can produce more than 15 t/ha under irrigation, however the $/t of grain is often relatively low. Due to the long growing season and high vegetative mass produced, there is a relatively high demand on available water and nutrients.

- This often limits growing to irrigation, or where good in-crop rainfall is expected. In irrigated systems, maize will often be competing with cotton for available water allocation
- Under raingrown conditions, maize competes with dryland cotton, sorghum or summer pulses in the rotation
- Under low, marginal or variable rainfall situations, sorghum will almost exclusively be chosen over maize.

For some, one of the attractive features of growing maize (prior to FAW) was the low incidence of insect pests and generally no need for additional machinery passes on the paddock following post-emergent herbicide application.

The majority of agronomists operating in these regions reported that FAW pressure drops off considerably over winter (or disappears completely). In spring, numbers start to build and typically peak in December / January. For most agronomists interviewed, this provided the opportunity to 'shift' the maize planting window.

- Prior to FAW, maize would be planted anytime from September (maize can be planted into slightly cooler soil temperatures than sorghum) through until December (*Authors note: we are aware of maize being sown with success in August in this region*)
- Agronomists reported that late November / December planted maize will be decimated by FAW, with some reporting complete mortality of emerging seedlings in worst case situations
- However, September planted maize often experiences no, or very light, FAW pressure at establishment and by the time the crop reaches the high pressure FAW window of December / January, many crops may be largely past the periods of most economic damage

- The downside of shifting planting to September is primarily that soil profiles may not be full, and often growers traditionally wait for spring storms before planting. So a September plant may require pre-irrigation in many years
- While bringing forward and condensing the planting window was seen as beneficial by all (and for some, the only possible way to continue to economically grow maize for grain), there was a recognised constraint that this would mean less area planted to maize. Additionally some suggested that this would concentrate harvest and potentially cause logistical issues for such a large volume crop requiring harvest in a very small window (and especially when it can be wet at that time of year).

Several reported that FAW numbers appear to drop away in February, and there was uncertainty over what was causing this noticeable drop in pressure.

- Some suggested that this 'may' be due to host crops (maize, vegetative sorghum) becoming less prevalent at this time of year. However, others argued that there has often been a significant area of 'susceptible' crops available in February and March which have not held high FAW pressure
- Another possible suggestion was that decreasing day length may be having an influence.

There are also some small areas of maize grown in south-east Qld (Fassifern Valley) and the Northern Rivers of NSW for dairy fodder, typically as silage or green chop. A small area is also grown for grain in these regions. As per the broader Darling Downs and NSW above, agronomists recognise that early planting in September or early October will substantially reduce FAW pressure. However in these regions, and especially for green crop, there is a strong desire to spread planting dates to have harvest extended for several months.

The management approach taken in these regions had several general consistencies across agronomists:

<u>Planting date</u> - There was a strong bias towards moving planting forward to September and early October wherever possible, to reduce overall pressure. Some agronomists were even suggesting that if growers are not prepared to plant into this window, then maize should not be grown at all.

<u>Establishment</u> – maize establishing under high FAW can sustain extreme pressure and cause plant mortality, sometimes requiring replanting. It is not uncommon for maize crops to require an insecticide application (or two under heavy pressure) somewhere before V6.

Typically agronomists are hoping to use pheromone traps to assist in timing the need for this application (ideally without the requirement for extensive monitoring time being spent in the paddock). However several mentioned that there is currently not adequate correlation between trap counts and presence in the crop to achieve this.

<u>Insecticide tactics</u> – There were differences for preferred insecticide options at this growth stage, and **this is an area where there is likely to be industry benefit in additional extension of 'best practice'**.

- Some appeared to want to position chlorantraniliprole (Vantacor) in this window, primarily citing that it was the 'least disruptive' to beneficials of the traditional insecticides as their reason to justify use at the expense of other alternative options. However, some others mentioned that growth dilution from rapidly growing crops may mean that the length of residual control is less when used at this growth stage, compared to targeting Vantacor at later applications. Within this particular demographic in particular, there was a strong and consistent belief that chlorantraniliprole is the most efficacious insecticide available, and that anything else would be an 'inferior' choice.

(Authors note: *When considered across the whole context of this report, it is our opinion that some of the relative positioning between different insecticides is based more on the total value package of Vantacor, including price, rather than just efficacy alone (see Section 11.3) and often this judgement may be an artifact of experience with Helicoverpa rather than FAW – as several of these agronomists had almost no firsthand experience of other products against FAW i.e. they are just going straight to Vantacor in the first instance*.)

- Success Neo was not being used at all. All expressed that price was too high and several also cited potential damage to *Trichogramma* as a reason to not use.
- Arguably the most common alternative to Vantacor, was indoxacarb (Steward). While several recognised that it was not as effective on FAW, it was arguably being utilised as the first-choice alternative as this is probably what most of these agronomists do when faced with *Helicoverpa* and need to rotate from chlorantraniliprole. The cost effectiveness and belief that indoxacarb is not overly damaging to *Trichogramma* were also factored into decision making
- A very small number of agronomists mentioned that emamectin (Affirm) was working well at this growth stage and suggested that this may be due to better coverage and/or the rapid growth not allowing Vantacor to demonstrate the expected residual.
- A single Darling Downs agronomist believed that no sprays should be applied at all, and just let beneficials build up (unless pressure was extreme). Most interviewed did not have this level of confidence and felt that they needed to apply 'something'. Commonly there were comments to the effect that once FAW are detected at all, "we can't let the population establish"
- Several were interested in using Fawligen at this timing, with most seeking more information on use rates and application strategies. In particular there was comment that growers could use ground rigs and apply 'relatively large water rates directed right over the row and into the whorl.'
    - Consistently there was feedback from all interviewed that Fawligen against FAW is not like Vivus against *Helicoverpa* – whereas with Vivus, a single 'early' application can be applied, and the virus will remain active in the paddock for an extended period. In the case of those using Fawligen there was recognition that control is only limited to those larvae present at application, and populations must be neonates or first instar only. This places considerable time constraints on scouting to correctly target FAW egg lays and then having growers committed to apply almost immediately after direction from their adviser – which can sometimes be especially challenging for those growers where cropping is not their primary business (e.g. dairy producers)
    - Interestingly, comments from Phil Armitage (AgBiTech) implied that one of the advantages of applying Fawligen at this growth stage was that it would do no damage at all to all beneficial populations. So even if the Fawligen provided very little direct efficacy, it may give the growers comfort that 'they have done something' yet allowed the beneficial populations to build more than any other insecticide mentioned above. And it may be the beneficials that are largely responsible for control following a Fawligen application.

Only a small number of agronomists interviewed mentioned that they were aware that a specific seed treatment (Fortenza) is in development for FAW management (See Section 9 for more detail).

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

This seed treatment, when available, may reduce the need for insecticide application at this establishment growth stage (potentially reducing in-crop sprays by one or perhaps 2 applications).

Several agronomists were prepared to accept some level of vegetative damage from around V4-6 to about V10. Most reported that crops would look 'untidy' but probably wouldn't impact too much on yield. Several mentioned protection of the last two big photosynthetic leaves as being very important.

Tasselling (which can be approx. V12-15, depending on variety) was the next important growth stage, followed by silking to early cob fill. Some crops may get an application at tasselling, depending on pressure. While most would get an application at silking. Vantacor appeared to be the preferred product by most at these timings.

For many, it was claimed that Vantacor could provide 2-3 weeks residual control when applied to crops after rapid vegetative growth had stopped, making Vantacor the preferred insecticide for tasselling / silking applications. (*Authors note: we did not uncover any hard evidence of quantification of 2-3 weeks residual being the case under continual FAW pressure, and this perception is possibly a reflection of experiences with chlorantraniliprole against Helicoverpa in pulse crops*). Many were expecting (hoping) that a well-timed Vantacor application at silking may be all that is needed for the remaining crop, unless under very high pressure.

In the South Burnett, Northern Rivers and Atherton Tableland there were several reports that in late summer 2022 (February onwards) there were significant levels of native *Metarhizium* identified in many crops, and it was thought that this may be assisting FAW control late in the crop (post-silking) and this may have been a contributing factor to the need for less frequent insecticide applications. For the South Burnett and Northern Rivers, it needs to be noted that this was in 2022, where these areas were very wet (i.e. experiencing flooding) for long periods.

There was some evidence that growers were 'hoping' to get away with two Vantacor applications per crop. Several agronomists mentioned that if they can grow grain maize on a two-spray program when combined with an early planting window, then some growers would find this acceptable and thus likely to continue to persist with growing maize. However, many indicated that a two-spray approach was often a 'wish' and generally hard to achieve.

There was some evidence to suggest that, where Vantacor was applied at the early vegetative timing and a second application at V10 to silking, then sometimes a third Vantacor may be used i.e. 'we only planned on a 2-application strategy, but that wasn't adequate, and a third application was needed'. However, at least for the purposes of our interviews, the majority of agronomists suggested that they would try to get growers to switch to a different mode of action for the third pass in this situation, which would most likely be Affirm at this growth stage. One agronomist added that many blocks of maize can be quite small, and these growers will buy a 20L drum of Vantacor and will not rotate while they still have remaining Vantacor on hand.

There was a strong underlying trend across many in this segment that Vantacor is perceived as much better value for money than any other available option, so many (most) are wanting to ensure that they use their 2 'allowable' (under the label / permit conditions) applications of Vantacor before considering rotational options.

While there were many variations due to existing FAW numbers, expected following pressure, and what had been applied early in the crop, some common examples of maize programs were similar to those depicted in Table 12.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Table 12: Typical FAW insecticide management sequences in maize crops

	V2-6	V6-10	V10-V15 Tasselling	Silking	Cob fill (not forage/silage)
Preferred '2-spray' strategy	Vantacor	Try not to spray	Hope not to need anything (Fawligen if required via pivot)	Vantacor	Hope not to need anything (Affirm if required)
If 3-spray strategy is expected	Steward or Fawligen		Vantacor	Vantacor	Hope not to need anything (Affirm if required)
4-spray strategy	Fawligen x 2		Vantacor	Vantacor	Hope not to need anything (Affirm or methomyl if required)
Very heavy pressure	Fawligen x 2	Affirm	Fawligen via pivot	Vantacor	Vantacor or methomyl
Alternate 3-spray strategy for silage maize	Vantacor	Fawligen	Vantacor	Try not to spray	Try not to spray

When crops exceed approximately 6-foot in height many are switching to insecticide application via the pivot, where available. This is strongly the case with Fawligen but is also often being done with Vantacor. Where overhead irrigation is not possible, aerial application will generally be used for these taller crops. However, with the relatively small block sizes and high water rates being applied, it is not uncommon for aerial application to be in the range of $30-$40 per ha per application, placing further cost constraints on maize growing, particularly if more than one aerial pass be required.

There is likely to be very high value in sharing extension outcomes that highlight successful strategies across all regions, as there are significant observations from agronomists interviewed that often poor insecticide choice of timing is resulting in increased frequency of applications. This is both leading to lack of confidence in growing maize, increased costs and potentially placing unneeded selection pressure on FAW populations.

In the opinion of the authors of this report and those who are aware of the Fortenza (Group 28) seed treatment in development, the concept of an on-seed insecticide that will reduce the early season need for monitoring and foliar insecticide application is likely to be very highly desired by maize growers, and hence uptake of this use pattern is likely to be high in this segment. **This will require a strong stewardship program to avoid season-long applications of Group 28 insecticides**.

9.5. Sorghum

Almost all those managing grain sorghum crops reported that, after establishment, vegetative sorghum can hold very high populations of FAW without sustaining significant losses in grain yield. Most also mentioned that as soon as the sorghum plant starts to develop a seed head then FAW appear to abandon the crop and look for other preferable hosts.

The magnitude of FAW pressure in vegetative sorghum is a factor of the time of year, and most likely the concentration of maize in the district and proximity to the sorghum crop. Similar to maize, sorghum planted in September/October in southern Queensland and northern NSW will often have lower FAW pressure during establishment, whereas December / January planted crops will be subject to higher pressures. It is more common for grain sorghum to be sown in southern Qld and northern NSW in the spring sowing window (seasonally dependent), while the large majority of the Central Queensland crop is all sown in the late December / January window.

Additionally, where there are significant areas of maize being grown in the district, FAW pressure is often considerably higher in vegetative sorghum grown in proximity to the corn, compared to regions where little maize is grown.

The primary concern of most sorghum agronomists interviewed was in regard to establishment. Once the crop is established, many indicated that sorghum appears to be able to withstand significant defoliation. Some agronomists reported that they consider that the published thresholds (from US information) of 30% leaf defoliation may be able to be increased to 40% (or even 50%) without significant impact on grain sorghum yield.

Forage sorghum crops, grown for vegetative matter, may have a lower tolerance level.

While direct FAW feeding damage may not be visually appealing and may not be impacting on grain yield, it is potentially requiring additional management cost for agronomists for time required to monitor crops, especially when they have not traditionally been checked thoroughly previously at the vegetative and establishment growth stages. Typically, scouting of grain sorghum for *Helicoverpa* does not commence until seed head initiation, which is the time that FAW are vacating the crop.

For most, *Helicoverpa* management in grain sorghum was almost a 'set and forget' application of Vivus once numbers reach threshold. Most likely this component won't change with the arrival of FAW and Vivus will still be required for *Helicoverpa*, with the potential for additional scouting expense, and insecticides where needed, applied earlier to manage FAW.

However, a few agronomists mentioned that *Helicoverpa* pressure in sorghum has been considerably lighter in the past couple of years since FAW arrived and were questioning if this may be just coincidence; or FAW 'displacing' *Helicoverpa* in the environment; or beneficials building with increased FAW food source; or earlier in-crop insecticide spraying for FAW suppressing low levels of *Helicoverpa* – or perhaps a combination of these.

When insecticide application is required, this typically appears to be either Vantacor or Fawligen that are chosen by agronomists.

No agronomist interviewed appeared to have considered their desire (or otherwise) for the Fortenza (Group 28) seed treatment in sorghum. While this may give 'peace of mind' and may reduce the need for early foliar insecticides in the first few weeks after emergence, this will come with a (currently unknown) cost of the seed treatment, so it is difficult to predict levels of uptake in sorghum where currently crops are often not being sprayed in many situations. However, if the seed treatment removes the need for early season intensive scouting, then this attribute alone may be highly valued, even in typically low-pressure situations.

9.6. Summer pulses

Summer pulses (mung bean and soybean in particular) are crops requiring considerable agronomic input from those interviewed. These crops are being regularly scouted for a combination of sucking bugs, *Helicoverpa armigera*, bean pod borer, loopers (especially in 2022) and the occasional cluster caterpillar.

Agronomists reported finding some FAW in these crops, however typically management specifically for FAW was generally only occurring where FAW numbers in the district were very high, and this was typically when in the presence of maize or sweet corn i.e. summer pulses were sometimes requiring direct management for FAW in the Burdekin and the Atherton Tableland, whereas in most other areas these pulse crops were only requiring management for other pests.

While in many situations summer pulses do not appear to be a primary FAW host crop, they require specific consideration as there will often be overlapping use of the same insecticides used in summer pulses, with those used to target FAW in other crops.

In many geographic locations there can be two key planting windows for summer pulses i.e. spring (September / October) and again early summer (late December to January). Commonly, a lot of these crops are not planted until the second window, often due to the soil profile being too dry for spring planting. Or in the case of double cropping, the winter crop needs to be harvested first.

The preferred planting dates were raised by several as both a major challenge with the current *Helicoverpa* IRMS for grains, and with discussion for any future IRMS that may include FAW – as the majority of agronomists identified that a 'window' excluding use of Vantacor (or Group 28 insecticides more generally) in January / February, as it currently stands for the *Helicoverpa* IRMS in grains, is likely to be the key time where this chemistry is required for use in pulse crops. There was strong feedback from those interviewed in that if any product is excluded from the position where it has the best technical fit, then there will be poor adoption / compliance with any IRMS.

This is currently evident with the existing *Helicoverpa* IRMS for grains – those agronomists who were not requiring the use of Vantacor in January / February, due to the crop rotations they were implementing with their growers, could recite the current grains IRMS almost verbatim and claimed to operate strongly within its scope. However, those who were wanting to regularly use Vantacor in the January / February window either claimed not be aware of the existing strategy at all, or had (conveniently) 'forgotten' of its existence and typically claimed that they had not seen this communicated for several years.

For summer pulse crops, the insecticide of choice was strongly driven by the pest spectrum requiring control.

Chlorantraniliprole (Vantacor), indoxacarb (Steward) and emamectin (Affirm) are all effective against loopers and *Helicoverpa*, including *H. armigera* populations. Often the choice of product used is reflective of the other pests requiring treatment at that time.

- Where *Helicoverpa armigera* is the only species requiring treatment, there is a tendency by several to regularly prefer Vantacor as it is often cheaper than the other insecticides; it has been positioned as the least disruptive to beneficials within these alternatives; and is perceived as providing the longest period of residual protection once canopy closure is in place and growth dilution has slowed. (Author note: *It is somewhat of interest to the author that often agronomists are claiming a key reason for use is that chlorantraniliprole is 'softer' than other competitors however are then tank mixing dimethoate, clothianidin or a pyrethroid to Vantacor where sucking bugs also require control, rather than switching to a different product that can effectively manage this complex without the need to tank mix. This is most likely reflection that the low-cost positioning of Vantacor relative to other options is* *arguably one of the primary reasons for preference, with several advisers and growers seeking to utilise Vantacor at the expense of other options wherever possible.)*

- Vantacor is commonly mentioned as the preferred choice where bean podborer is also present. Podborer 'concern' is often stated by industry as a reason to justify the use of Vantacor over other available options, especially for those arguing for use when the existing grains IRMS window for chlorantraniliprole is closed
- Steward is sometimes preferred when sucking bugs (in particular mirids) are also present. Some perceive Steward to be damaging to some beneficials (in particular lady beetles) and there was some evidence several years ago in some locations of a slight sensitivity shift in *Helicoverpa* tolerance. These reasons are typically given to support justification of a preference to Vantacor, whereas the most common pest spectrum (*Helicoverpa* plus mirids often present, with some GVB and RBSB) would suggest that indoxacarb often may have a better technical fit in this market segment
- Affirm may be preferred where mites are also present, although mites are rarely a problem. Affirm can provide 'suppression' of mirid populations at the cotton application rate, however it is not particularly effective on mirids at the pulse application rate. So typically not much Affirm is used in pulses
- Skope (emamectin + acetamiprid) is positioned as a relatively broad-spectrum option in summer pulses, registered to control *Helicoverpa*, loopers, cluster caterpillar plus silverleaf whitefly, mirids, Rutherglen bug, GVB, RBSB, mites and aphids. The major limitation that appears to be preventing more widespread use is a 4 week withholding period in mung beans and 6 weeks for other pulses. These long WHP's typically limits applications to vegetative / early pod set timing only. (Vantacor WHP is 2 weeks in pulses, while Affirm and Steward are 3 weeks).

Pyrethroids, methomyl or a tank mix of the two are still used by several, particularly where there is a mixed population including sucking bugs, and especially where short withholding periods are required. Typically pyrethroids will not be used alone where *Helicoverpa* armigera is expected to be the dominant *Helicoverpa* species.

10. New products and solutions

Intrepid® Edge – Corteva have submitted a registration application (Feb 2022 submission) for Intrepid Edge (300 g/L methoxyfenozide + 60 g/L spinetoram) for use in chickpeas, mung beans, soybean, cotton, sorghum and maize to control various pests including *Helicoverpa* and fall armyworm.

The recommended use pattern on the label is expected to be two applications applied 14-days apart, and then no further applications in that crop (Rob Annetts pers. comm.). The label has been written this way predominantly with efficacy against FAW in mind, however this does also place a cap on frequency of use from a resistance perspective.

Comparative pricing has not yet been released.

Fortenza® seed treatment – Syngenta has submitted for registration (Feb 2022 submission) of Fortenza (600 g/L cyantraniliprole) as a seed treatment for control of *Helicoverpa* and FAW in cotton, maize, sweetcorn and sorghum.

While this is the lead registration, it is expected that the actual product released to the market will be Fortenza Duo (cyantraniliprole + thiamethoxam). Most hybrid maize seed already comes treated with thiamethoxam as Cruiser® seed treatment.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Comparative pricing has not yet been released.

While final label statements are still in development, it is expected that Fortenza Duo may have similar wording to Syngenta's Durivo product (chlorantraniliprole + thiamethoxam) which has been available for several years. The Durivo advice for resistance management reads:

- DO NOT make more than one application of DURIVO or any other soil applied Group 4A insecticide per crop
- Following the use of DURIVO rotate to alternative mode of action (MOA) insecticide class(es) for a period covering at least one generation of the target pest. For many pests this will require a minimum of 2 applications of alternate MOA insecticides
- The total exposure period for all Group 28 insecticides applied through the crop cycle (from seedling to harvest) should not exceed 50% of the crop cycle
- DO NOT apply any other Group 4A insecticides as a foliar spray after soil application of DURIVO in that crop
- Monitor insect populations for product effectiveness.

Proclaim Opti (44 g/kg emamectin) – Syngenta have submitted a registration (Jan 2022 submission) for Proclaim Opti to add FAW in sweet corn.

Affirm (17 g/L emamectin) – Syngenta have submitted a registration (November 2021 submission) to add sorghum to the Affirm label.

Piperonyl butoxide – During the course of this research it was raised that resistance in FAW to pyrethroids is from rapid metabolism. This then led to the question from a researcher if the pyrethroid synergist piperonyl butoxide (PBO) would be viable strategy to suppress pyrethroid resistance, as was done in the 1990s with pyrethroid use in cotton in Australia. In a recent research paper (Bird, Miles, Quade, & Spafford, 2022) the authors showed that the addition of PBO resulted in a 69.8 and 35.6-fold reduction in the required LC_{50} of gamma-cyhalothrin and alpha-cypermethrin respectively, thus suggesting that significant reversal of resistance and associated improvement in efficacy may be expected from the addition of PBO.

There are hundreds of pyrethroid formulations currently registered in Australia that contain a PBO synergist in their formulation, however these are mainly for use in non food crop situations i.e. animal health and household pest control applications. Several SP + PBO formulations are registered for use as a grain protectant.

To the best of the authors knowledge, there are no stand-alone PBO products for agricultural use currently available for sale in Australia. However some registrations for PBO use with pyrethroids in cotton are still active, as per the APVMA PubCris database. Most of these labels only support use in cotton, however the Synergy label below indicates that previously this was supported in cucurbits and tomatoes in addition to cotton (this label is still registered to Nufarm and was last updated in 2013).

PBO Crop Care.pdf

While the science underpinning the use of PBOs to suppress metabolic pyrethroid resistance is well understood, there is likely to be little manufacturer support for the required studies needed to support extensive registration for use in the wide range of food crops attacked by FAW. Further, pyrethroids are extremely damaging to all beneficial populations. Removal of beneficials may result in the reduction of other insecticides that reply on beneficials to assist their efficacy, while also having the potential to flair some other pest species that are currently being suppressed by beneficials. Therefore, even if a pyrethroid + PBO was shown to work on FAW, use would most likely be constrained until very late in the crop.

Cotton experience from the 1980/1990s also demonstrated that some organophosphates also provided a similar ability to overcome a level of metabolic pyrethroid resistance by providing short term suppression of cytochrome P450s monooxygenases responsible for pyrethroid metabolism. This led to widespread tank mixing in conventional cotton prior to the introduction of Bt-cotton and is also likely to explain why growers still find a benefit in making tank mixes of these modes of action in a range of crop situations.

11. Insecticide application

There is little application information for FAW insecticides in the public domain. Most agronomists interviewed did not perceive that they were in an educated position to provide specific recommendations to their growers – apart from making comment that crops like maize, sweet corn and sorghum where it is difficult to achieve good coverage, 'high water rates are better and especially if product can run down into the whorl'; and, 'coverage becomes even more difficult on large plants'.

Hugh Brier (QDAF) conducted some application trials in 2022 and is starting to generate some interesting results, noting that results are preliminary and need confirmation before extension to industry. All data below was provided by Hugh Brier (pers. com.) in raw format and has not yet been published. Trials were conducted in young vegetative maize, using Vantacor at 55 mL/ha (33 gai/ha) which is the top permit rate for maize (and the low permit rate for sorghum). This is significantly higher than the 24.5 gai/ha for pulses and 20 gai/ha permitted for use in sweet corn, so the rate used needs to be taken into consideration when extrapolating data. The registered chlorantraniliprole rates in the USA for FAW in maize are equivalent to ~50 – 75 gai/ha.

Consistently across these trials conducted to date, this treatment rate of Vantacor is providing approximately 20 - 60% reduction in FAW populations in these application trials, when applied with a semi-commercial applicator.

Having trials deliver around 50% control is generally optimal for 'application' comparisons' to be able to demonstrate minor differences between treatments. If the rate chosen delivers very poor, or very high, control then often treatment differences are very difficult to detect.

While the chosen application rate used in these trials has fortunately been very good for treatment differentiation, many growers and advisers are likely to be surprised that this 'permit' application rate of Vantacor has only delivered 'suppression' at best in maize. And this is when applied with small plot accuracy and to small plants, with treatments optimised for coverage using a semi-commercial scale applicator – so control may be further reduced on large maize plants where coverage is likely to be inferior, or where grower application is not to the same standard as used in these trials.

Trial to compare application coverage and water volume.

Various nozzle types and orientation were compared across a range of water volumes. All Vantacor treatments were applied at 55 mL/ha. Pressure was maintained at 4 bar and speed 11 km/hr for all applications.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

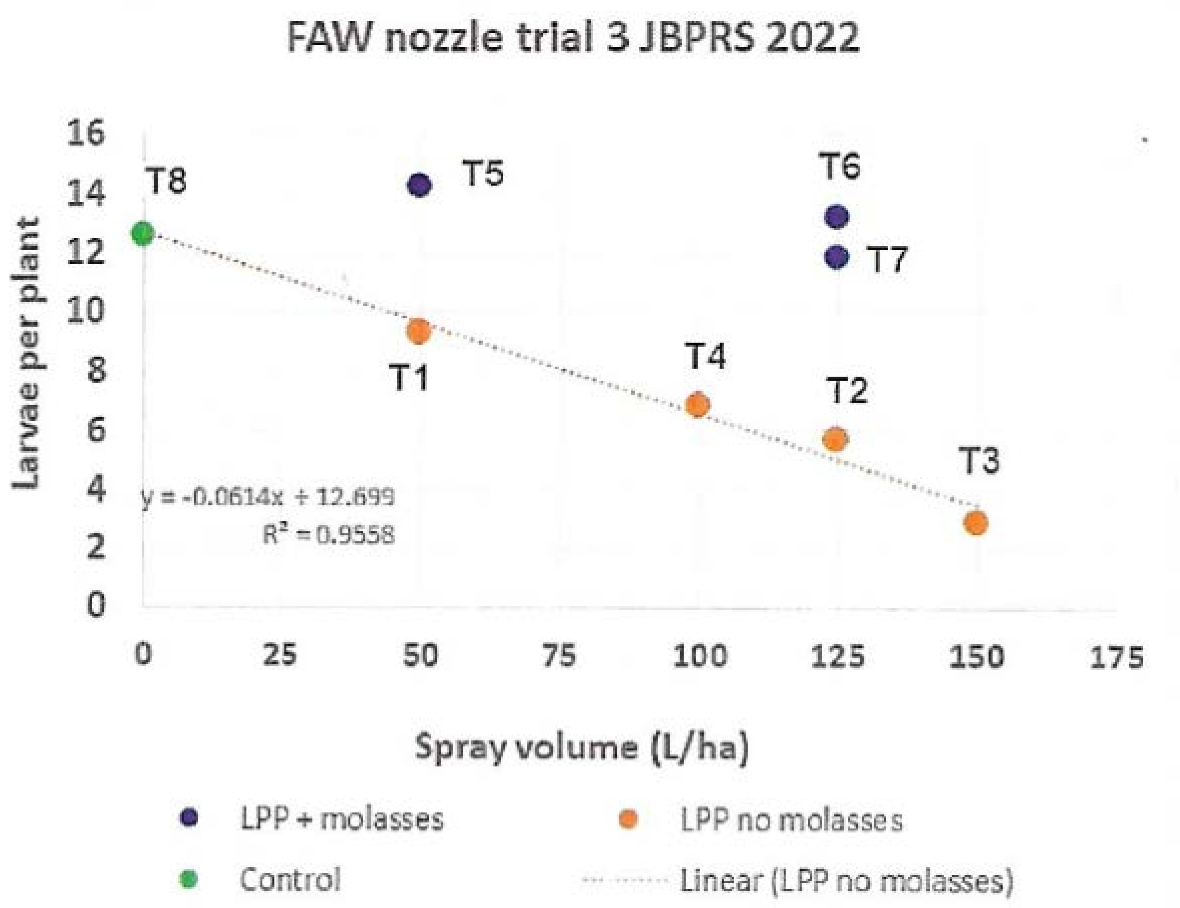
Treatment list

Treatment	Product	Nozzle	Size	Angle	No. per row	Spray vol.
T1	Vantacor	XR TeeJet	02	80°	1	50 L/ha
T2	Vantacor	TO8005	05	80°	1	125 L/ha
T3	Vantacor	XR TeeJet	02	80°	3	150 L/ha
T4	Vantacor	Flat fan	02	110°	2	100 L/ha
T5	Molasses	XR TeeJet	02	80°	1	50 L/ha
T6	Molasses	TO8005	05	80°	1	125 L/ha
T7	Vantacor + molasses	TO8005	05	80°	1	125 L/ha
Control	No spray					

It can be seen from these data below that there was a linear increase in control with increased water rate (orange treatments). This is consistent with field experience from some agronomists.

The 'best' treatment was the treatment with 3 nozzles per row (directed either side and one over the top of the row), however this was also the treatment that delivered the highest water rate in total. So it is not immediately clear if this is a water rate effect, or a nozzle positioning effect, or a combination of both.

The treatment where molasses (a feeding attractant) was added to Vantacor (T7) resulted in a significant decrease in control compared to the comparative 'no molasses' comparison (T2).



Trial to compare droplet size

In this trial, application volume was kept constant, but nozzle type, travel speed and operating pressure were altered to change spray quality.

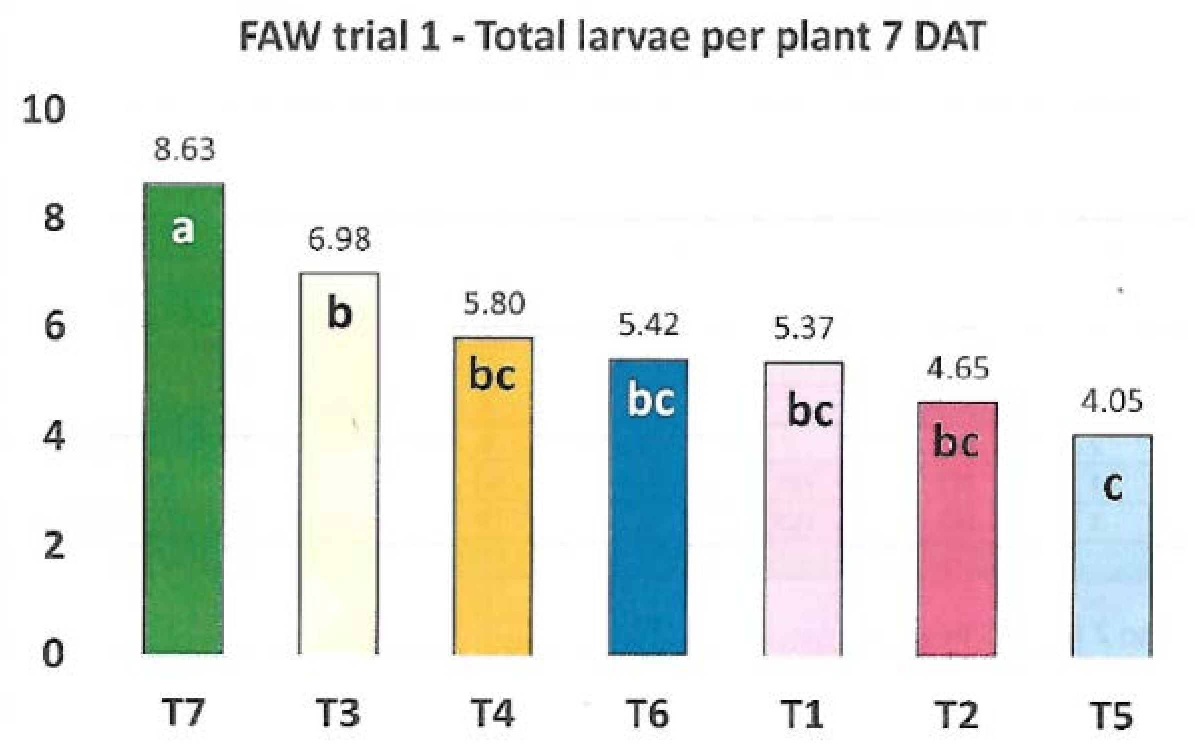
Treatment list

Treat	Nozzle	No. orifices	Air induction	Pressure (bar)	Speed (kph)	Spray vol. (L/ha)	Spray quality
T1	Hardi LD-110	1		2.2	8	100	M
T2	Hardi LD-110	1		2.2	8	100	M
T3	Hardi LD-110	1		2.2	4	200	M
T4	TeeJet TTJ60	2		2.2	8	100	M-C
T5	TeeJet AIXR	1	Yes	4.0	11	100	M
T6	TeeJet AIXR	1	Yes	2.2	8	100	C-VC
T7	No spray						

All nozzles were 02 (yellow)

At the 7 DAA check, there were slight differences between nozzles, however even the best treatment only achieved slightly better than 50% population reduction. Somewhat interestingly, the treatment where water rate was increased from 100 to 200 L/ha (by halving travel speed) delivered the numerically poorest control in this trial.

By 14DAA (data not presented here) there was no significant difference between any treatment and the untreated control.



Trial to compare water rate while attempting to hold pressure and spray quality constant

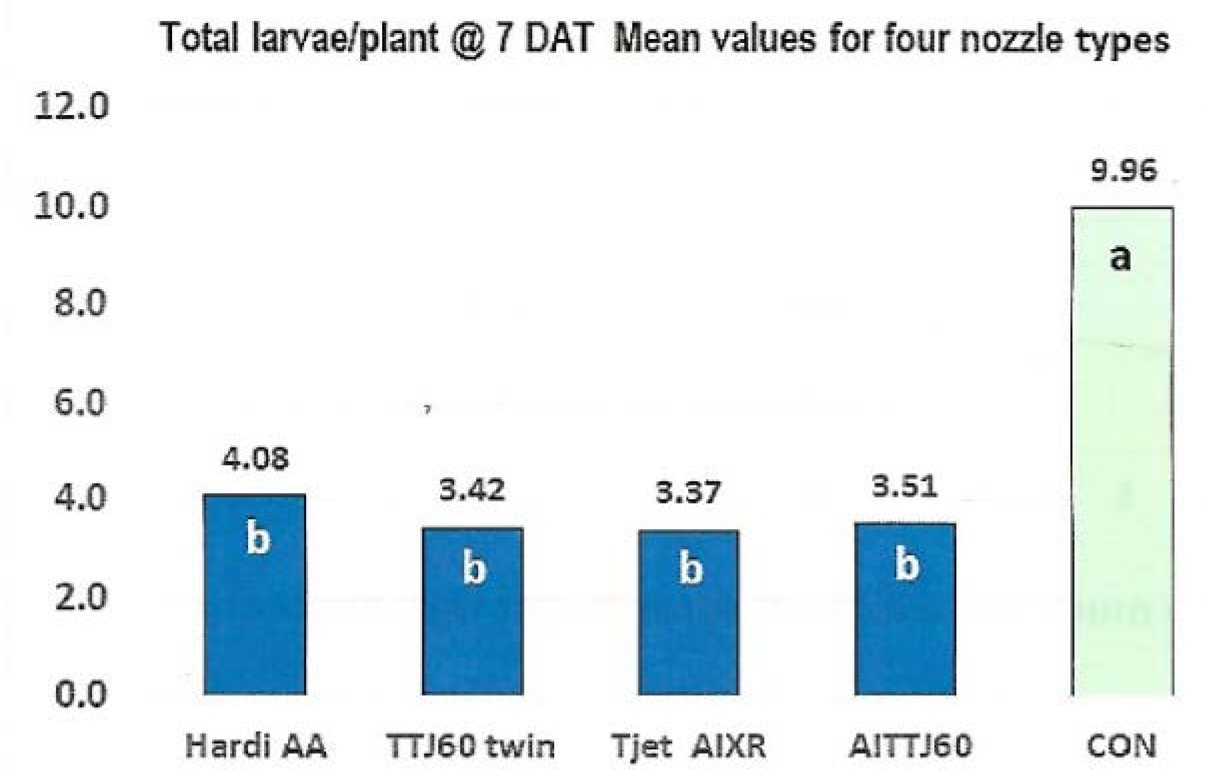
In this trial, travel speed was the variable used to compare different nozzles at 100 and 200 L/ha.

Treatment list

Treat	Nozzle	No. orifices	Air assist	Air induction	Speed (kph)	Spray vol. (L/ha)	Spray quality
T1	Hardi LD-110	1	Yes		11	100	M
T2	Hardi LD-110	1	Yes		5.5	200	M
T3	TeeJet TTJ60	2			11	100	M
T4	TeeJet TTJ60	2			5.5	200	M
T5	TeeJet AIXR	1		Yes	11	100	M
T6	TeeJet AIXR	1		Yes	5.5	200	M
T7	TeeJet AITTJ60	2		Yes	11	100	C
T8	TeeJet AITTJ60	2		Yes	5.5	200	C
T9	No spray						

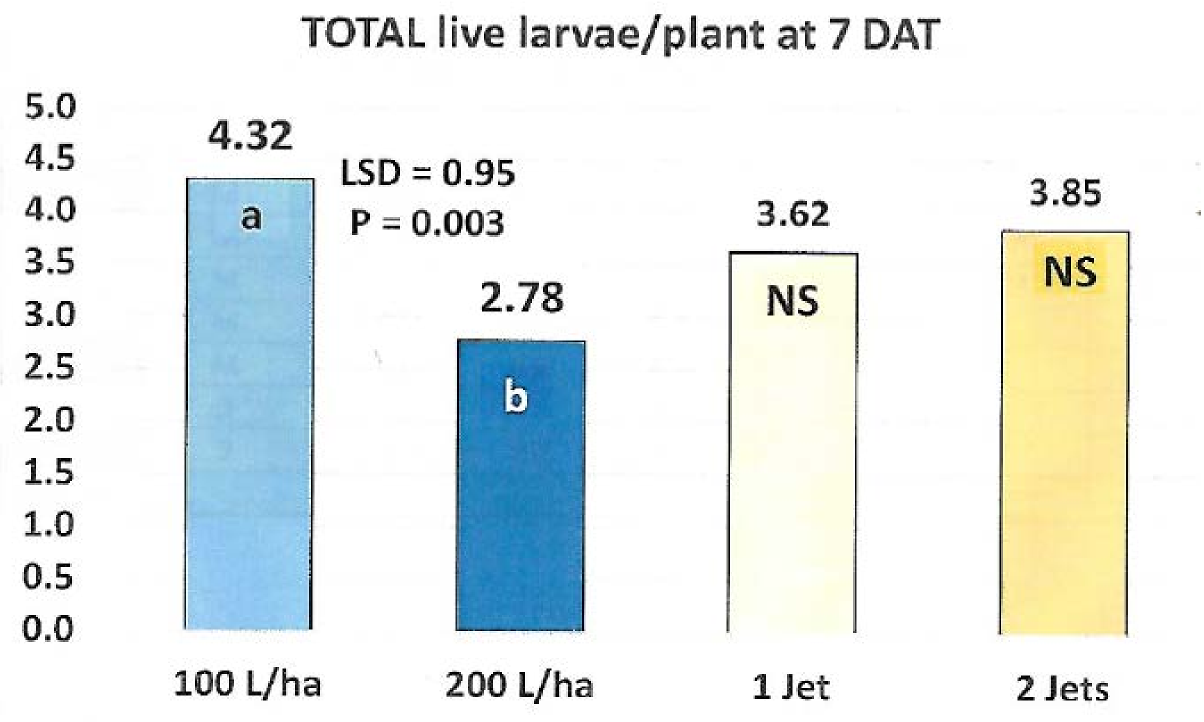
All nozzles were 02 (yellow), applied at 4 bar pressure

When data from both spray volumes were combined, there was no significant difference between nozzle type at the 7DAA check.



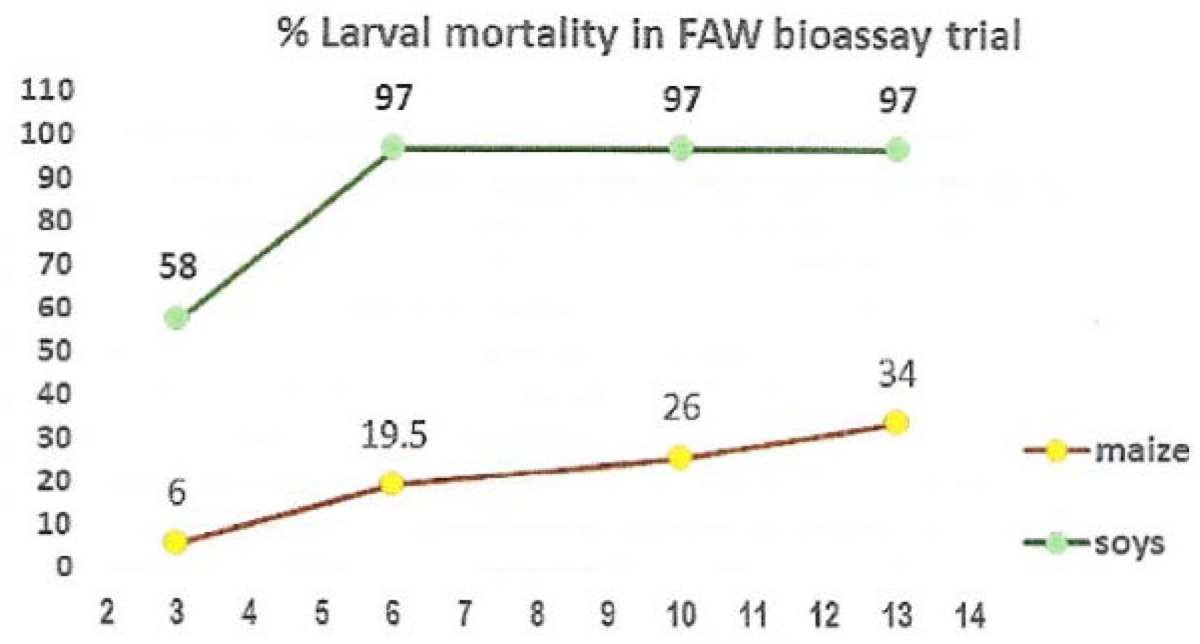
Additionally, where data was pooled, it was shown that there was no significant difference between nozzles with 1 or 2 orifices, or between air induction or not (data not shown). However there was a significant advantage to 200 L/ha over 100 L/ha.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).



Comparison between young maize and soybean

In this trial, young maize plants and an adjacent soybean crop were simultaneously treated with the commercial plot sprayer equipped with Hardi 110° flat fan nozzles and air-assist, using the same tank of Vantacor insecticide on both crops. Approximately 5-6 hours after application, treated leaves were collected from both crops and used for a bioassay. Field collected, unsprayed larvae were placed on treated leaves and mortality was measured over the following 13 days.



By day 6 there was very high mortality from larvae placed onto treated soybean leaf. However control was poor for the entire length of the trial where larvae were placed on treated maize leaf.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

As these crops were treated with the same tank of insecticide, at the same time and using the same spray application set up, this would suggest that plant species interaction is likely to be the cause of the differing results. As this was a feeding bioassay on treated leaves, feeding behaviour can also be dismissed (i.e. often it is mentioned that larvae may be able to hide in cryptic locations in a maize plant, and thus escape insecticide exposure).

In the opinion of the authors, **this may possibly be explained by different levels of leaf retention or insecticide penetration/uptake between different species. This requires further research as it could be critical in explaining product performance.** Should this be confirmed, then further work is required to understand if this may be happening with all insecticides applied to different species; or is this specific to chlorantraniliprole; or specific to maize; or may even be specific to individual formations (i.e. the adjuvant package in the formulation). This may also assist in explaining why FAW control is very difficult in maize, while crops like soybean were reported as hosting FAW but generally were not requiring extensive and continual insecticide applications.

12. Considerations for development of resistance management strategies

The charter for this project was to collect base information to inform development of resistance management strategies for noctuid moths, including FAW, with development of actual strategies likely to occur via subsequent investments.

When designing insect resistance management strategies, some useful principles to consider are presented in the Plant Health Australia Fall Armyworm Continuity Plan (Kearns, et al., 2020).

> ***Make informed decisions and act decisively***
> *1. Do not spray unnecessarily, only spray when economic thresholds are reached*
> *2. As there may be multiple infestations within a season, multiple treatments may be required*
> *3. Consider spraying when larvae are actively feeding (e.g. out of the leaf whorls), for instance early morning or at dusk to maximise effectiveness. This is also when honeybees and other pollinators have returned to their hives. During these times be aware of surface temperature inversion conditions as these are unsafe for spraying as the potential for spray drift is high*
> *4. Select insecticides that have minimal impact on natural FAW enemies, beneficial insects and honeybees*
> *5. Where possible, avoid the use of broad spectrum foliar applied insecticides in the production system for both larvae and moth control. If broad-spectrum insecticides are to be used, apply at timings when preservation of beneficial species is less likely to be important – i.e. at end of growing season*
> *6. Always follow label and permit directions for individual insecticides*
> *7. Practice IPM and follow resistance management strategies*
> *https://www.croplife.org.au/resources/programs/resistance-management/various-fall-armyworm-spodoptera-frugiperda-draft/*
> *8. Spray smart. Timing and coverage are both critical to achieving good control of FAW Inappropriate timing risks crop loss and the costs of retreating and increases the likelihood of insecticide resistance*

9. Once thresholds are reached, do not delay; manage the crop early and accurately. Target early instar stages (hatching larvae) of the pest before they become entrenched in the crop (e.g. lower whorl of maize, sweet corn or grain sorghum)
10. When spraying an insecticide: a) use enough water to ensure thorough coverage of the crop; b) use a well calibrated, functioning boom spray with appropriate water rate for the target crop to ensure optimum spray coverage; c) use the full insecticide rates as stipulated on the relevant permit or label; d) use an adjuvant if stipulated on the relevant permit or label
11. Inspect the performance of application 3 to 4 days after treatment
12. Always document the effectiveness of each insecticide application and never re-spray a failure with an insecticide with the same Mode of Action (MOA)
13. Do not treat successive generations of FAW with products of the same MOA
14. Rotate insecticides from different MOA groups, especially for crops that currently only have one or two chemicals permitted or registered within a MOA group
15. Plan future insecticide decisions considering permit and label instructions, such as the maximum number of applications per crop per season, minimum reapplication interval and minimum withholding periods if considering using the crop for feed
16. Where possible, an Area Wide Management strategy should be adopted where the same MOA insecticides are used by all growers in the same time period
17. Keep abreast of the evolving FAW status in your area through local newsletters and grower networks.

12.1. Examples of FAW IRMS from other countries

South Africa, who have been dealing with FAW since 2016, have developed IRAC (Insecticide Resistance Action Committee) supported integrated strategies for FAW in maize (IRAC South Africa, 2021) which may assist as a starting point for consideration when building IRMS for Australia. The South African 'window-based' strategies have been developed for both genetically modified Bt maize (noting that Bt maize is currently not available in Australia) and 'conventional' maize. Figure 16 outlines the conventional maize strategy.

Of note, this strategy places a heavy reliance on broadspectrum Group 1 (OP, carbamate) and Group 3 (pyrethroid) insecticides as the first, and last, application timings. While early application may give these insecticides their best chance of success, due to a small plant target and opportunity to contact larvae before they become entrenched, the resistance status of FAW and the desire to 'go soft early' in Australia would require modification of this approach. At the tail end of the crop, resistance levels in Australia are already present/high for these modes of action so many agronomists would be concerned to rely on Group 1 and 3 insecticides in Australia for cob protection.

Additionally, this South African strategy does not incorporate biological control agents such as nucleopolyhedrovirus (NPV), other non-insecticide control options and potential seed treatments which may become a component of FAW management strategy in Australia.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

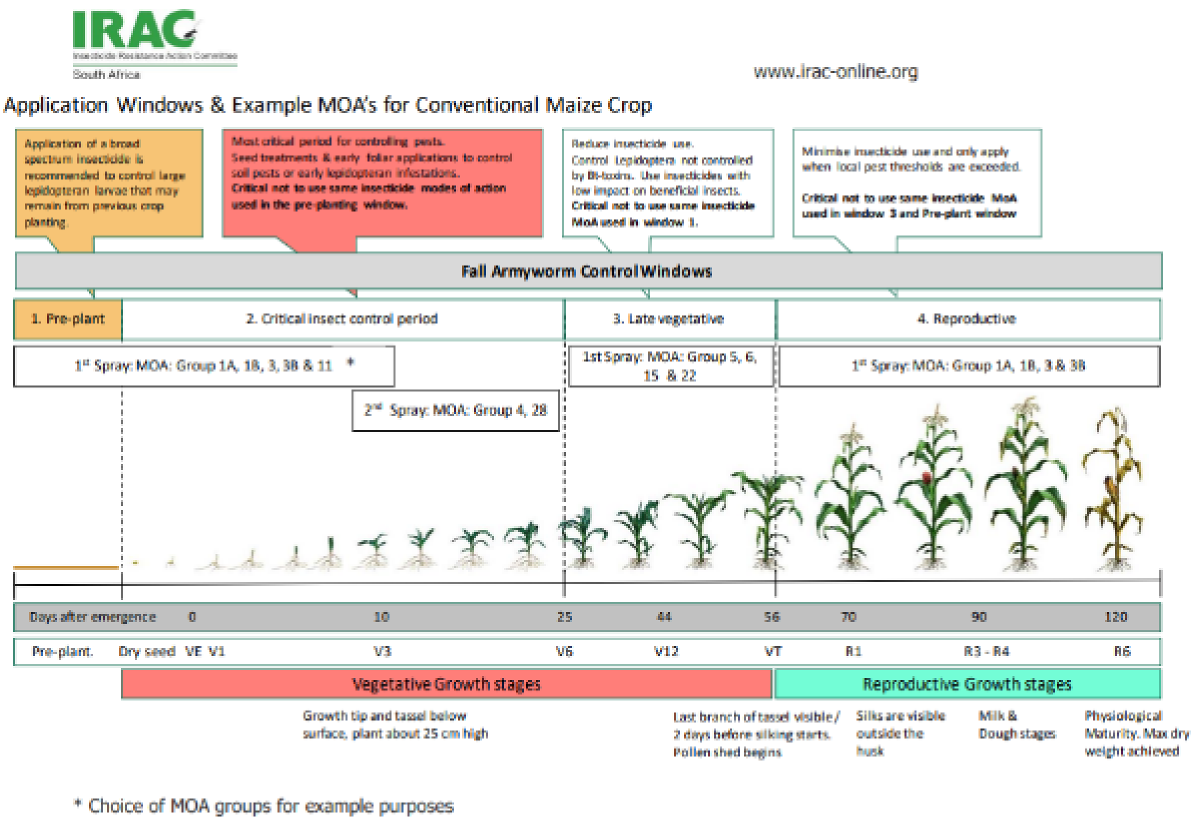


Figure 14 Window-based, integrated resistance management strategy for South African conventional maize (IRAC South Africa, 2021)

While there are obvious differences in how the individual components would be assembled in a potential window-based strategy for Australian maize, the basic principles of this strategy should still apply; i.e. approximately 30-day 'windows' for use of certain insecticide modes of action which align with a single FAW generation; with the insecticides used in one window not permitted for use in the following window.

12.2. Developing a local integrated FAW resistance management strategy

There was consistent feedback from almost every agronomist who were concerned with overuse of insecticides in general and in particular to chlorantraniliprole. With comments such as "we cannot afford to lose Group 28 chemistry to resistance." These comments were particularly in reference to the use of chlorantraniliprole in pulses against *Helicoverpa*, with the arrival of FAW "just making things worse for Group 28 overuse."

In geographies where *Helicoverpa* and/or FAW pressure is low, or crops are being grown predominantly for grazing or silage, agronomists reported that there was generally considerably less interest from growers in 'resistance management'. In practice, a grower who only 'occasionally' sprays for insect pests is unlikely to consider an IRMS – however with less frequent use of insecticides, they are also unlikely to be significantly contributing to resistance selection.

In moderate to higher pressure situations, agronomists interviewed were universally aware of the need to consider resistance management as a component of development of a crop management plan. While many agronomists did not have a 'documented' crop or resistance plan for FAW, the vast majority did articulate many similar fundamental principles for managing FAW, especially in high pressure crops like maize.

Key management pillars reported by several included:

- Understand when FAW pressure will be highest and avoid having host crops at a critical growth stage during that time
    - For many from central Queensland and further south, FAW populations drop away in winter and rebuild again in spring, with numbers often peaking in December and January. Therefore many were seeking to have maize crops well past tasselling by or before December. This often requires a major shift in planting date i.e. bringing forward planting to August/ September. This was generally seen as possible for crops grown under irrigation (the crop can be watered up), however was often not possible in dryland crops requiring winter/spring rainfall to fill the profile before planting, or 'double crop' scenarios where the previous winter crop isn't harvested until November/December
- Most saw the advantage of using the 'softest' insecticides during early vegetative growth stages to encourage beneficials
    - While this principal was held by most agronomists interviewed, many were still seeking additional information on what specific beneficials are most valuable against FAW. As all realised that different insecticides can have very different activity on specific beneficials
    - Some had tried commercial releases of commercially reared beneficials – almost exclusively this was *Trichogramma*. One agronomist was an advocate, although they were predominantly targeting *Helicoverpa*, with the occasional FAW. The rest who had tried commercial releases were unsure or unconvinced of the value, and mostly are unlikely to continue with this tactic unless some robust evidence becomes available to support these releases
    - Conversely, two experienced entomologists mentioned that high level control from the best chemistry applied during the establishment phase may be more important to suppress the early development of an endogenous population from developing within the crop, as opposed to applying an inferior application just because it is considered 'soft'.
- Most interviewed saw the need for a high level of scouting in key host crops, and this scouting needs to be implemented very early (and, in most crops, considerably earlier than this has been in the past prior to the arrival of FAW. FAW can be very damaging in the establishment phase)
    - This presents a major challenge for some crops – in particular those crops that have not required intensive scouting previously. The current ratio of hectares to be checked per agronomist is unsustainable as existing business models are not set on the service levels now being required for these crops. Additionally the growers of these (often relatively low value) crops are reluctant to pay for intensive scouting in addition to a much-increased insecticide and application cost
    - Exceptions were expressed by several agronomists in high pressure crops (maize and sweetcorn) in high pressure regions, where pressure was seen as 'guaranteed' and thus a program spray approach was deemed as needed, with scouting more to assess effect and impact and to tweak spray timing
- Accepting that some level of increased scouting is going to become the norm, many agronomists desired to have pheromone traps (or another early warning system that is not

labour intensive) as a key early detection mechanism to indicate when scouting needs to ramp up
    - Several commented that they were hoping that there were opportunities for improvement in the lures being used, with several not seeing high correlation between trap numbers and in-field pressure
    - It was a common observation that crops were receiving high levels of damage, but traps were not attracting adult moths and were thus a poor indicator of risk and spray timing. Similar comments were received from multiple entomologists
- There was generally high interest in the concept of 'lure and kill' technology (e.g. Magnet in combination with methomyl) to reduce adult moth populations.
    - There was high interest in further research to understand how to optimise this tactic
    - Some were looking for a less-disruptive insecticide component for this technique, as they were concerned methomyl was killing too many beneficials. Spinosad / Spinetoram was suggested by some as a possible alternative, especially in lower value broadacre crops where this chemistry isn't considered for broadacre use due to price
    - Some suggested that alternate attractants (e.g. QM FAW) may be more useful for FAW
- Most considered insecticide coverage to be important, particularly in maize, sweet corn and sorghum where larvae will often become entrenched in the whorl. Where these crops are being grown under pivot irrigation, several reported that insecticide efficacy is enhanced where the product is applied through the pivot. Most were seeking validation / conformation application trials to guide recommendations
- There was high recognition to avoid overuse of any particular insecticide, while still maintaining a marketable crop. However, how this objective was being achieved differed across agronomists and crop type (see below for further discussion).

In crops under extreme pressure (sweet corn and capsicum in particular) agronomists interviewed were highly concerned about insecticide resistance for all of the key MOAs, and not just chlorantraniliprole. Currently several of these insecticides are being applied to their maximum number of permitted applications (as per the label or permit) and substantial crop damage is often still occurring. So while there is a desire to reduce selection pressure, nobody saw that this was practical unless there are a number of new and effective modes of action available i.e. placing restriction on the frequency of application of any product currently being used will simply increase selection pressure on the remaining insecticides available in that window.

In these crops, it could be argued that resources may be better deployed in the short term to support research that targets area wide population reduction strategies, rather than to focus on asking growers to adopt windows of non-use for existing insecticides. If the total number of applications can be reduced to significantly less than 6-8 applications per crop by implementation of best-practice management, then there may be opportunity and justification in developing resistance management strategies which can allow for certain insecticides to be given a 'break'.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Maree Crawford, Elders Northern Technical Services Manager explained that within the Elders network they have developed a management plan for FAW in maize and sweet corn which is an integrated strategy and does not reply on any single tool. (In the Burdekin, where FAW pressure is much higher, this strategy is also utilised in other host crops).

Maree mentioned that as FAW was first detected on one of the Elders research sites at Georgetown, "we have been dealing with FAW for a year longer than most." In addition to these general strategies above, the Elders internal strategy also includes a very strong focus on understanding the G (genetics) x E (environment) x M (management) for each individual situation.

- Genetics – they believe there are considerable differences in FAW attractiveness between different maize and sweet corn genetics, so varietal selection will be based on expected pressure at that location x time of year. "This means some existing varieties will be dropped altogether."
- Environment – understanding expected FAW pressure at the location x time of year is essential. This will drive planting date, variety choice (susceptibility and length of maturity) and management tactics when the FAW arrive.
    - Environment also determines rate of lifecycle development, which is important to determine insecticide timing after an egg lay.
    - Environment also encompasses FAW dispersal. They have found that often after a major storm, FAW has been dispersed and population declines.
    - Maree also mentioned that 'trials' that do not capture environmental data are not helpful in being able to understand the 'E' that is determining FAW pressure at any point in time.
- Management – The key to managing FAW is to "keep in front of the population." This is "absolutely critical" in north Queensland, although though they have "slightly more time to react in southern Queensland." To achieve this:
    - Early detection of what is happening in the paddock is fundamental. This is achieved by both pheromone traps and thorough scouting. This will determine:
        - The need for 'lure and kill' tactics, targeting moth reduction
        - The timing of egg lays that will influence when to release beneficials and when to target spray applications to target neonates.

Other tactics forming an integral part of the Elders 'management' package include:

- Paddock selection and management of these paddocks leading into the maize planting.
- Importance of an 'optimum' nutrition package for maize and sweet corn. Agronomists obviously want crops to be growing vigorously to 'out-grow' FAW damage but have found that crops grown with 'excessive' nitrogen in the soil appear more attractive to FAW. Part of the Elders agronomy package for maize is that all fields will be soil tested before planting maize.
- Seed treatments are an important tool and will become more so with the upcoming availability of cyantraniliprole seed treatments. This will then require a change to the current positioning of Group 28 foliar applications.
- No repeat use of the same MOA within a 60-day interval.
- Standard 'lure and kill' application spacing for *Helicoverpa* is not adequate for FAW and "closer is better." They have now come in to strips every 30m for Magnet, "but closeness of strips needs to be balanced against cost."
- Naturally occurring *Metarhizium rileyi* is an important bio-control tactic. Elders are 'advanced' in bringing this to market as a sprayable option.
- Additionally, they have found that FAW have the ability to complete their complete lifecycle within maize and sorghum stalks and may not need to enter the soil to complete their lifecycle in this crop.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

It may be argued that the concept of a 'management strategy' such as the Elders approach above (which incorporates the requirement of at least 60 days between application of the same MOA as one of the points) may be more appealing to some growers and more likely to get 'buy-in' than a specific IRMS strategy document that may be perceived as telling them 'what they are not allowed to do' in terms of insecticide choice.

12.3. Chlorantraniliprole

Group 28 chemistry, and specifically chlorantraniliprole, was the insecticide of most concern by most interviewed. By far, the majority of use was either Vantacor (broadacre crops) or Coragen (horticulture crops) although a small number of horticultural agronomists mentioned use of Belt (flubendiamide) or Durivo (chlorantraniliprole + thiamethoxam).

In horticultural crops in general and sweet corn in particular, agronomists were conscious that they were putting all of the main insecticides under extreme selection pressure due to the frequency of applications. This included chlorantraniliprole, emamectin and spinetoram in particular (with some slight differences in relative importance between geographies); while indoxacarb, Fawligen and even sprayable Bt's were mentioned by some.

In broadacre, chlorantraniliprole was unanimously the front-of-mind insecticide of concern by all. Specifically as it has become the primary insecticide for *Helicoverpa* in pulses and is now being also positioned as the main option for FAW in maize and vegetative sorghum. Outside of chlorantraniliprole, most other insecticides are only being used judiciously in broadacre crops.

Efficacy – While some agronomists were carefully considering how chlorantraniliprole was used in their programs, almost universally they or their growers were wanting to apply it at least once per crop, and often to the 'maximum' number of applications permitted on the relevant label. In situations where FAW is present, there was an even stronger desire by some to ensure maximum Vantacor use, due the perception by several that <u>Vantacor</u> was the 'best' option.

Interestingly, our research found that chlorantraniliprole sold as Vantacor (or Altacor before rebranding in 2021) strongly held this perception of the 'best' product, whereas Coragen (same active ingredient, but containing horticultural registrations) was generally not considered as dominant amongst it's direct competitors in several horticultural markets. So care needs to be taken when some users are claiming that Vantacor use restrictions will not work "as nothing else is effective", as often what they were really meaning is "nothing else is as good value for money."

This is most likely a factor of the relative pricing of each brand compared to their direct competitors and the rates applied – the top application rate on FAW permits for Vantacor is 55 mL/ha (33 gai/ha) in maize and 90 mL/ha (54 gai/ha) in sorghum. Whereas the Coragen FAW permit allows a rate of only 20 gai/ha in sweet corn and vegetables.

Vantacor has become <u>the</u> major insecticide for both FAW and *Helicoverpa* across most summer broadacre crops. This is due to several factors including:

- Efficacy (at use rates applied) is perceived as being at least as good as any other insecticide, and often better that many
    - Indoxacarb is recognised as not as good on FAW. Some also mentioned that there is already some evidence of indoxacarb resistance in *Helicoverpa* from historical resistance testing, and this was another reason given for non-use

    - Emamectin is often only used when targeting egg lays or very small neonates by many and has the perception that it doesn't have long residual. So will only be used in certain specific applications
    - Spinetoram is only used in horticulture, as it is generally considered too expensive for use in grain crops
- Residual activity of chlorantraniliprole is claimed to be significantly longer than all other available options. It is also claimed to have full translaminar movement through the treated leaf, with some systemic movement in the xylem (upwards, outwards).

Much of this relative comparison above appears to be from user experience over several years when predominantly targeting *Helicoverpa* in broadacre crops (where the chlorantraniliprole application rate is significantly higher than in horticultural uses). Several broadacre agronomists making these positioning statements reported very little experience with either emamectin, spinetoram or indoxacarb against FAW under directly comparative conditions, and appear to be just assuming that performance against FAW will be similar to their experiences with *Helicoverpa*.

In addition to known differences in efficacy between *Helicoverpa* and FAW (see Table 10), it needs to also be considered that the use against *Helicoverpa* in most crops typically occurs after crop growth dilution has subsided, and that is where the extended residual of chlorantraniliprole is most likely to be of benefit. Often FAW applications are applied to young, rapidly growing crops so 'length of residual protectional' may not be relevant at these timings due to rapid growth dilution affecting all products.

A few broadacre agronomists who appear to have closely compared these insecticides, or several horticultural advisers who are applying Coragen at considerably lower rates (gai/ha basis), often did not share the same perception of relative performance against FAW as the 'consensus' position of Vantacor users. Many of this group suggested that emamectin and spinetoram (in particular) are at least as good, or often superior to, chlorantraniliprole against FAW under comparative situations (when excluding price). This relative positioning appears to be supported by comparative bioassay trials and some comparative replicated field trials being conducted for product registration purposes.

In addition to this efficacy positioning above, chlorantraniliprole is often considered to be 'softer' on beneficials than other alternative options and Vantacor is often cheaper than most other 'soft' broadacre insecticides (on a $/ha basis). This is important in also building the overall value proposition.

Lastly, there are chlorantraniliprole registrations / permits in most key crops, which adds to the overall attractiveness. Registrations for *Helicoverpa* and other caterpillar pests include:

- Vantacor (600 g/L formulation) – cotton, summer pulse crop group, winter pulse crop group
- Altacor Hort (350 g/kg formulation) – pome and stone fruit, grapes, almonds
- Coragen (200 g/L formulation) – wide range of brassica, leafy and fruiting vegetables, lettuce, potatoes, strawberries, sweet corn
- Voliam® Targo (chlorantraniliprole + abamectin) – pome fruit, grapes
- Durivo (chlorantraniliprole + thiamethoxam) – brassica, fruiting and leaf vegetables as a seedling drench

While permits for fall armyworm include:

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

- Vantacor - Maize (PER91386 @ 40-55 mL/ha), Rice (PER90621 @ 40-55 mL/ha), Sorghum & millet (PER91616 @ 55-90 mL/ha), Peanuts (PER86014 @ 40 mL/ha), Sunflower & safflower (PER89457 @ 40-55 mL/ha)
- Altacor - Maize (PER91386 @ 70-90 g/ha), Peanuts (PER86014 @ 70 g/ha), Sunflower & safflower (PER89457 @ 70-90 g/ha), Sugarcane (PER89384. In-furrow + foliar), Cotton (PER89259 @ 150 g/ha), Pulses (PER89259 @ 70 g/ha)
- Coragen - Ginger (PER90758 @ 100 mL/ha), Sugarcane (PER89384. In-furrow + foliar), Vegetables (PER89259 @ 100 mL/ha)
- Durivo - Vegetables (PER89280. In-furrow at planting).

The combination of these factors results in chlorantraniliprole (especially Vantacor in broadacre crops) being perceived by several in broadacre market segments as significantly better 'value for money' than other available options. In several broadacre crops, this appears to be encouraging Vantacor to be used first to extract maximum 'value', with users then only considering other modes of action after they have used their Vantacor allocation.

While not specifically verbalised, there was an underlying tone from many advisers that if an alternate insecticide MOA were used early and hence chlorantraniliprole 'was then not needed' later in the crop, then this may actually be seen as a negative outcome, as they could have got better / longer / cheaper control had they used Vantacor instead at the start. For some interviewed, there is almost a 'fear of missing out' if they do not get the opportunity to use the full allocation of Vantacor.

Application frequency – The Vantacor label for 'broadacre' crops contains the following statements immediately preceding the table of use directions.

> *DO NOT make more than 3 applications per Cotton crop per season, and no more than 2 consecutive sprays per field per season*
>
> *DO NOT make more than 2 applications per Pulse crops per season. Applications must be a minimum of 7 days apart.*

Whereas the Coragen label for horticultural vegetable crops states:

> *A maximum of three (3) applications are to be applied to any one crop. No more than two (2) consecutive sprays per crop, with a minimum interval of 7 days (unless otherwise stated). Further treatments should be made with alternative mode of action insecticides.*

Typically for the FAW permits issued to date, these application frequencies have been continued i.e. a maximum of 2 applications for broadacre crops and 2 or 3 applications for horticultural crops. Statements on permits in place for Coragen for FAW, read directly as per the Coragen label with regard to number of applications and time between retreatments.

However, for Vantacor permits targeting FAW the statements are slightly different, and read:

> *DO NOT apply more than 2 applications per crop.*
>
> *DO NOT apply less than 7 days after the initial treatment.*

From interviews conducted, there appears to be wide understanding and acceptance of the maximum number of applications per crop. There was generally no evidence of consecutive applications being applied within the 7-day minimum retreatment period, as generally maximum efficacy has only just been achieved at that interval.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

On product labels, typically under the 'Resistance Management' section of the label, there are additional recommendations (text below is from the Vantacor label, but similar text is contained on the Coragen label):

> *Strategies to minimise the risk of insecticide resistance are available. To help prevent the development of resistance to Vantacor insecticide observe the following instructions:*
>
> - *Use Vantacor insecticide in accordance with the current Insecticide Resistance Management (IRM) strategy for your region.*
> - *Apply Vantacor insecticide or other Group 28 insecticides using a "window" approach to avoid exposure of consecutive insect pest generations to the same mode of action. Multiple successive applications of Vantacor insecticide or other Group 28 insecticides are acceptable if they are used to treat a single insect generation.*
> - *Following a 'window' of Vantacor insecticide or other Group 28 insecticides, rotate to a 'window' of applications of effective insecticides with a different mode of action.*
> - *The total exposure period of all 'Group 28-active windows' applied throughout the crop cycle (from seedling to harvest) should not exceed 50% of the crop cycle.*
> - *Incorporate IPM techniques into the overall pest management program.*
> - *Monitor insect populations for loss of field efficacy.*
> - *Cultivate all cotton and pulse crop fields as soon as possible after picking/harvest to destroy over-wintering pupae of Helicoverpa armigera.*

Several agronomists interviewed reported that FMC "support consecutive applications" (which is also covered via label statements and permits as mentioned above), however only some interviewed mentioned the further detail "that this needs to be on the same generation of FAW." Almost universally, compliance with the second bullet point above is poor, as chlorantraniliprole is regularly being applied to consecutive generations of FAW in maize / sweet corn. Additionally, several mentioned that they 'expect' that chlorantraniliprole will provide 'at least 21 days residual control', so therefore a second consecutive application will almost always cross FAW generations over summer months.

Additionally, no agronomist interviewed mentioned the label bullet point that chlorantraniliprole should not be used for more than 50% of insecticide applications in the same crop. By definition, this implies that a <u>minimum</u> of 4 applications need to be expected to be applied to the crop, before users should even be considering consecutive Vantacor applications – however these same broadacre agronomists are generally trying to limit applications in maize to 2 or 3 applications per crop in total wherever possible (predominantly for financial reasons). **Any future extension of resistance messaging should reinforce compliance with all parts of the current label as a minimum, and particularly highlight this point in the current label.** In practice, for most grain crops this should mean that a second Vantacor cannot be until at least the fourth spray in any crop. Simply enforcing this existing label statement is likely to have a significant reduction in current exposure.

It should also be noted that while there are now 'permits' for use against FAW in almost every crop type grown in northern Australia, many of these crops (with the exception of maize, sweet corn, capsicum and ginger) are reported not to be sustaining the level of FAW populations that are likely to require more than 2 or 3 spray applications in total in these crops. Therefore, in order to comply with bullet point 4 above, **any renewal of permits in these other crops should be restricted to a maximum of a single application per crop** (if the permit renewal is required at all - see Section 11 for further commentary on permits).

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

In discussion with the technical managers of several of the main insecticides (and not just for chlorantraniliprole), there was general belief that most of these products work best when two back-to-back applications are applied and hence there will be other labels expected to be registered in the future that may also recommend this strategy of consecutive applications. (At least one label in current development is expected to recommend two back-to-back applications and then no further use at all in that crop).

For any insecticide where back-to-back applications are supported, there is likely to be a fixed minimum re-treatment period (7 days in this Vantacor example) which is likely to be driven by crop residue considerations. However, the maximum time between consecutive applications can be somewhat ambiguous. For example, with Vantacor, the current label wording suggests that two consecutive applications is “acceptable if they are used to treat a single insect generation”, but also this should only be in situations where >3 application in total are required.

It is acknowledged that lifecycle length will be different for individual species of pests controlled and this will vary significantly with geography and environmental conditions. An on-line tool (Darabug https://thebeatsheet.com.au/darabug/) predicts these times by region and time of year, however this was only mentioned by one agronomist interviewed. For the remainder, the timing of the second application did not appear to be well defined, with many ‘claiming’ that they expect to get 21 days residual from Vantacor (even on rapidly growing crops) and often appear to be trying to stretch the interval between consecutive application ‘as long as possible’. Exceptions were in sweetcorn where spraying was occurring on a weekly basis in high pressure situations.

For these reasons, in the opinion of the authors, **any future label revisions or IRMS documents should state a firm number for both minimum and maximum days between consecutive applications**, to be simple and clear for users. While we note that a fixed number of days to define generations is a vast oversimplification, and would need to be ‘conservative’, however a label statement that reads something like ‘a second consecutive application can be applied between 7 and 21 days following the first application’ would both meet the needs of the label registrant who wishes to have two applications close together for maximum performance, while also discouraging growers to extend the length between applications for ‘as long as possible’.

Compliance with bullet point 7 on the Vantacor label statements regarding pupae busting is low and decreasing in cotton, as changes to the Bollgard 3 IRMS means that most growers can now avoid the need for ‘pupae busting’ in the majority of situations. Pupae busting is typically not practiced at all in pulse crops. Hence this bullet point is adding little.

Selectivity to beneficials – Public communication messaging around both IRM and ‘selectivity’ of insecticides (for all products) to beneficials also needs to be considered, particularly as these two communication topics are often delivered by the same individuals. For insecticide resistance management, the technical advice from the research community is typically to use multiple different modes of action on rotation and not to use the same insecticide consecutively. Whereas the messaging around selectivity against beneficials encourages growers to use the most effective insecticide with the least impact on beneficial insects (see Appendix B for beneficial selectivity ratings for grains crops).

In the case of chlorantraniliprole in particular, this is likely to create marketplace confusion and an ‘excuse’ by some growers to overuse chlorantraniliprole, on the basis that users may believe that that are being ‘directed’ to use it over other alternative modes of action due to the perception that chlorantraniliprole has a large safety advantage against beneficials compared to most competitors.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

On the positive side, almost every agronomist interviewed was concerned over the potential for resistance selection to Group 28 and was receptive to considering strategies to mitigate this. Additionally, most are still trying to develop their preferred FAW management strategies that work in their region. Therefore **there is an immediate opportunity for industry to highlight 'best practice' strategies that can demonstrate effective FAW control without requiring more than one foliar application of chlorantraniliprole**, to overcome the current belief by several in broadacre (which is largely untested) that anything other than extensive reliance on Vantacor is likely to result in additional crop injury.

Supply management – A key strategy used by several original manufacturers of agricultural products is to provide different labels and/or formulations targeted at different crops. This may be as a result of different crops requiring different application rates at similar price point per hectare; or in some instances to maximise profit from market segments that may have more 'opportunity to pay'.

From a resistance management perspective, differential pricing per market segment can be one of the most effect tools available to limit product use in certain market segments i.e. price can be raised on a certain formulation / label to manage volume of use in that crop segment.

FMC currently have three chlorantraniliprole formulations / brands targeting different foliar market segments in horticulture / broadacre at different price points, plus a turf formulation.

Chlorantraniliprole is about to come off patent in Australia, with several generic labels already approved (as at June 2022), with more currently in the registration process. Not all 'registered' uses of Vantacor / Coragen are likely to be supported on initial generic labels (due to data protection requirements reflecting different initial registration dates for later approved uses). However, as generic labels expand, it is common for generic suppliers to seek to simplify their supply chain by consolidating crop registrations onto a single formulation, and hence the strategy of using 'price' to limit use in certain crops segments is likely to be lost over time. This often results in a significant price reduction in certain crops – compared to the current chlorantraniliprole marketing strategy of several different labels / formulations for different market segments. It would therefore be expected that there will be ongoing increases in chlorantraniliprole use, as more generic product enters the market, and especially if the price erodes in some segments.

Further, several of the existing FAW permits for chlorantraniliprole allow for use of a specific named formulation 'plus other registered products'. So this is likely to see any generic product able to be used for 'most' FAW use patterns (on permit) as soon as the generic label is approved.

Currently the majority of chlorantraniliprole formulations supplied by FMC are sold on an 'agency' arrangement, via selected distribution partners. This marketing strategy means that only certain resellers are 'approved' to supply these products to growers. As part of the agency agreement, product stewardship training is generally supplied to the selected agents which includes training on resistance strategies. Often with the arrival of 'generic' products, the supplier of these generics will target those parts of the distribution channel that have not previously had access via the 'agency' distribution channel. Historically the arrival of generics has often signalled the end of preferred agent distribution models and also often the extent of product stewardship and price 'control' that comes with selective distribution arrangements on patent protected products.

It could therefore be expected that there is likely to be a significant relaxation of supply, along with most likely some price reduction in chlorantraniliprole formulations 'available' to growers, commencing from 2022/23. This is likely to result in increased availability and use.

New use patterns – When interviewed for this research, Geoff Cornwell indicated that FMC are in the process of converting several FAW permits to a registered label claim (commercial-in-confidence). However, FMC do not believe that 'all' existing permits for the use of chlorantraniliprole should be supported, as several permits are in place for crops that do not host FAW.

While final Vantacor and Coragen labels are not yet finalised, Geoff indicated that most likely they intend to add FAW for summer cereals (maize, sorghum, sweet corn); safflower; sunflower; sesame; quinoa; capsicum; ginger and sweet potatoes to respective labels.

In addition to adding these FAW use patterns to additional crops, FMC also plan to increase application rates for FAW, as some of the current permit rates are considered to be too low for robust control.

Cyantraniliprole seed treatment – Syngenta have submitted a registration application for Fortenza® Seed Treatment (600 g/L cyantraniliprole) for use as a seed treatment in cotton, maize, sweetcorn and sorghum seed for the early season control of *Helicoverpa* spp. and fall armyworm. Registration was submitted to the APVMA in February 2022. While this registration submission is for a standalone cyantraniliprole product, it is expected that it will be the Fortenza Duo product (cyantraniliprole + thiamethoxam) that will be commercially available to users (thiamethoxam is already registered and applied to the majority of hybrid sorghum and maize seed as Cruiser® brand seed treatment). Based on expected regulatory timelines, first applications may be expected for spring 2023 use.

Some agronomists interviewed for this research project indicated that both Pioneer and Pacific Seeds are currently trialling this use for FAW, but typically there did not appear to be wide knowledge of this development.

Ken McKee (Syngenta) indicated that cyantraniliprole was chosen over chlorantraniliprole primarily as it is slightly more mobile within the rapidly growing seedling. Cyantraniliprole is also slightly less persistent – while this may mean a shorter period of control, the upside is that pests will not be exposed for as long to a residue 'tail' of sub-lethal rates. Ken reported that 3-4 weeks protection from FAW may be achievable, while Melina Miles (QDAF) suggested that protection may be shorter than this under high pressure.

The availability of a seed treatment that is effective against FAW has the potential to significantly alter management strategies, especially in high pressure crops such as maize and sweet corn (and possibly sorghum) where currently establishment is often requiring one or two insecticide applications.

The crops targeted for the first Fortenza label are all grown using hybrid seed supplied annually by a relatively small number of seed suppliers. It is likely to be a somewhat 'easy' decision for growers to simply 'tick the box' on their seed order to have this treatment pre-applied, and hence could rapidly result in significant market share, especially for 'high pressure' crops. It is even a possibility that some seed companies may elect to only offer seed for sale that comes pre-treated, should they perceive that demand will be high and therefore do not want to run duplicate lines of 'treated' and un-treated' varieties.

In key crops where the cyantraniliprole seed treatment is also used, industry guidelines need to be developed as to when foliar applications are supported with following chlorantraniliprole applications. Key questions to be answered include:

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- What is the period of effective protection from a Fortenza seed treatment application? Does this differ with different crop species or when targeting different pests (e.g. *Helicoverpa* versus FAW)?
- Under typical FAW pressure (which varies greatly across geographic regions and crop type), how many insecticide applications are likely to be required after the cyantraniliprole seed treatment has 'run out'?
- Can further foliar applications of Group 28 (e.g. chlorantraniliprole) be supported from a resistance management perspective? If so, how many? What is an appropriate time, or crop development stage, between applications?
- Is there a requirement (from a resistance management perspective) to have one or more different modes of action (effective on *Helicoverpa* and FAW) be applied after the seed treatment and before a subsequent foliar Group 28 application(s) can be used? If so, how many applications and/or modes of action are required?

It is currently unclear what resistance management strategies may be required when the Fortenza seed treatment becomes available. However, Syngenta have been selling Durivo® (chlorantraniliprole + thiamethoxam) as a seedling drench applied at-planting in selected horticultural crops for in excess of 10 years and this may provide a point of reference. The label for Durivo requires no other use of a Group 4A insecticide in that crop after the 'at-planting' application of Durivo, plus a recommendation to "rotate to alternative mode of action insecticide class for a period covering at least one generation of the target pest. For many pests this will require a minimum of 2 applications of alternate MOA insecticides. The total exposure period for all Group 28 insecticides applied through the crop cycle (from seedling to harvest) should not exceed 50% of the crop cycle."

While Syngenta are still to announce use patterns and their recommended resistance management and stewardship plans, it can be most likely expected that Syngenta will be supporting a program something similar to:

> *Fortenza Duo applied to the seed, followed by one or two back-to-back emamectin applications (Affirm or Proclaim depending on the crop) as required – either applied in the vegetative stage, or if pressure is lower, then held to tasselling / silking. Before the option of rotating back to a Group 28 (or different) mode of action.*

In practice, if two applications of emamectin (or other 'effective' modes of action) were mandated before a subsequent foliar Group 28 were applied again, then it is probably unlikely that the foliar Group 28 would be applied within the same generational lifecycle of FAW in the majority of situations. Even in high pressure sweet corn crops, most reported that they often only require 1 or 2 foliar applications before V6 and then were often not spraying extensively again until V10. So if the seed treatment can provide protection at establishment, then two applications of a different MOA 'should' get crops through until at least the next generational lifecycle. Exceptions may be in very high pressure areas where weekly spraying across larger farms was a common practice.

In the opinion of the authors, a situation where this may not hold could be where the seed treatment is used at establishment and under high pressure, there are frequent applications of Magnet + methomyl being applied on a less than weekly schedule. If these lure & kill applications are counted as a 'different mode of action, then potentially 'two applications of a different mode of action' could be applied and users could theoretically be back to the option of foliar Group 28 within the same FAW generational lifecycle. However this is unlikely, is not a financially or agronomically viable strategy, and is only really likely to be enacted by those consciously looking for a way around the intent of the strategy.

On the positive side, almost every agronomist interviewed was concerned over the potential for resistance selection to Group 28 and was receptive to considering strategies to mitigate this. Additionally, most are still trying to develop their preferred FAW management strategies that work in their region. Therefore **there is an immediate opportunity for industry to highlight 'best practice' strategies that can demonstrate effective FAW control without requiring more than one foliar application of chlorantraniliprole**, to overcome the current belief by several in broadacre (which is largely untested) that anything other than extensive reliance on Vantacor is likely to result in additional crop injury.

12.4. Potential use mitigation strategies

As previously mentioned, almost every agronomist interviewed was concerned about selection for resistance. In broadacre crops this was mainly, but not exclusively, directed towards Group 28s and in particular chlorantraniliprole. In horticulture, this was equally Group 28s plus emamectin, spinetoram and indoxacarb.

12.4.1. Window strategy

There was general recognition by almost every agronomist interviewed of the concept of restricting applications to a 'use window' as a potential resistance management strategy. Examples of some current 'window' based strategies are included in Section 5.1 of this report.

However there was very strong feedback (from most) that if a window-based strategy was to be implemented for any insecticide, then **this window needs to be "where we want/need to use it" and several comments that if the window does not align with local preferred timing for product use, then the strategy is unlikely to be adopted in that district.** So, in general, most were saying that they are going to use their preferred product where it fits best locally. If their preferred use timing happens to align with the proposed IRMS then this is 'great', and they will become an advocate for the strategy. Otherwise, pushback and non-compliance should be expected.

> As an example, one Queensland agronomist reported "Windows of use for some of the products in the grains industry IRMS didn't align with the needs in CQ. For example, it is recommended not to use Vantacor on mung beans between February-April, which is the main time we need it to control bean pod borer. Vantacor is one of the only effective chemistries we have for bean pod borer, aside from Affirm. Steward has been registered recently but we're reluctant to use it as we're unsure how effective it is compared to Vantacor/Altacor."

In this commentary, there is acknowledgement of alternative chemistries that 'could' be used at that timing, but in this situation, this would mean that they would not be able to use their 'preferred' option of chlorantraniliprole at all in this crop. So hence their choice is to not comply with the strategy and claim that the strategy is the problem. While this specific verbatim response was chosen to highlight this point, there were many similar examples also reflecting a similar sentiment.

For this reason, in the opinion of the authors of this report, the development of a multi-region x multi-crop x multi-pest IRMS is unlikely to be adopted by industry in regions where their 'preferred' option is restricted from use at a particular timing. Or to obtain adoption, there will need to be many strategy variants i.e. each region will want a version that allows them to use certain products when they want to use them. It could be argued that, without restrictions that results in sometimes a product is 'not used' when a user would like to use it, then the strategy is somewhat meaningless.

Due to the complexities of the different crop mix grown in different regions, different climatic conditions driving different FAW pressure, and in some crops different timing of FAW and *Helicoverpa,* then a customised window-based strategy is likely to be required for each region for a strategy to have any chance of success. The regional information collected in Chapter 14 of this report is designed to assist in understanding the regional drivers that focus development of local strategies. The greatest challenge with this approach is likely to be the time and resources required to build the various strategies and obtain 'industry buy-in' during their development, which includes rationale for end-users as to why the strategy is required at all. Additionally, there will be ongoing need for continual updating, extension and communication of strategies to both keep them relevant and front-of-mind with users.

Assuming that regionalised strategies are developed, then extension resources will also need to be regional and require local 'champions' to drive adoption. For crops like cotton (and to some extent vegetables) there are regional grower associations and industry development officers who may be able to assist with coordination of industry buy-in and who could lead extension, however in most other broadacre grains and forage crop markets, this network does not exist.

An alternative 'window' strategy that may be considered is to have a simple two-window strategy for all products across all regions for the entire year i.e. similar to the original diamondback moth strategy in brassicas (see Section 5.1 for more detail) where any product is only available to be used for 6 months per year. While this would be simple to understand and communicate, and the least likely to continue to need annual revisions, the major challenge that can be foreseen are:

- Where are the changeover points situated? Ideally this would be 'mid-crop' but as mid-crop varies widely with region, crop type and planting date, then any specific date will be a compromise at best
- Many crops may be grown entirely within one window, so some products may not be able to be used at all in that crop
- For crops requiring very frequent use, there may be insufficient available remaining options if some products have been excluded due to crop planting date
- This is likely to attract a level of pre-buying of preferred insecticides when they are available, for use after the window has closed for that product.

These reasons above are perceived as why the original DBM strategy was not particularly effective, and this was only developed for a single insect pest and one crop group in isolation.

Our research indicated that in horticulture, non-use windows in high pressure crops like sweet corn or capsicum was acknowledged as something that many advisers would 'like' to be able to do to manage potential resistance in FAW. However everyone suggested that restricting <u>any</u> product in the current program would immediately just result in much higher selection pressure being placed on the remaining options. Most did not see that as advantageous. Additionally, in situations where growers 'ran out' of the number of permissible applications of remaining products, then they would be forced into a corner of either exceeding the legally allowed frequency of applications on the product label or breaking the strategy – with the latter deemed as most likely to occur. For almost everyone interviewed in this segment, there was recognition that, for a non-use window to be implemented for any product, there either needs to be a number of additional effective management tools available to provide more choice. Or management systems are needed to reduce the overall frequency of applications required. For most in these crops, the best compromise strategy they have come up with, and are mostly using, is a continual rotation of existing options (however many are conscious that this may still be resulting in more than one application within a particular generation when under heavy FAW pressure).

For broadacre crops, discussion of application 'windows' to restrict use, quickly became very focused on chlorantraniliprole (and specifically Vantacor), as several recognised that Vantacor was the 'value for money' proposition in this summer crop segment (combination of efficacy, length of residual, selectivity to beneficials and broad crop registrations/permits) so any 'window' may reduce the opportunity for use in these crops, depending upon where the window is situated. In the opinion of the authors, the current exceptional 'value for money' proposition of Vantacor (at least against *Helicoverpa*) is driving some users to make sure they maximise their allowable of use of this product first, before then looking at alternatives (should something else still be required). Several agronomists interviewed implied that they may not be doing the right thing by their grower clients if they recommend something other than Vantacor, where chlorantraniliprole is still an available option as per the registered label / permit.

Noting that any 'value proposition' is only relevant at current pricing of that product and the price of competitors and a significant change in relative pricing can quickly change behaviour. For example, a major increase in Vantacor pricing (while unlikely due to upcoming generic entrants) or significant increase in application rate is likely to reduce demand and may see other options considered more favourably. Alternatively, many indicated that they believe Success Neo to also be very effective on FAW, but nobody was using it in broadacre crops due to the comparatively high price when compared to Vantacor. So a significant price reduction in Success may also potentially affect primary product choice.

When designing a long-term product use strategy (such as an IRMS) it is often easy to forget that 'preferred' product choice also includes price. Within some boundaries (and especially prior to generic activity), companies elect to set their product pricing to reflect their market share objectives. So it needs to also be considered that industry attempts to reduce product use by implementing non-use 'windows' could be met by counterproductive pricing decisions by some companies attempting to secure market share objectives.

Alternate strategies to a window-based IRMS

The following two sub-chapters propose alternate strategies that are worthy of discussion that may be equally, or arguably more effective in reducing overall use of key important insecticides.

12.4.2. Optimal use of products in the best technical fit position

While not a resistance management strategy per se, it is the opinion of the authors that there is substantial opportunity to reduce overall insecticide applications for FAW by informing users of better use strategies for their current suite of management tools. Reducing over application may be the most effective short-term strategy to reduce selection pressure.

As FAW is still relatively new, many agronomists are still trying to work out the most appropriate products to use, how frequently to apply and when and how to use them to optimise results. Most are still looking for assistance in defining the 'best' strategy and are currently gleaning information from a wide range of sources. However, as a general rule, most are heavily relying on experience with *Helicoverpa* as their starting point. Strategies to manage *Helicoverpa* do not always translate as applicable to FAW.

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Throughout the field research component of this project we were able to glean several observations and experiences which can be used to feed into a best management plan. Typically any single user may understand some of these, however there would be significant value in developing and presenting an entire plan to the broader industry which may result in users gaining more confidence around a total package.

Key considerations of a FAW best management package are likely to include:

Planting date – In regions where pressure declines over winter, there was strong anecdotal evidence to support that planting maize or sorghum in the August to October planting window, as opposed to the December / January window resulted in much lower FAW pressure earlier in the crop, with often the crop being largely passed its attractive stage by the time FAW pressure ramps up.

In some regions it is almost the case whereby if maize (in particular) cannot be planted in August to early October, then growers are strongly discouraged to plant at all and to seek a different option that is less attractive to FAW.

It is likely to be of industry benefit to develop case studies that compare the yield and gross margin of maize planted in August / September versus December in these regions.

Chlorantraniliprole efficacy – Chlorantraniliprole is considered by many (especially in the broadacre crops) to be the preferred insecticide option for FAW. However, several of those interviewed appeared to make this assumption without having accurately compared other active ingredients under side-by-side conditions. For several, it appears that this positioning may be reflective of previous experiences in managing *Helicoverpa*, however it needs to be noted that most use when targeting *Helicoverpa* will occur after crops have largely finished rapid vegetative growth, and this is where the extended residual of chlorantraniliprole is likely to be of greatest benefit.

This relative positioning may be further explained that in those *Helicoverpa* markets where chlorantraniliprole is not selected, then the most likely alternative option is a pyrethroid when targeting *H. punctigera* or indoxacarb for *H. armigera*. In several situations, broadacre agronomists who had tried something other than chlorantraniliprole for FAW, mentioned that they had tried either pyrethroids, methomyl or indoxacarb – all of which have been demonstrated to have 'poor' efficacy on Australian FAW populations – so this is likely to be reinforcing that chlorantraniliprole 'is as good as it gets', as chlorantraniliprole was compared to far less efficacious alternatives.

However, those who have been exposed to side-by-side research trials (Figure 17) or have directly compared chlorantraniliprole against other comparative insecticides (in particular emamectin and spinetoram) under the same application conditions and especially in young rapidly growing crops, often did not share the opinion that chlorantraniliprole is the standout treatment, especially in horticulture where the permitted rate of chlorantraniliprole for FAW is only 20 gai/ha.

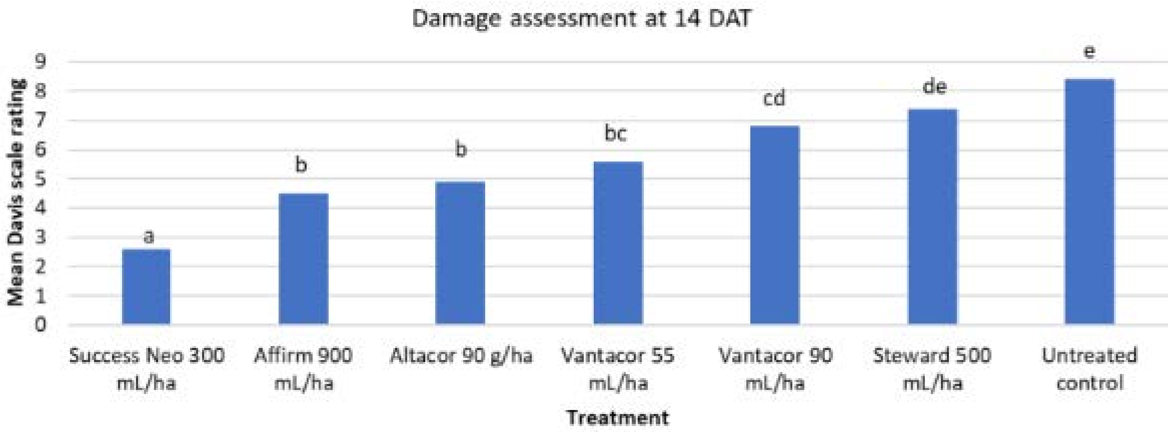

Figure 15 Assessment of comparative FAW damage 14DAT (Miles, Quade, Volp, & Eyre, 2022)

As previously indicated, the Australian rates for chlorantraniliprole are significantly lower than registered rates in the USA for the same pest. USA label states a use rate of approximately 50-75 gai/ha. While Australian FAW permit rates are 20 gai/ha for horticultural crops (including sweet corn), 24 gai/ha for pulses, 24-33 gai/ha for maize and 33-54 gai/ha for sorghum.

Even for those advocates of chlorantraniliprole, most were still expecting that there would be some level of survivors and often put this down to application difficulty in getting insecticide to larvae in protected locations, especially on maize with large canopies when trying to apply by high clearance sprayers or aircraft. This was leading some to apply chlorantraniliprole via chemigation. However, in the view of some researchers, these lower rates on Australian permits may be a significant factor resulting in sub-optimal efficacy. This position was reinforced by one agronomist from the Atherton Tableland who mentioned that they were using a single application of a ‘double rate’ Vantacor in maize (so effectively the USA registered rate) to replace the two consecutive applications that most others were applying. This agronomist was convinced that this gave both better knockdown and longer residual than two applications at the permit rate.

There was suggestion from some researchers interviewed that the chlorantraniliprole application rate should be raised, as this is currently leaving a level of survivors which may lead to relatively rapid retreatment being required. In addition to the added cost of retreatment and the damage that survivors may incur during this time, this need for retreatment is increasing selection pressure by increased number of applications, while also potentially leaving some larvae exposed to sub-lethal doses.

FMC (Geoff Cornwell pers com) indicated that they are in the process of moving some of the current FAW permits to a full registered label claim, and in this process “application rates for FAW will be increased”. Specific rates by crop were not mentioned by FMC, however a researcher believed that a ‘minimum’ rate of 30 gai/ha was being considered by FMC for registered labels.

An increase in application rate is likely to be beneficial for resistance management for the reasons discussed above. Additionally, all other things being equal, the increased cost of a higher rate is potentially likely to result in some being more willing to consider alternate insecticides in some market segments, which should also be beneficial for resistance management objectives.

There would be benefit to have independent field trial data against FAW in maize comparing a single and double application of the most common field application rate (40 mL Vantacor /ha), compared to the maximum permissible application rate (currently this would be a single or double application of Vantacor at 90 mL/ha in vegetative sorghum under PER91619) to show both knockdown of existing populations and residual protection. [*Authors note: However, the maximum rate chosen for these demonstration trials needs to be within range of a potential label registration i.e. this could be counterproductive if 2 x 90 mL/ha showed significant benefit, but was never likely to be registered for other reasons*.]

Chlorantraniliprole residual – Chlorantraniliprole is considered by most to be one of the longest residual options available, once inside the leaf. This position has been established from use against *Helicoverpa*. It is likely that rates of chlorantraniliprole when registered for FAW will be at least the same, or in some cases higher, than rates currently used for *Helicoverpa*. Increasing application rate is likely to result in extended residual (in addition to improving knockdown efficacy).

Extended residual is of maximum value once a crop has finished rapid vegetative growth and hence growth dilution has slowed. Many agronomists recognise this and were targeting application of chlorantraniliprole around tasselling / silking in maize. In several situations, agronomists were hoping that a single, well targeted Vantacor application applied at silking may then be enough to get the cobs past the critical stage for damage. A higher application rate may assist at this timing. This is arguably the preferred technical fit for chlorantraniliprole.

However, a smaller set of agronomists were wanting to use chlorantraniliprole against early FAW infestations in both vegetative maize and sorghum. FAW can be extremely damaging at this growth stage, and these users were generally perceiving that chlorantraniliprole is the 'most effective' product against FAW. So even if it does not give great control or residual at this growth stage, then it is 'still likely to be better than anything else'. In the worse case situation, a few agronomists were applying an early Vantacor (V2-V6), monitoring the crop and only applying alternate options 'if needed', and then applying a second (and occasionally a third) Vantacor at tasselling / silking. In sorghum, they were often hoping to apply a single (or sometimes a double) Vantacor during early establishment, and then nothing further until Vivus is applied for *Helicoverpa* at early head emergence.

There is likely to be significant resistance management benefit in communicating to users that the 'extended residual' of chlorantraniliprole is unlikely to be of significant benefit when applied early to rapidly growing crops, and there are other viable alternative options that can also be considered at this growth stage which will result in less selection pressure being applied to chlorantraniliprole.

> The most common 'alternatives' that have been tried at this stage have been Fawligen or Steward (indoxacarb). These appear to have been chosen primarily as they are cost comparable to Vantacor and generally considered to be relatively 'soft' to most important beneficials at this stage (specifically *Trichogramma*).
>
> Fawligen has been promoted as a FAW specialist product, while Steward is the most common rotation partner in summer crops for *Helicoverpa* when Vantacor is not chosen, so these factors have also been important in considering alternatives to Vantacor.
>
> When applied alone as an alternative to Vantacor, both of these alternatives typically do not deliver the same performance on FAW. This has reinforced for some that Vantacor is the 'best' option for FAW.

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However, both emamectin and spinetoram are highly effective on FAW, so are likely to be viable alternatives for an early season vegetative application timing, especially where growth is rapid and longer term residual control is unlikely from any product.

> A small number of agronomists interviewed were already utilising Affirm in maize at this early use pattern under PER89371. Additionally, Syngenta have already submitted a label extension to the APVMA to add sorghum to the Affirm label.
>
> Another alternative that has been suggested at this early application timing is band applications of Success Neo. Broadacre application of Success is currently not considered, primarily due to price, with the top permit application rate (PER89390) of 300 mL/ha costing in excess of $120/ha. However it has been suggested that the lower permit rate (250 mL/ha), applied as a 50% band, may be more cost comparable to other options. However we did find any evidence of this being done currently

In both cases, these options are still likely to be more expensive than Vantacor, so this is most likely the primary reason for non-use. Many appear to 'justify' their reluctance to consider either of these options, by claiming that both of these products were 'too hard' on beneficials.

Indoxacarb performance – When managing *Helicoverpa*, indoxacarb is generally considered the first alternative to chlorantraniliprole in many crops, or to Vivus in sorghum. Therefore, when faced with managing FAW, many sought to use indoxacarb as their first rotational option.

While indoxacarb does have activity on FAW, the relative toxicity between the two species (see Table 10) suggests that a very much higher application rate will be required for FAW to deliver similar levels of performance to what is expected against *Helicoverpa*. This obviously would make the cost of indoxacarb significantly higher than other standards at the rate required for robust control.

FMC (Geoff Cornwell pers. com.) has indicated that FMC do not intend to register indoxacarb for these reasons above.

There are several FAW emergency use permits approved for indoxacarb use in several crops. All of these are at application rates 'similar' to registered rates of *Helicoverpa* in the same crops.

Table 13 Current emergency use permits (as of June 2022) for control of FAW in selected crops

Holder	Expiry	PER	Crop	Use rate by formulation type		
				150 g/L	**303 g/kg**	**200 g/kg**
PHA	3/23	89279	Soybean	400 mL/ha		
HIA	3/23	89286	Turf			375 g/ha
HIA	3/23	89278	Several horticultural fruit, vegetable & tree crops		170-250 g/ha 17-25 g/100L	
CA	3/23	89306	Cotton	500-850 mL/ha		
CA	4/23	89311	Pigeon pea	400 mL/ha		
PHA	5/23	89530	Maize cereals	400-500 mL/ha		
HIA	11/23	90374	Sweet corn		250 g/ha	
AOF	1/24	90577	Peanuts	300-500 mL/ha		
AOF	2/25	90761	Linseed	400 mL/ha		

PHA (Plant Health Australia) HIA (Horticulture Innovation Australia) CA (Cotton Australia) AOF (Australian Oilseeds Federation)

As FMC have determined that they will not be supporting the use of indoxacarb via product label updates, and the relative performance versus *Helicoverpa* would indicate that a substantially higher application rate is needed for equivalent control of FAW, then it is highly questionable if these industry permits are providing the best agronomic advice to industry.

While the authors of this report understand that no, or minimal, efficacy data is required to obtain an emergency use permit, the expectation of the majority of users is that product use, when covered by a permit, should be effective and is basically an industry endorsement of recommended use.

In many situations, and especially where FAW pressure is ongoing, we found users continuing to apply indoxacarb as a rotation option, believing that they are doing the right thing for overall resistance management by rotating to a different MOA. However, if these applications result in sub-standard control and allow escapes, then this could be rapidly selecting for resistance.

It is recommended that those holders of permits for indoxacarb in Table 13 consider if the advice provided within their permits is sound and is not contributing to use of product which may give sub-optimal performance and hence place users at risk of crop damage, need for retreatment and potentially placing undue selection pressure on FAW. In some crop situations there may not be alternate options available, so it may be argued that 'some' population reduction (as a result of indoxacarb application under permit) may be better than none at all. While in other situations, it may be possible to improve control by recommending an increased rate (where residue data is available to support its use). For some of these permits, it is questionable if these crops actually host FAW, and therefore if the permit is required at all.

A Bundaberg agronomist who is also involved in contract small-plot research trials on behalf of registrants, indicated that they are commercially using Plemax (320 g/L indoxacarb + 80 g/L novaluron) as an alternate to straight indoxacarb in crops where Plemax is registered (specifically fruiting vegetables) in situations where they are faced with the combination of *Helicoverpa* and FAW and they still desire to apply indoxacarb (due to a desire to rotate all available tools in the toolbox). In their opinion, the addition of novaluron brings an additional mode of action (Group 15), while the combined performance of the two actives raises efficacy against FAW to at least similar to other leading insecticides (e.g. chlorantraniliprole, emamectin). Providing this advice is correct, and Plemax is 'substantially' more efficacious than straight indoxacarb against FAW, there may be argument to consider 'replacing' standalone indoxacarb permits with a permit for Plemax in crops where Plemax is registered (noting that novaluron has limited registrations in Australia).

Some, but certainly not all, broadacre agronomists were starting to switch positioning of Vantacor away from summer pulses (where it has been the dominant product) to preferentially position either Steward (indoxacarb) or Skope (emamectin + acetamiprid), or both where two applications are required, as their 'primary' pulse insecticides. Generally *Helicoverpa* is still the dominant pest species in these crops (unless in very heavy FAW pressure environments). This then opens the opportunity to reposition Vantacor into maize and vegetative sorghum, specifically for FAW. The objective of these agronomists was to try and prevent their growers from 'using chlorantraniliprole everywhere'.

Fawligen strategies – Most interviewed have had some experience with Fawligen.

The majority of those interviewed had also had extensive experience with Vivus (or other NPVs) and were all quick to point out that Fawligen against FAW is 'nothing like' Vivus against *Helicoverpa*.

When using Vivus against *Helicoverpa*, an initial application to sub- or at-threshold populations will generally control at least up to third instar *Helicoverpa* and the virus will establish and transmit throughout the crop from that time forward. Providing environmental conditions are not adverse, a single application at early head initiation is often all that is required in crops like sorghum. Application timing is not overly critical, provided instars are not too large.

When targeting FAW using Fawligen, application must be made to very small (1st and early 2nd) instars only for maximum efficacy. Figure 18 demonstrates recent efficacy by instar size (Miles, Quade, Volp, & Eyre, 2022)

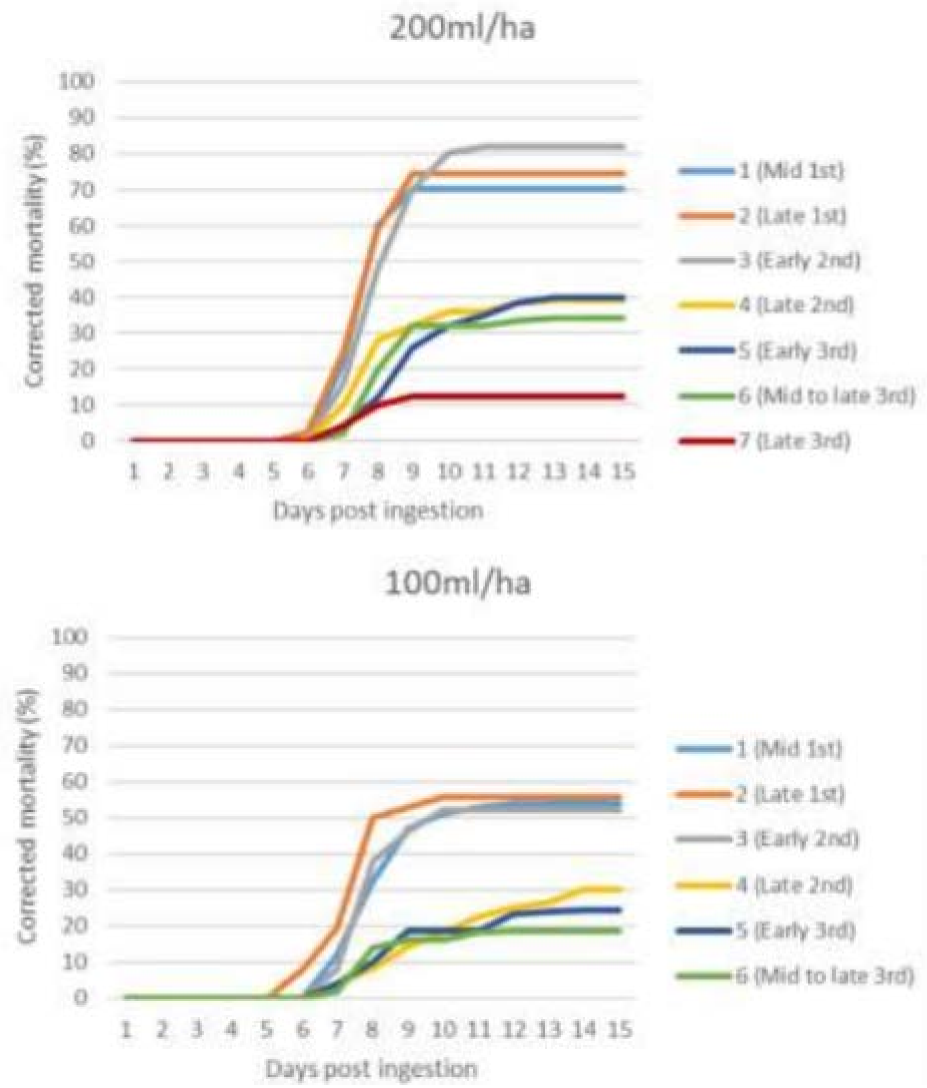

Figure 16 FAW mortality by instar size – days after ingestion. https://www.youtube.com/watch?v=4CHzPjF8LDs

In several key crops that host FAW and especially maize and sweet corn, correct timing of application can be extremely challenging. Often there will be a very wide range of mixed larval sizes present. Additionally, first and second instars can be extremely difficult to find in a big bulky crop such as advanced maize and particularly when they are present at sub-threshold numbers, where Fawligen is likely to work best.

Application coverage appears to be extremely important. In young crops, high water rates with nozzles directly above the row and concentrating spray into the whorl appear to be working best. Later in the crop, several reported having success with Fawligen applied via chemigation (i.e. applied through the pivot).

A number who have tried Fawligen have since moved away, mostly in favour of a more traditional insecticide that is expected to be more consistent on populations of mixed larval size.

Those that are continuing to use Fawligen are more likely to be applying it multiple times per crop (i.e. regularly, or semi-regularly) and typically in combination with other conventional insecticides, or sometimes in combination with Vivus where both FAW and *Helicoverpa* are present. One sweet corn agronomist reported using up to 800 mL/ha per crop (up to 8 applications @ 100 mL/ha) when under heavy FAW pressure i.e. it was being added to 'most' conventional applications.

In the view of AgBiTech (Phil Armitage pers. com.) one of the major benefits of Fawligen is that it has no detrimental impact at all on beneficials, so it is often the associated control from the beneficials that is heavily contributing to the control observed where the product is used alone.

Almost all of those interviewed were at least interested in better understanding how to obtain optimal performance and where is the best fit as a component in a program.

Lure & kill strategies (e.g. Magnet + methomyl) – During the course of this research we did not uncover anyone regularly using this tactic on light, pre-threshold populations as a population suppression strategy, however this may be arguably where this may have best fit. Generally most were implementing a 'do nothing' approach when populations are light.

There appeared to be two broad strategies that have been tried. Several reported that they had tried Magnet + methomyl on 'moderate' populations as an attempt to <u>replace</u> a conventional spray. Almost all who have used it in this way reported that it was able to take out 'some' moths, however the general comment was the 'pressure quickly overran the treatment'. Most who have tried this approach appear to be no longer using, as they have determined that it is not able to 'replace' an insecticide treatment.

Agronomists who are continuing to use lure and kill strategies, are typically applying it within a standard insecticide program, as a tool to complement the insecticide and further reduce populations. This is often in heavy pressure situations and may be applied at the same time as a broadcast spray i.e. a dedicated spray line is set up to dribble out some Magnet + methomyl from the tip of one boom wing. Users who are applying frequently were the ones who reported most benefit. Some of these also added that it was important to keep spacing of strips narrower, rather than wider for best performance.

The key downsides identified were the cost of regular applications (especially if using narrow strips), lack of rainfastness (which makes it particularly challenging to use under pivot irrigation systems) and potential 'collateral damage' to beneficials that also decide to feed on it, especially where Optimal is also included.

A small number of broadacre agronomists questioned if Success Neo (spinetoram) may be a suitable replacement for methomyl in this use. The rationale being that spinetoram may be less damaging to some groups of beneficials and it may allow a position for spinetoram use in broadacre crops where it is considered too expensive to be applied as a broadcast application. Spinetoram is approved for use on the Magnet label in cotton, green beans and sweet corn when targeting *Helicoverpa*, but is not included on the current permit for FAW control.

Seed treatments – Only a subset of those interviewed raised the potential for seed treatments.

Some were aware that Syngenta were progressing a registration of Fortenza, as this had been mentioned to them by one of the maize seed suppliers who had commented they had trials underway. While a few others had seen 'a seed treatment option' included in QDAF trials.

Very few interviewed had firsthand experience, but some did offer their opinions.

Almost exclusively, those providing commentary saw the concept of a seed treatment to provide 'a few weeks protection at establishment' as highly desirable. A small number who were operating in the fruiting vegetable market understood the convenience that a similar use pattern with Durivo can deliver in transplanted fruiting and brassica vegetables, in terms of not needing to be as concerned about insect pest damage at establishment.

However, almost without exception, the comment was added 'please not a Group 28.' This comment is largely coming from the majority who have firmly entrenched beliefs that foliar Group 28 is the 'best' strategy against FAW (see above for further discussion).

QDAF have completed trial work (in association with Corteva) to evaluate chlorantraniliprole as a seed treatment. Melina Miles (pers. com.) reported that this work has now been stopped.

Syngenta have submitted a registration for Fortenza (cyantraniliprole) however when registered, is expected to be available as Fortenza Duo (cyantraniliprole + thiamethoxam). Depending upon the length of field protection provided (2 to 4 weeks has been claimed by various parties) this could result in significant market uptake in crops like maize, sweet corn and sorghum.

The required changes to resistance management recommendations that are expected to come with this use pattern is likely to influence foliar Group 28 applications in these crops.

> It could be expected that, in maize, there will be a requirement for at least 1, possibly 2, applications of a different MOA to be applied before coming back to a Group 28. This potentially pushes foliar Group 28 applications back to tasselling / silking, arguably where they have best technical fit.
>
> In sorghum, the requirement for additional modes of action following a Group 28 seed treatment may remove the need for further foliar applications against FAW (as not much spraying of sorghum occurs post establishment).

While some may see the registration of a Group 28 seed treatment as putting further selection pressure on this mode of action, the counter view is that, with the resistance management requirements that are expected to come with this registration, it could be argued that overall use of Group 28 may not be increased at all, possibly decreased for those who are using multiple foliar applications, and the timing of subsequent foliar applications are likely to be positioned where this will deliver the best efficacy. Early control measures that protect establishment of maize crops and remove or reduce survival of early infestations, can lead to better crop establishment and substantial reductions in endogenous population growth that reduce the level of pest pressure in later crop growth stages.

In summary, the authors of this report have identified that some current insecticide use patterns and best management advice may have significant room for improvement, as many advisers (and therefore growers) do not fully understand how to optimise their performance. This is especially the case with FAW, as it is a new pest, and several are still learning, often by trial and error.

There is now a reasonable body of evidence and experiences, much of it summarised in this report, that collectively can be utilised to share learnings that are likely to result in improved confidence in management approaches for FAW. Should this be extended to the industry, there is likely to be an immediate benefit in removal of applications that are poorly timed, or ineffective. This would have a significant short term economic benefit to growers, while giving advisers more confidence in their decision making. In addition, a medium to longer term benefit will be reducing selection pressure from insecticide overuse and potentially slowing down the inevitable march towards insecticide resistance.

A key recommendation of our research is a short-term requirement for extension of best management practice with regard to insecticide use for FAW. It is acknowledged that there are still significant knowledge gaps requiring further research (see Section 12), however it is seen as more important to get extension of what is known underway immediately to improve some of the identified poor use practices. Extension messaging to 'fill the gaps' can be added as new research answers these questions.

12.4.3. Label directions

An additional strategy that may result in improved outcomes to limit overuse of insecticides in general, could be to consider label directions. There were many comments from those interviewed along the lines of 'compliance' with resistance strategies will be much stronger where the number of applications and timings are specifically stated on the label.

This is especially the case for large horticultural operators where product supply to the retail chain is generally subject to quality assurance programs from these customers, and hence label compliance is mandatory. In broadacre grains, label compliance in terms of number of applications and their withholding periods is usually also fairly good, however timing between applications may have room for improvement where resistance management is the desire. From our interviews, label compliance by some small pastoral users and horticultural producers, especially those supplying local 'farmers markets', may be more questionable.

Feedback from interviews suggested that to achieve high resistance management compliance for any product, the label should be the primary tool to dictate product use (rates, frequency, number of applications, crop growth stage or other requirements). With any industry use strategy seen as being 'voluntary advice' at best.

Additionally, label statements are more 'permanent' and less likely to change and will always be present (providing the label is read before use). Whereas a standalone separate resistance management strategy can tend to be 'forgotten' unless users are constantly reminded through ongoing extension.

Currently, labels of most of the 'newer' insecticides have a maximum number of applications stated, which sets the maximum frequency of use. Some also have commentary as to how frequently these can be applied. Many older labels do not have any particular frequency of use constraints, so initiatives to improve label directions would also be of high relevance to older products, should label updates be initiated.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Despite contrary views by several users, restrictions on the number of applications on labels are typically developed with regard to use patterns that define commercial objectives and/or residue limits in the produce (i.e. the number of applications and use rate is used to set MRLs). In some instances it was reported by technical managers that sequential applications were recommended for improved efficacy.

Table 14 & 15 summarise number of applications currently supported for key insecticides of interest to this report. Often the number of applications mentioned on the label becomes the 'de facto' resistance management strategy.

Table 14 Key insecticides for Helicoverpa and FAW control in key broadacre crops

MOA	Active	Example	No. applications on label for *Helicoverpa*	No. applications on permit for FAW
1A	Methomyl	Lannate	Not stated on label	As per product label
5	Spinetoram	Success Neo	2 (pulses) 3 (cotton) Not registered in sorghum	2 with min. of 10 days between applications (sorghum, maize, millet) 4 (cotton, pulses, canola)
6	Emamectin	Affirm	2 (pulses) 4 (cotton) Not registered in sorghum	2 with min. of 7 days between applications (cereals, maize, pulses, canola) 4 (cotton)
6 + 4A	Emamectin + acetamiprid	Skope	2 (pulses and cotton)	No permit
22A	Indoxacarb	Steward	1 (pulses) 3 (cotton) with no more than two consecutive Not registered in sorghum	1 (linseed, pigeon pea, soybean) 2 with min. of 7 days between applications (peanuts, maize) 3, no more than 2 consecutive (cotton)
28	Chlorantraniliprole	Vantacor	2 (pulses) 3 (cotton) Not registered in sorghum	2 with min. of 7 days between applications (rice, millet, sorghum, peanut, maize, sunflower, safflower) 1 in-furrow/banded + 1 foliar per year

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Table 15 Key insecticides for Helicoverpa and FAW control in capsicums and sweet corn

MOA	Active	Example	No. applications on label for *Helicoverpa*	No. applications on permit for FAW
1A	Methomyl	Lannate	Not stated on label	PER9279 – 2 PER89293 – as per label
5	Spinetoram	Success Neo	4	4
6	Emamectin	Proclaim	Maximum of 4 per crop. Also maximum of 4 per year on the same land where more than 1 crop is grown	As per label for other pests
22A	Indoxacarb	Avatar	3 (in capsicum) Not registered for sweet corn	3 (sweet corn and capsicum)
22A + 15	Indoxacarb + novaluron	Plemax	3 (in capsicum), but no more than 2 consecutively Not registered for sweet corn	No permit for FAW
28	Chlorantraniliprole	Coragen	3 (but no more than 2 consecutively)	As per the label for other pests
28	Flubendiamide	Belt	3 (in capsicums) Not registered for sweet corn	No permit in place
28	Cyantraniliprole	Benevia	Max 2 per crop applied within 7-10 days (in capsicums) Not registered for sweet corn	No permit in place
28	Cyantraniliprole + Diafenthiuron	Minecto Forte	Max 2 per crop (in capsicums) Not registered for sweet corn	No permit in place

Historically those developing product labels have suggested that restrictions of applications for 'resistance management' should be the domain of CropLife or an industry IRMS, and may argue that product use should be 'less constrained' at launch, with industry restrictions only enacted once there is actual evidence of sensitivity shift. However, in the case of each technical manager interviewed for this project, there was acknowledgement that resistance management for FAW specifically needs to be a consideration as labels are updated to move permits to registered label claims. Further, Group 28 insecticides such as Vantacor, Coragen and Durivo already contain specific label statements around resistance management for this mode of action.

As an 'industry' there is the opportunity to establish a tighter set of recommendations 'for resistance management' for **all** insecticides and seek to have this accepted as industry best practice – and have this incorporated into all 'new' product labels (including older products as labels are updated). For example, this is currently being implemented for spray drift management for all products, whereby new products and significant registration updates to older products are now requiring label statements upgraded to the new industry standard recommendations for spray drift management as part of the registration approval. Where this becomes 'industry standard' and applies to all products, then there is more likelihood to have supplier acceptance of the label change, as opposed to working product by product in a crop specific IRMS document.

As mentioned previously, label statements regarding resistance management for some Group 28 insecticides has been attempted by various registrants, however wording is not consistent between products and this level of detail is not being applied to all products. There is likely to be more user recognition, consistency and acceptance should this become industry standard practice. For example, the wording used on several Vantacor permits for FAW is not in line with the wording on product labels and is potentially confusing to some with regard to the permitted frequency and timing of applications when targeting FAW. A consistent format across all labels is likely to be of industry benefit.

It is also unclear how much input the scientific entomology community has had into the resistance statements being included on the current Group 28 insecticide labels. Having a coordinated industry-wide approach that seeks to have resistance management statements included on all product labels is likely to better engage 'experts' in development of these statements.

In addition to the number of applications, guidance around consecutive applications from the same mode of action also needs addressing on all product labels. As stated in the preceding chapter, statements that imply words to the effect of 'Consecutive applications can be made, providing they are applied to the same generation' may be technically correct from a science perspective, but highly open to misinterpretation, lack of understanding or abuse at a practical level and hence we would recommend that they are avoided where possible. A much better label (for user compliance) would be to include a statement such as something similar to:

> '*An insecticide from a different mode of action group must be used as the next application <u>AND</u> there must be [insert number based on science] days between application of [insert product name] and subsequent use of any insecticide from the same mode of action group*'.
>
> Or, where the registrant seeks to recommend back-to-back applications for improved efficacy
>
> '*Two applications are required to be applied within a minimum of 'X' and maximum of 'Y' days between applications. Thereafter a different mode of action group must be used as the next application AND there must be [insert number based on science] days between application of [insert product name] and subsequent use of any insecticide from the same mode of action group*'.

It is acknowledged that defining periods with hard numbers will be a compromise, with 'science' suggesting that generation lifecycle times are arguably a more accurate measure of resistance risk. However, from a psychology perspective, a simple, uniform and consistent number across all insecticides is much easier to understand and remember, and is thus much more likely to result in compliance.

In the opinion of the authors, a requirement to have a maximum of (for example) 21 days between consecutive applications and then a minimum retreatment period of (for example) 40 days and the requirement to use at least one other insecticide MOA before coming back to the initial MOA would mean that it would be highly unlikely to see any single MOA applied to consecutive generations, and most likely the insecticide would be only applied in one block in the vast majority of broadacre crops.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

The most likely way to implement an approach such as this would be to have a scientifically developed and supported set of guidelines for insecticide resistance management presented to CropLife Australia to update their current general resistance management advice for all insecticide use. Specifically, as suggested above, recommendations such as a maximum number of applications per crop and the requirement to always have a different mode of action used for the next subsequent application AND a stated number of days between reapplication of the same mode of action. Once this is in place there would be obligation for registrants to include these principles on product labels, as this advice will not change over time, regardless of local changes in resistance frequencies. This is, in the opinion of the authors of this report, likely to reduce frequency of applications of any insecticide that is in 'heavy' use. While also being simpler to implement, easier to be understood and likely to have much greater compliance than a voluntary 'window' based strategy.

13. Unanswered research questions

During the course of this research, several questions and 'knowledge gaps' were identified by agronomists. These are summarised below.

FAW identification – Several advisers sought additional in-field identification systems to be able to separate FAW from other caterpillar species when at the neonate to second instar size. Exclusively this request was coming from (experienced) advisers operating in regions where FAW are currently an 'irregular' pest, and they were not confident selecting management options when unsure if the neonates were *Helicoverpa* (*armigera* or *punctigera*), FAW, some other armyworm species.

There was mention that it was possible to send larvae to QDAF or NSW DPI for confirmation, but agronomists were looking for an in-field test to allow management decisions to be implemented immediately. The concept of the Lepton test used in the 1980 / 1990s for *Helicoverpa* was suggested as an example of what they were seeking.

In higher pressure areas, or areas where FAW has become endemic, it was generally assumed by most that any larvae found in maize or sweet corn will be FAW, and hence treated accordingly. While these agronomists did not mention the need for an in-field identification tool, it is possible that sometimes crops are being treated aggressively on the assumption that larvae are FAW, when possibly that may not be and hence a less aggressive management strategy may have been more appropriate and therefore placed less selection pressure on the overall system.

Pest behaviour – Several (experienced) agronomists were seeking improved understanding of fundamental pest behaviour to assist in development management plans. Some factors mentioned included:

- Behaviour of instars during the night and day. It was commonly perceived that FAW are very sensitive to UV light. Is there a preferable time of day or night where insecticide applications should be applied that would result in higher levels of mortality?
- Additionally, is there a preferred time of day when crops should be scouted to increase the likelihood of accurate population identification?
- There were reports from experienced agronomists of FAW pupae being found inside the bells of capsicum and inside the stalks of maize. Does this mean that FAW do not have to move to the ground to complete their lifecycle?

- One agronomist reported that late instar FAW were found on emerging plants, so it was not possible that these had come from egg lays. This paddock did have previous maize stubble that had been incorporated by cultivation, so the assumption is that FAW had continued to survive and develop on buried trash.

Control thresholds – many agronomists sought latest information on economic / action thresholds for key crops but understood that it takes time for this information to be developed and tested. Some threshold development work is underway in maize and sorghum, being funded by QDAF / QAAFI (Miles, Quade, Volp, & Eyre, 2022). This seeks to understand:

- At what pre-flowering crop growth stage(s) is FAW defoliation yield limiting?
- What effect does crop yield potential have on crop loss due to pre-flowering defoliation?

The exceptions were in higher pressure regions/crops, or in vegetable crops with zero tolerance of any damage who regarded thresholds of little value 'as they have to spray anyway'.

Beneficials - The most consistently raised knowledge gap by the majority of respondents was to better understand the importance and role of beneficials. Key questions are:

- Which beneficials are important? Does this change with FAW instar size?
- What ratio of beneficial to FAW larvae is required to supress populations?
- If the beneficial species of importance is not one currently considered (for *Helicoverpa*) then do we understand the effect of our main insecticide options against this species?
- Is it possible to commercially raise species of importance? And, if so, what are recommended release rates and cost?

Understanding the potential effectiveness of beneficials will influence decisions to spray or not. While also understanding which species are most important, and in what context, will influence which insecticides may be applied.

Effectively no agronomists interviewed were using any form or quantitative assessment (e.g. predator/prey ratios) as they were still seeking the basic understanding of which beneficials to consider.

Additionally, several had tried releases of commercially raised *Trichogramma*. There was general interest in this concept, however almost everyone who had done this commented that it was very hard to understand if they had helped or not for FAW management, due to so many factors in play at any point in time. However, nobody reported clear and obvious benefit. So, with the cost associated with commercial releases, the majority mentioned that they have discontinued this practice. In order for this practice to become established then either hard data from research trials, or possibly testimonials for well-respected advocates, is likely to be required.

Early identification of FAW - Advisers seek reliable systems and tools to identify FAW. In several crops this is sought without the need for regular, intensive in-crop scouting.

Some crops (e.g. vegetables, summer pulses, cotton), are regularly scouted for other pests, so any FAW are likely to be detected by this process.

However, in several other key host crops for FAW such as maize and fodder crops, there is historically no history of extensive scouting. Sorghum crops generally are strategically checked for *Helicoverpa* and midge, but this occurs well after FAW have caused their damage. As these crops are 'relatively' low value, there is reluctance from growers to spend money on frequent insecticide applications for FAW. There is also pushback from advisers to dedicate the time required to intensively scout these crops, typically once or twice weekly from emergence until well into grain formation. Several advisers mentioned that if they were to fully recover their cost of scouting in these crops, it is likely to be the final straw that will see growers drop these crops entirely, in favour of less attractive host crops (noting that this has already occurred in several regions). In some regions, there was the suggestion that additional agronomists would need to be employed to undertake the level of scouting being recommended, yet many businesses cannot find agronomists to fill currently available positions.

As a result, some businesses are pushing the requirement for scouting back onto the grower – but realistically understand that this will result in lower quality and frequency of insect scouting data, especially as FAW egg rafts and the critical first and second instars are extremely difficult to identify. Some are resorting to making management decisions based on visual damage and not intensive scouting for eggs and instars, as this is much quicker for data collection. Although then requires confidence in the ability to be able to 'pull up' infestations.

Pheromone traps – Universally, agronomists were seeking additional research into pheromone traps for male FAW.

Almost everyone interviewed had hoped (and many are still hoping) that pheromone traps will be able to be calibrated to be able to be used as a tool to predict what is happening in the crop, without the need for intensive scouting. Several mentioned that they were hoping that the traps would detect a flight of months, which would then be followed by an egg lay and the agronomist could use this information to time an application such as Fawligen or Magnet + methomyl. Even if this objective can never be achieved, should users gain confidence that pheromone traps will at least pick up the 'arrival' of FAW, then traps are still likely to see significant use, as this would give confidence to busy advisers that they do not need to spend time scouting 'for no results' when FAW are not present, and only commence physical in-crop intensive scouting when the traps have alerted them to FAW presence.

Currently, several have tried pheromone traps and some advisers are continuing to monitor traps. However it was evident that several were 'losing interest' in the potential role that traps may be able to play (as a result of low correlation between moth capture in the trap and what is occurring in the crop), and several were likely to 'sit out' in the near-term and let someone else continue to work on refining the system, with a view to picking it up again when industry confidence in trap data improves.

The current un-met research goal is this lack of robust correlation between trap counts and in-field experience. It was reported by multiple advisers and entomologists that it was common to see substantial crop damage in fields, when nearby traps had not shown any moth activity.

Some have questioned if the frequency of traps, or frequency of clearing/counting, may improve correlation. Others have suggested that maybe more information is required on correct sighting of the traps.

Several, especially on the Darling Downs, reported that the lure used in the 2021/2022 traps appeared to be less effective than in previous years. A few, but not all, understood that the lure had been changed from previous years but most interviewed did not understand the significance of this and were just reporting that the 2021/2022 traps 'caught fewer months'.

Lure & kill strategies – There was high interest from several agronomists in the concept of lure and kill strategies, with most seeking to understand how to optimise the results. Most who are currently using, or had tried, this concept were utilising standard *Helicoverpa* tactics of Magnet + methomyl

+/- Optimol and using standard *Helicoverpa* application frequencies and spacing. However a few had experience with an alternate attractant, QM FAW, that they perceive attracts more moths.

Un-met research questions included:

- Are the label directions for frequency of application and strip spacing that are on the label for *Helicoverpa* the same to optimise performance against FAW? Some suggested that strip spacing needs to be reduced when targeting FAW, but this both increases cost and causes more damage to beneficials
- Especially in crops grown under overhead irrigation it was reported that it was difficult to use this technique, as frequently irrigation will wash off the bait. Several were interested in recommendations for perimeter baiting strategies to apply adjacent to, but outside of the irrigation area. The current Magnet label does provide advice for this use pattern
- Some had tried, or had heard about, QM FAW as an alternate attractant to Magnet. Those that had used QM FAW generally appeared convinced that it was better at attracting FAW, however no hard data was available to support this. Those who had used QM FAW were seeking it to have it commercially available / registered
- Is methomyl the best insecticide to be used?
    - Some raised concern that FAW moths may be carrying resistance to methomyl, so a different insecticide may improve results
    - Some also suggested that methomyl was causing ‘significant’ mortality to several beneficials when applied via this use pattern
    - Some suggested that maybe this lure and kill technique is a place to use spinetoram in broadacre crops, where it is considered too expensive to be used at all as a broadcast application. Additionally, spinetoram may be less damaging to some beneficials. The Magnet label supports use of spinetoram for *Helicoverpa*, but the FAW permit does not support spinetoram use.

Insecticide application – Several interviewed mentioned that they believe that it is critical to achieve very good coverage for control of FAW, however most were unaware of specific information on water rates and spray settings to be used to optimise kill rates – apart from ‘more is better’.

Some recent trial work from Hugh Brier (QDAF Kingaroy) has been reported in Section 10 of this report, however this is yet to be extended to industry.

In particular, additional work is required to further quantify optimal spray set up and water volumes for maximum performance. Also resources should be directed to understanding if there are significant differences between leaf uptake / retention between crop species, as a single trial suggested large differences in efficacy with Vantacor between maize and soybeans.

Several mentioned that coverage of large maize plants can be especially difficult. Up to a point, relatively high water rates can be used with high clearance ground rigs. However these are not always available. The alternative is generally aerial application, however water rates by air are practically capped at around 40 L/ha and, at these water rates, the aerial application cost alone is often around $40/ha. Some also reported that aerial application was not readily available in their location. A few respondents were interested in exploring application by drone as costs are ‘coming down’, however this was generally only where other application options were not easily accessible.

These challenges, along with a belief that efficacy can be improved, was resulting in several moving to application via chemigation for crops being grown under pivot irrigation (see below).

A common thread was that where insecticide performance was less than desired, it was common to explain this away as 'poor coverage', however with indoxacarb and chlorantraniliprole in particular, the results that were being achieved are likely to be reflective more of the product rate applied i.e. users are expecting much better performance from these products than what trial data would show to be their expected performance at the rates being applied for FAW. Likewise for Fawligen, many substandard results are put down to poor application, when mostly it may be FAW instar size and rate that are the most important factors to get correct.

Chemigation – Several agronomists, in particular those managing crops grown under pivots, are looking for best practice advice for insecticide application when applied via chemigation.

There is a belief by several that application to maize, sweet corn and sorghum can be enhanced by application via chemigation techniques, especially where this results in greater spray deposition into the whorl.

Additionally, AgBiTech (AgBiTech, 2021) looked at application of a dye (no insecticide) applied in maize to compare cob coverage from a conventional boom application at 100 L/ha and via a 10 mm chemigation event through the pivot. They suggested that, under this chemigation technique, it is likely that the silks are 'wicking' the water, and therefore potentially the insecticide, into the cob and this is likely to result in improved control.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Figure 17 Comparison of dye applied via a convention boom at 100 L/ha (top) and applied via a 10 mm 'water run' application through the pivot (bottom) and how this is likely to affect deposition in the cob.
https://www.youtube.com/watch?v=4CHzPjF8LDs

Currently the Fawligen label provides recommendations for application via chemigation, with this application method recommended by AgBiTech where available.

Some agronomists were also extending this application to other 'conventional' insecticides, in particular Vantacor, and believed that this was assisting results, although no quantitative data was presented.

Some agronomists were seeking to understand the quantification of results for key insecticides when applied via chemigation and desired product labels updated to add this application use pattern.

Technical opinion on sequential applications – As mentioned through this report, there is difference in opinion with regard to sequential application of the same insecticide (or same mode of action).

Some advocating for sequential applications (including most of the technical managers of key insecticides) suggest that it is preferable to apply two back-to-back applications on a reasonably tight schedule i.e. 7-14 days apart, as it is believed to result in the best efficacy. Primarily this is claimed to be due to the two applications controlling all hatchings over a 10-21 day period, which can really drive down populations, which then take longer to rebuild.

The position is made that two applications close together 'should' be targeted to the same generation of insects (at least where there are defined generations), and therefore the argument is that this should not be placing add any significant additional selection pressure on the overall population.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Some product labels now support this position via label directions, with more likely in the near future. For example, one technical manager suggested that they were considering two back-to-back applications on a 14-day schedule for a new product in development, followed by no further use of that MOA at all for the remainder of the crop.

Conversely, some entomologists suggest that the preferable position is that different modes of action should always be used for subsequent applications, and no second application of the same mode of action is applied until another generation has passed. It is noted that several entomologists are promoting the use of subsequent applications of the same chemistry, with the caveat that use is limited to the one generation. However, for a grower (or often an adviser) insect generations are somewhat more difficult to understand and implement than a more directive label statement.

It would be useful to have a research-led position paper on sequential applications and resistance selection, including modelling to test various scenarios. This is likely to be important in development of any IRMS that may arise from this investment.

Varietal sensitivity – Field experience indicates that there are significant differences in the ability of different maize and sweet corn varieties to cope with FAW. Mechanisms and relative positioning of different varieties needs research to better articulate the role of varieties and contributing mechanisms.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

14. Key geographic areas

The ultimate aim of this investment is to provide information to underpin the development of IRMS(s) that encompass best management of fall armyworm. It is unlikely that FAW would be limited in a geography to a single crop. Additionally, as it will mostly be the same insecticides that will be used across FAW infested crops, any IRMS targeted at FAW will inadvertently need to also consider insecticide use in multiple crops and which also target other problem noctuid moths within that region.

As mentioned in Section 4, ICAN developed a matrix of host crop x key geography to focus resources on understanding where to direct interview time. At the commencement of each sub-chapter below we have indicated the crop segments of key focus for that region. While interviews were not exclusively limited to commentary on the identified primary crops, this was used as a guide for the interviewer to ensure that appropriate information was collected across the full scope of regions and crops produced.

14.1. Queensland

14.1.1. Southeast Queensland (SEQ)

For the purpose of this study, the SEQ region primarily encompassed the horticulture dominated regions of the Lockyer Valley and Fassifern Valley. Some cropping / fodder, particularly for dairy, was also of relevance.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	SEQ	X	X							X

Expected FAW pressure

Several Lockyer Valley growers also have operations in Bowen (to spread diversity of production), so several first experienced FAW on their northern farms in 2020, particularly in sweet corn.

Since FAW has arrived in the Lockyer Valley it is present for several months of the year. Numbers dissipate over winter months and then rebuild again in spring. Peak pressure is later in summer. One agronomist reported that pressure can change with the prevailing climate, and in particular can be high following a ‘windy’ event.

In the Fassifern Valley, one agronomist mentioned that several growers appeared somewhat complacent until FAW arrived in February 2021. “One particular paddock of silage corn which would have expected to cut 50 t/ha was lucky to chop 20 t/ha and the whole district heard about it virtually overnight. Another corn-on-corn paddock had 75% loss before the crop reached V6 stage – at which time the plants were absolutely decimated and looked like it had been hit by hail. This has certainly changed many growers’ attitude to the need for a proactive approach to control.”

This agronomist suggested that they are still trying to understand population dynamics at different times of the year. “It’s difficult to know, as the seasons have been so different with 2020-21 being dry and 2021-22 being so wet. There is less FAW incidence this year, but maybe that’s due to a combination of wet weather, no late crops and a more proactive suppression strategy, rather than dissipation over winter.” “In the 2021-22 season, FAW didn’t start appearing until October, but we had also switched to shorter season varieties. Any grubs that are small in November seem to struggle because of the heat, but if they’re larger in November, populations can very quickly become out of control.”

Grower identification of FAW is still “a work in progress”, according to one of the agronomists interviewed. “Accurate identification tends to be difficult when the grubs are small - they’re often confused with other army worms. This can lead to growers hitting the panic button and wanting to spray, without considering the implications for the remainder of the crop. In sweet corn for example, this can see them running out of insecticide options as the season progresses.”

A different agronomist had similar views “There’s a level of grower proficiency in identification to a point. There appears to be a sub species that looks like a cross between a FAW and a northern armyworm which can make identification challenging. They behave like a FAW, but the damage is different. FAW are the only grubs that window out the leaves. Misidentification can lead to management issues, primarily around interpreting thresholds and timing of applications. If the grubs are FAW, growers need to act quickly to maximise control / efficacy.”

One agronomist mentioned that the “large majority” of growers take on board agronomist advice, however “There is a small percentage (probably less than 5%) who will do their own thing. These farmers often aren’t consistently the client of any one agronomist. There are also several growers in the Lockyer Valley who have a `spray to kill’ sentiment, which can be difficult to change.”

In the Lockyer there are both maize (for grain) and sweet corn crops, with agronomists reporting that pressure is much higher in sweet corn, and therefore management much more difficult. In sweet corn, there are also product quality and market access issues i.e. you can’t sell a cob that has been damaged by FAW. In maize for grain, there may be some yield impact, but undamaged kernels are still marketable. One agronomist added that, where both crops are grown together, the FAW appear to have a preference for sweet corn, with plant survival rates in maize also better than sweet corn.

For silage crops in the Fassifern Valley, damage is “less vegetative matter going into the pits”. While in grain crops, it is a combination of loss of yield plus holes in the cobs, potentially allowing for increased access for fungal diseases such as corn smut.

Management strategies

In an area such as the Lockyer Valley, where FAW pressure is high and preferred host crops are grown, the key to management is “diligent scouting so that FAW can be detected and controlled early.” One agronomist adding that “Insecticide rotation and timing of applications are critical. Also, early planting can assist in managing FAW pressure, but we do not know if this is a viable longer-term solution. Keeping natural beneficials (wasps) is also important.”

A Fassifern Valley agronomist shared similar views “Scout regularly. This needs to be a combined effort between consultants and growers. Go in early with control, at lower threshold numbers. Don’t wait until grubs are larger and more prevalent, because once they move into whorls, they are extremely hard to control. Timing is critical so ensure you are organised and ready to spray at short notice.”

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Maize (for grain or silage) – Typically the planting window for maize for grain was anytime from late September to first week of January in the Lockyer Valley. However with the introduction of FAW, this has seen almost all growers either move to a very early planting window or drop maize from their program completely.

In the Fassifern Valley, it was relatively common for growers to grow two back-to-back silage crops over summer for the dairy market. The first planting was from the first week in September, with harvest mid to later December, and then a second crop planted in first week of January. Since the arrival of FAW, this rotation has been forced to change to an early silage maize crop followed by either grain sorghum or soybeans.

FAW has "also required a major change in mindset for these growers, who are mainly dairy farmers. They are used to planting the crop and basically not looking at it for 100 days. Now, with the arrival of FAW, they are having to regularly scout and be prepared to spray several times a season to keep FAW pressure at bay. We are not aiming for FAW elimination, but simply to be proactive by applying control measures early to prevent pressure build-up as crop growth progresses."

Sweet corn – Planting commences in late August and traditionally runs to early January. Planting later in this window will often be shorter season varieties. Harvest runs from December to March (variety and planting date dependent).

Frequent insecticide rotation is currently the main management tool (see below).

Sorghum – In the Lockyer Valley, sorghum is not a major cash crop for most but is grown as a rotational break crop in some programs. The planting window is generally fairly tight (September to late October) with harvest in December to January "so as not to restrict options for the successive crop."

In the Fassifern Valley there are some forage sorghum crops along with some sorghum crops grown for grain on mixed farming enterprises. The window is not as tight as the Lockyer Valley, with planting from mid-November. This year, due to wet conditions and changing crop rotations, some crops were not planted until early January.

Summer pulses – Mung beans are grown as a quick cash crop, mostly to give the paddocks a break from continual vegetable production. Planting can be from late September to early December, with most harvested in January / February.

Some soybeans are grown in the Fassifern Valley, with planting traditionally November / December. However, with FAW changing the cropping rotations, some shorter season varieties are being planted early in the new year. Mostly only *Helicoverpa* requires treating, and "because it's a reasonably mild and wet area, applications of NPV or Bt last longer than would normally be expected."

Pumpkins – A range of different varieties are planted (Jap, Butternuts, Greys) with planting from the end of September to early January. Harvest will run from January to March.

Other crops – Winter crops that are grown in the Lockyer Valley include wombok, cabbages (red, green, savoy), lettuce, broccoli, barley, wheat and he odd paddock of chickpea. One agronomist indicated that they "Haven't seen FAW in any of these crops but did hear of one case in wombok in 2021, although that was just the odd grub and not in large numbers." "Insecticides (in particular Success and Proclaim) are used regularly in winter vegetables for control of diamond back moth and *Helicoverpa*" so this is likely to suppress any FAW populations in these crops.

Important insecticides

Historically, in the Lockyer Valley, there has been some applications of diazinon at VE to V2 growth stage of maize and sweet corn, targeted at cutworms and earwigs as the crop is emerging. This is not common, and one agronomist was particularly trying to avoid this application and only using it as a last resort if "absolutely necessary, as it can have an adverse effect on naturally-occurring beneficials such as *Cotesia* wasp, which has proven to be very effective in helping control FAW."

Maize – Since the arrival of FAW, early scouting has become essential to determine when the first applications are needed. One agronomist commented that FAW can be particularly damaging at V6, then again at tasselling and then at R3 when the kernels are fleshy, so these are the important growth stages to protect.

One agronomist suggested that a typical FAW management program may start with a Fawligen (200 mL/ha) + Vivus (100-150 mL/ha) applied around V6-V8 growth stage. "This works well (with efficacy rated at 4 to 5 out of 5) if targeted to very small larvae, although this may drop to a 1 or 2 out of 5 if larvae are too big at application. The preference is to keep Vantacor out of this application where possible, but sometimes it may be required. If pressure is high, a perimeter spray of Magnet + methomyl will also be applied.

This is then followed by one, or sometimes two, applications of Fawligen (200 mL/ha) + Vantacor (55 mL/ha) +/- a feeding attractant such as Optimal, applied around V10 to tasselling, depending on pressure.

Then another Fawligen + Vivus is applied "as late as possible". This may be around V14 or may be determined by the spray boom clearance available on the farm. One agronomist added "We haven't found aerial applications effective – can't achieve adequate coverage."

Silage crops in the Fassifern Valley have a generally similar approach, however as they are being cut earlier and used for stock feed then there is somewhat less pressure on protecting the cob, and most of the focus is on production of vegetative bulk.

Several appear to be managing FAW in silage crops with a 2-spray program. An early vegetative application at V2-V4 is common. This has been either methomyl or Vantacor, however the agronomist interviewed was intending to switch to Fawligen + Optimal applied via the pivot for this timing in 2022. However, as paddocks have been saturated all summer, then there has been no pivot irrigation applied this season.

Some growers initially tried Lorsban for FAW "But we didn't have great success and I won't use it again. It is also harsh on beneficials." Some growers also tried Dipel + Helicovix (NPV) without success "It might have controlled other grubs, but a successful FAW management program needs to be much more targeted."

Crops will then commonly get a Vantacor pre-tasselling. However some missed this application in 2022 due to extended periods of poor weather.

There are some high clearance self-propelled sprayers that can get over the crop up to about 6' in height. If application is needed past that stage, then aerial application is required, which can be challenging due to the lack of aircraft. Vantacor is the product of choice for aerial application.

Sweet corn – With sweet corn attracting more pressure and requiring greater level of cob protection, a greater intensity of spraying is the norm.

The first spray is typically Fawligen (200 mL/ha) + Vivus (100-150 mL/ha). If planting early, then this may not be required until the V6 to V8 growth stage. "However it has been applied as early as V2 where early pressure is high."

Following this initial application, it is common to commence a 7-day rotational program as soon as plants move past the vegetative only growth stage. However, if FAW pressure is very high, the more robust insecticide strategy may need to be bought forward. Insecticide programs once plants commence the reproductive stage will be a tight rotation of Coragen (100 mL/ha), Success Neo (400 mL/ha), Proclaim Opti (250 g/ha), Steward (400 mL/ha) and Bt's (Dipel or Delfin) (1.5-2 kg/ha), targeting both FAW and *Helicoverpa*. In the view of one agronomist, "Proclaim is the strongest on FAW (4 or 5 out of 5) while the other options are mostly a 3 out of 5. We are trying not to use Success too often in the spray rotation as it has been so heavily used for so long to control other chewing pests in the Valley, so it doesn't seem to be as effective as it once was. It's also expensive and has an adverse effect on the *Cotesia* wasps."

One agronomist mentioned that they have heard of others using methomyl and alpha-cypermethrin, but that was not part of their program.

Sorghum – *Helicoverpa* is the main concern during grain fill. Often crops are not sprayed at all. However, where *Helicoverpa* control is warranted, this will be Vivus Max at 100 mL/ha at early grain-set.

In the Lockyer Valley, occasionally some sorghum crops may be treated for FAW. Typically just prior to the commencement of grain set is where they are likely to be most evident, if at all. "As soon as the head is out, barely any FAW are present in sorghum."

Where FAW control occurs, it is typically to address overall FAW pressure across the farm / district and reduce the chance of FAW numbers building and pupating and then affecting the next crop in that paddock, rather than for specific concern around damage to the sorghum. Where FAW is treated, this will generally be Fawligen + Vantacor +/- Optimal (as per maize).

In the Fassifern Valley, it appears more common for a single application targeting FAW to be applied. This may be as a result of a significantly later planting window. Typically this will be Vantacor applied to protect early vegetative growth "as the FAW are attracted to plants when they're soft and sugary. Once the plants start to harden up, the FAW don't touch them. At the end of the day it's a balance between thresholds and cost – the strategy has to be economical."

Mung beans – Most crops require 1 or 2 applications for caterpillar pests. This could be either Vivus (150 mL/ha) if only for *Helicoverpa*, or Vantacor (40 mL/ha) if both *Helicoverpa* and pod borer is the target. Applications are only made when scouting pressure supports it. "We keep a close eye on activity around the flowering stage."

Starkle® (90 g/ha) may be occasionally required for mirids.

Chickpeas – Few chickpeas are grown in the Lockyer Valley. But where they are grown, they will typically require at least two applications in spring for *Helicoverpa*. This will either be Steward (300 mL/ha) or Vivus + alpha-cypermethrin. The 21-day withholding period for Steward "can be an issue."

Winter brassica vegetables e.g. wombok, cabbages – The key target is *Helicoverpa* and diamond back moth, but other sucking pests are treated as needed. The insecticide strategy of one agronomist was to start early in the crop with a 5-7 day rotation of sprayable Bt insecticides. This will be an alternating strategy of Dipel or Delfin, followed by Xentari for the next application. Most crops will potentially receive about 10 applications. Other insecticides are added as required, based on scouting. This could be any of Success Neo (400 mL/ha), Proclaim Opti (250-300 g/ha), Avatar Evo (170-250 g/ha) or Coragen (100 mL/ha) if *Helicoverpa* and/or diamond back moth pressure is high and the Bt requires assistance.

Transform® (240 g/L sulfoxaflor) @ 300 mL/ha may also be added to the programmed spray if control of Rutherglen bug or aphids is required.

Occasionally alpha-cypermethrin is added by some growers, trying to achieve knockdown of moths and other flying pests.

Most crops will get a very late application of alpha-cypermethrin just prior to harvest as a broad-spectrum knockdown for any insect pests in the head. Or sometimes this will be methomyl, especially if jassids or Rutherglen bug (RGB) are the target.

Biological agents

Preservation of natural beneficial populations was mentioned as important in crops such as maize, sweet corn, grain pulse crops and pumpkins. With an agronomist adding “It’s preferable to have the beneficials natural in the environment. It isn’t always cost effective to release beneficials. We are always mindful to keep chemistries as soft as possible, to minimise damage to beneficials.”

Trichogramma and *Cotesia* are considered important. One agronomist mentioned that they do not measure these quantitatively but rely on in-field experience when making spray decisions.

“*Cotesia* eggs lays are quite visible.” This agronomist reported that *Cotesia* can be quite effective on FAW. *Trichogramma* are known to be effective on *Helicoverpa*, although “we have seen *Trichogramma* released into a paddock of maize for FAW and it wasn’t successful.” “We try to use softer insecticide options whenever possible. Even Vantacor can have some impact on beneficials, but it’s not substantial.”

A different agronomist suggested that they are also not quantitatively counting beneficials, but “relying on our experience to guide decision making. Beneficials are an important part of the whole approach to FAW control. We need to keep our spray program as proactive and as soft as possible, so we aren’t forced into a situation where harsher chemistries are the only control option left.” This agronomist mentioned that “*Trichogramma* can be effective on ‘small’ FAW.” In maize, they are relying on natural populations and have not done commercial releases. “Hover flies and long-legged flies can be very effective on northern armyworm in maize. In soybeans, assassin bugs are a general predator of caterpillars.”

Cultural / non-chemical management tactics

One of the agronomists interviewed saw pheromone traps as a useful tool and were using these across the farms under management. However offered the following:

- Traps are useful for identifying FAW pressure build up
- They can also be deceiving – without enough traps it’s easy to misinterpret how dense the pressure actually is
- The placement and number of traps is very important
- Also, we are finding that the pheromone needs to be changed constantly to get good results.

A different agronomist was also using their own pheromone traps and reported that these “can give a good indication of incidence/density and movement.”

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Crop rotations have already changed as a result of FAW. In the Lockyer Valley, where corn is still grown, planting has been bought forward to a very tight window. With several growers dropping out maize for grain completely. In the Fassifern Valley, back-to-back silage maize has been dropped and replaced by maize-sorghum or maize-soybeans.

Each of the agronomists interviewed suggested that early season planting of sweet corn or maize means that the crop is subject to lower FAW pressure in the early stages, and the cobs are more advanced in November / December when the FAW pressure really ramps up. This does make FAW management much easier in grain corn.

However, in silage crops, this can "present challenges when everyone is trying to cut crops at the same time and there aren't enough contractors."

For sweet corn, the general strategy has been to spread harvest dates to match supermarket demand, so there is grower reluctance to concentrate planting / harvesting windows.

One agronomist mentioned that they intended to use a lot more Magnet this year and had stock on hand. But with the continual rainfall every week there was little point putting it out.

Due to the farming systems in both valleys, it is fairly common for growers to want to cultivate to remove corn trash soon after harvest. So, in the eyes of one agronomist, this was effectively de facto pupae busting.

Existing resistance, IRMS and impact of FAW on IRMS

As per all other regions surveyed, chlorantraniliprole was raised as the primary insecticide 'of concern' to all agronomists when it comes to the potential for resistance selection.

One agronomist said that they were "Not aware of any current resistance" in the Lockyer Valley however questioned if Success Neo was performing as well as it has done previously on chewing pests, although did not have any hard evidence to back this up. This same agronomist also mentioned "There were anecdotal reports about resistance to Group 28s in diamondback moth. But that was a few years ago, and before my time in the Lockyer Valley."

This agronomist also mentioned that there had been some rumours of off-label use of Vantacor in horticultural crops, "although I haven't seen this personally. There's been a temptation for some growers see Vantacor as a silver bullet for FAW, as it's triple the strength of Coragen which isn't working quite as well as it once was."

> *Authors note: In Australia, the registered rate for Coragen for vegetables and sweet corn is 100 mL/ha (20 gai/ha) and this is also the same rate for FAW on PER89259 when used in these same crops. The registered rate of Vantacor is 40 mL/ha (24 gai/ha) for Helicoverpa in broadacre crops (excluding cotton which is 55 or 90 mL/ha). However, there are FAW permits for use in maize at 24-33 gai/ha (PER91386) or for use in sorghum at 33 to 54 gai/ha (PER91616).*
>
> *In the USA, the registered rate for FAW control in maize is approximately 50-74 gai/ha, and 50 to 100 gai/ha in cotton. In discussions with Melina Miles (pers. com.), local trial data indicates that the 20 gai/ha Australian rate is too low for high level of control and is potentially exposing populations to sub-lethal applications. Geoff Cornwell (pers. com.) also indicated that FMC are looking to increase the application rate of chlorantraniliprole in several Australian market segments (specific details not given).*

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

With regard to future IRMS, one agronomist commented that "For an IRMS to be implemented by a large number of growers, strategies need to be a good fit with current practice. For example, the Lockyer Valley Growers Association have a resistance strategy for diamondback moth in place (see Section 5.1), which doesn't always fit with the crop windows. Timing of control comes down to environment and pest stages of growth and it can be difficult for an industry strategy to fit around those requirements. IRMS are a great initiative and furthering industry understanding about the science and issues behind the strategies is always worthwhile, but practically those strategies can sometimes be difficult to adhere to."

In the Fassifern Valley, one agronomist suggested that growers were mainly dairy farmers growing 'low input' forage or grain crops. Paddock area is small and generally insecticide use has been very low, hence resistance management is not front of mind. However most growers understand the need to rotate chemistry. Implementation of any IRMS in these mixed farming systems where cropping is not the main focus will be difficult "and almost impossible to regulate. A great deal of responsibility will end up lying with consultants. On-going education and awareness would be critical."

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- Seed treatments for FAW. (x2) "We have seen some successful trial work with soil drenches"
- Further research into commercially available 'fungus' sprays (e.g. out of South Africa).

14.1.2. Darling Downs (DD)

For the purpose of this study, the Darling Downs region covered a geographic area west of Toowoomba that is dedicated primarily to broadacre grains and cotton, although there are some small pockets of vegetable production.

To the south, west and north there are large areas of extensive beef and sheep grazing on native pastures where no insect scouting, or management will be occurring.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	DD	X		X			X	Mung	X	

Expected FAW pressure

On the inner Downs, one agronomist suggested that FAW was probably in corn crops from 2019/2020, although all indicated they were finding it by the 2020/2021 summer. A western Downs agronomist didn't become aware of FAW until early 2021.

Maize is clearly the main crop of concern for FAW for all agronomists. One commented "The two full years where FAW have been present have been vastly different in terms of seasonal conditions – one very dry and one very wet – so it's difficult to compare. In 2020/2021, some growers moved away from maize into other crops however there has been a slight return to corn this season. Experience with *Helicoverpa* has shown that visually crops can look terrible, but the yield reduction is comparatively minimal. We expect this may be similar with FAW. One of the biggest impacts has been to the $/hectare costs for growers across a season. Since FAW has arrived, we are now budgeting on two sprays per season using products that cost in the order of $50/ha per spray."

Regarding sorghum, "We have had random infestations in grain sorghum but haven't needed to apply insecticides. We have only seen vegetative damage in sorghum and the rapid crop growth rate of the crop has enabled the crop to compensate. In grain sorghum, have found that once the crop reaches the boot stage and sugar levels change, the FAW disappear. We haven't seen FAW on sorghum heads in this area to date."

FAW numbers appear to subside each winter. "Once temperatures drop below 26 degrees and single figure night temperatures occur, FAW disappear. This means pressure on the inner Downs is very high for about 3 months (December – February) and then numbers drop significantly. I have a client at Glen Innes (cold area) and FAW are only present for around a month. On the southern Downs, February tends to be the highest pressure, although this year it has run into March given the warm and humid weather. Application has been the biggest issue this year due to wet weather – where we have been forced to rely on aerial applications which isn't ideal."

Several agronomists saw the reduced pressure over winter meaning that is still possible to grow a maize crop planted early in spring, before pressure in November / December gets too high in later plantings. One agronomist mentioned that "often pressure will drop away after tasselling in maize, unless the early pressure was high."

It was suggested that identification of FAW when larvae are very small can be problematic (and this may have delayed first detections), however most are now comfortable in identifying larger instars.

In the opinion of one agronomist, FAW pressure across the paddock can be very variable, compared to *Helicoverpa* which is usually quite consistent across the paddock. "One week you might find FAW in a maize crop everywhere you enter, the next week they are gone, the week after you have lots of damage. This can make decision making for insecticide applications very difficult, along with evaluating how well an application actually performed."

One agronomist mentioned that they have been able to quantify yield losses in maize. With some plants actually 'killed' under high pressure in the early vegetative stage. In sorghum, they have not yet been able to correlate FAW damage with actual yield loss to date, however they are monitoring sorghum crops closely and are still trying to determine the correlation between vegetative leaf damage and yield.

Similar sentiment was reflected by a different agronomist "In corn, loss of leaf area is linked to loss of biomass and loss of yield. Also, direct damage to silks affects pollination. Cob damage can increase the incidence of diseases such as Diplodia and toxic fusarium (especially with wet weather late in crop growth), and cause quality downgrades in gritting varieties, along with direct losses from chewing of the cobs.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Expectation setting with growers is important. "Most growers take on all recommendations. Normally we discuss strategy with growers pre-season, particularly around FAW management and the need for use, rotation and application of products."

An agronomist from the western Downs noticed some FAW in an early grazing oat crop in 2021 around Chinchilla. While they were present and did some leaf damage, it was not enough to be concerned about. Typically grazing cereal crops on the western Downs are no longer checked for anything after post emergent broadleaf herbicides are applied.

Management strategies

Maize – Some maize has been traditionally grown on the inner Downs for grain or silage, with some silage maize grown under irrigation on the western Downs. The planting window commences any time from the mid-August (avoiding late frosts) and has historically run until mid-January, although November planting is generally avoided as crops planted then will be flowering in peak summer. One agronomist mentioned that historically December planting was preferred as "Our grain fill would be into our cooler months and easier on the crop, although grain dry down for harvest can be slow in some years with this late planting date."

Silage (typically for feedlots) will typically be cut in December - February, while grain crops will go through to harvest from March to August, depending on planting date.

An example was given whereby a grower commenced planting maize in August 2021 which continued through until end of January. The 'early' plantings had low FAW damage, with Fawligen applied (via the pivot) as more of a strategy to suppress population build up to protect the later plantings, rather than for direct damage to the early plantings. Despite this early Fawligen, Vantacor applications were still required at the 6-8 leaf stage of later plantings as they were suffering substantial leaf damage. This agronomist commented "Fawligen is effective but does not persist in the crop (like Vivus does on *Helicoverpa*) so it will control FAW which are present in the crop at application but won't control any further FAW that hatch after the application. For this reason, even under pivots, Vantacor and Affirm were applied in the later planted crops at silking and tasselling – as the pressure was just too high."

One agronomist commented that "maize is rapidly becoming the crop with the highest insecticide requirement, when it used to require the least."

Another also mentioned that "prior to the arrival of FAW, it was rare to ever need to spray maize for insect pests. However, their management strategy for FAW is still being determined." This agronomist is trying to go 'soft' with an integrated management strategy of Fawligen and Magnet (+ methomyl) to retain beneficials, potentially complemented by a vegetative stage application of Vantacor. For this agronomist, the timing of Fawligen and Magnet/methomyl applications is being driven by a calculator (DARABUG) to estimate when the next hatching will occur. DARABUG is accessible directly from the Cesar Australia website https://cesaraustralia.shinyapps.io/darabug2/, or via The Beatsheet website https://thebeatsheet.com.au/darabug/.

With the presence of FAW, all agronomists interviewed suggested growers are moving away from 'late' plantings and "going to early spring plants to 'beat' the FAW pressure and get crops through into grain fill before FAW build up." There was consensus around the idea of needing to restrict the planting window for maize (or at a minimum bring it forward as much as possible). "The planting window may have to be tightened, simply because it is costing too much to treat the late crops." Each agronomist mentioned the 'last 2 weeks of August' as probably the ideal planting window, but there was some variation in responses as to how long planting is 'acceptable' after August.

Typically, from the depth interviews conducted, the consensus of a 'preferred' program for maize would be some variation of: restricting planting to an early window; scouting from early vegetative stage; one or more planned Fawligen (or Fawligen + Vivus) applications in the early vegetative stages (applied via the pivot where possible); supplemented by Magnet + methomyl; ongoing monitoring, with selective insecticides being applied only where the above strategy is not keeping up with the pressure. Choice of insecticide may be determined by the IRMS restrictions applicable at the time. Vantacor is considered the product with the best efficacy / length of residual, with Affirm often mentioned as the next best alternative.

Another inner Downs agronomist, who is well known to prefer to avoid any insecticide use wherever possible, was asked to comment on their FAW strategy in maize. He indicated that they have been able to continue to grow high yielding maize crops (14-19 t/ha) without (or extremely rarely) spraying for FAW or *Helicoverpa* at all. In his opinion "FAW in maize is the classic IPM story. You will get heavy egg lays early in the vegetative stage, but a week or so later this will result in masses of beneficials, *Cotesia* in particular but also several we don't commonly see for other pests." He is finding that leaving the beneficials unsprayed can usually take care of the FAW pressure, although 'occasionally' they may apply an early Vantacor. "If people are having FAW problems in maize then it is self-induced due to spraying." His business is not recommending spraying anything at all at tasselling / cob set as "maize doesn't need it, and you can't get decent coverage anyway with the size and height of the canopy."

One likely key difference between this agronomist and others is that they manage their growers / fields on a 'landscape' basis (as opposed to an individual field). This means that the use of all insecticides is minimised throughout the whole farm (and preferably district) and in all crops, potentially resulting in much higher levels of beneficials across the landscape - as opposed to others who are really only thinking on a single paddock and single season scale. As examples, he specifically mentioned that "I don't get why people are using 'lure & kill' tactics such as Magnet plus a broad-spectrum insecticide such as methomyl or thiodicarb every few meters across the crop. There are way too many beneficials killed with this tactic." He also commented that, using his very soft approach, they mostly didn't spray cotton at all this past summer, even for sucking pests. Whereas most other agronomists were applying 2-3 (broadspectrum) sucking insecticides 'as the normal' for cotton.

Sorghum – Sorghum traditionally makes up a large percentage of the available cropping area on the Downs. Planting commences from mid-September, providing there is adequate soil moisture and soil temperature. Recent research has shown that late July and August sowings may hold benefits for earlier flowering, without too much additional risk with respect to establishment and early growth. This work may see increased uptake of earlier sowing dates in the future. Growers typically avoid planting in late October – November, as crops planted then will be flowering during mid-summer, with higher risk for poor pollination due to extreme heat.

There is also a summer sowing window which runs from mid-December to early January (late January on the hotter western Downs).

On the western Downs, some larger growers will seek to have a range of planting dates as a risk management strategy.

One agronomist suggested that FAW was not being seen in sorghum, while another mentioned that he had only found FAW in one grain crop, and numbers slowly dwindled and did not require treatment. However, lush young forage sorghum crops grown under irrigation (pivots) have appeared to be more attractive (some questioning if surrounding vegetation is drier and less attractive?) and have "been hit hard". Especially if they are planted adjacent to corn. To date, these have not been treated and the have just let the rapid crop growth outpace the vegetative damage. However, they "may reach the point where an early application of Fawligen via the pivot is considered."

Summer pulses – Some soybean is grown on the inner Downs only, while mung beans may be grown across the Downs. For both summer pulses, planting typically occurs in December, but may extend until mid to late January. Preferred planting date for soybean depends on the variety being grown.

Mung beans is a much shorter crop, with harvest in March to April, while soybeans typically have about a month longer growing period. The 'short' growing period for mung beans can make them particularly attractive to growers in years where the soil moisture profile is only 'part-full', or the planting rainfall did not arrive in time to plant other summer crops such as cotton, sorghum or soybeans.

One agronomist mentioned that he has not seen FAW in mung beans. However, standard practice for them for *Helicoverpa* and sucking bugs is generally a Skope® (emamectin + acetamiprid) followed by Vantacor + SP mix 10-14 days later, so they believed that this is likely to suppress any FAW at that critical growth stage.

Mungbean crops are typically sprayed once or twice for control of *Helicoverpa spp*. often in combination with mirids and a range of sucking bugs. Soybeans may receive an additional application (i.e. a total of 2 or 3 sprays), due to the longer growing period.

Chickpea – Typically chickpea will not typically be planted on the Downs until June – July, when suitable soil moisture is available and frost at flowering is likely to be avoided. Harvest generally occurs from late October to prior to Christmas. Later planted crops are more likely to require additional management for *Helicoverpa* in spring, as conditions start to warm.

Cotton – Planting of dryland crops commences mid-September where there is adequate soil moisture but will continue until around late-November if waiting for rainfall. The irrigated planting window is usually much tighter – mostly mid-October to mid-November. Most cotton is Bollgard® 3 and there were no reports of FAW occurrence in this crop. It is extremely rare for applications of insecticides targeting chewing pests to be applied in Bt transgenic cotton.

Important insecticides

Maize – Hybrid seed normally comes pre-treated with either Gaucho® or Cruiser® for control of soil pests, although one agronomist mentioned that they also apply Talstar® (bifenthrin) as a water injection at planting. One agronomist also commented that these neonicotinoid seed treatments also provide some "establishment vigour", which can be beneficial with cold starts.

With the relatively recent arrival of FAW, agronomists interviewed appear to be still 'working out' the best management programs.

One agronomist mentioned that maize crops were treated 'several times' with Fawligen (100 mL/ha) in the vegetative stage. The number of applications likely to be required, and the best timing to apply these is still being determined. The current thinking is that Fawligen needs to be applied "as close as possible to egg hatch." Coverage is important, ideally getting the product deep down into the whorls. Some is being applied via overhead irrigation (pivots).

This early season Fawligen was often complemented by 2 to 3 strip applications of Magnet + methomyl. The first application at early vegetative stage with another at silking. Some crops had a third application. Most crops this season also had a Vantacor, typically around V6 to V10 growth stage.

A second agronomist had a similar strategy. Magnet + methomyl was the main tactic in the early vegetative stage, treating 1 row every 72m. Typically 2 applications are made. At tasselling, most crops will receive a Fawligen (150 mL/ha applied by the pivot in an approximately 10 mm/ha irrigation event). Vivus (75 mL/ha) may be added if *Helicoverpa* are also present. Early crops will generally only require one Fawligen application, while later plantings will get a second application at silking, and possibly a third application. If pressure is high, these applications may be replaced by Affirm (600 mL/ha) or Vantacor (40 mL/ha).

A different agronomist had used some Vivus targeted against FAW at the tasselling growth stage in silage maize and suggested that it "helps reduce the pressure". However, they are moving towards a more pre-programmed approach consisting of a Fawligen at V2 to V3 and then another application two weeks later, applied through the pivot. The crop would then be monitored through to tasselling and Vantacor (55 mL/ha) + Vivus (100 mL/ha) applied as required. There is a desire to stay within the grains IRMS, which allows chlorantraniliprole to be applied up until mid-November "which is manageable, but difficult" as late November / December is the period where FAW numbers really start to ramp up. If Vantacor cannot be applied, and the earlier Fawligen is not holding numbers (i.e. larvae are at medium) then Affirm (900 mL/ha) would be substituted for Vantacor in the mix.

A fourth agronomist suggested that their program typically involved 1 or 2 applications of either emamectin (600 – 900 mL/ha) or Vantacor (55 mL/ha), based on scouting pressure. The choice of product is determined by the windows in the current grains IRMS. However, the preference is to use emamectin as the first application where possible. This agronomist rated both products as a 4 out of 5 for FAW, suggesting 60-90% control is being achieved. Some Fawligen has been used in maize (100-150 mL/ha) although this is "Mainly used through fertigation systems as standard coverage through a boom spray is not adequate and requires higher levels of spray coverage for optimum control."

Sorghum – In the view of agronomists interviewed, foliar insect control in sorghum is still focused on historical pests (and not FAW).

For *Helicoverpa*, three inner-Downs agronomists were running a similar program where most crops will get an application of Vivus Max (100 - 150 mL/ha +/- a feeding attractant such as Optimal) at early head initiation and may not get any additional insecticides. Methomyl (1.5 – 2 L/ha of a 225 g/L product) is a backup if there are larger *Helicoverpa* present and a quick knockdown is required, with one suggesting less than 10% of crops would receive a mid-season methomyl. Occasionally some crops (particularly for later planting) will get a mid- or late-season pyrethroid for sorghum midge.

A western Downs agronomist was spraying more frequently for *Helicoverpa* and mentioned that most crops would get a Vivus (80-150 mL/ha) at mid flowering, and this may sometimes have methomyl (2 L/ha) added if grubs are larger. This may require a follow up treatment (50% of crops) of alpha cypermethrin (300 mL/ha) + Vivus for both *Helicoverpa* and sorghum midge. Occasionally a third clean-up application may also be needed.

From time to time in grain sorghum, midge may need controlling. As most varieties now contain midge resistance, spraying with synthetic pyrethroids for control of this pest is becoming less frequent and is rarely required on winter/spring sown crops. However, some crops that are sown in the summer planting window are still sprayed for midge control notwithstanding high varietal tolerance levels for this pest. Midge numbers tend to breed up, particularly on later sown crops and on related vegetation species such as sorghum alum and Johnson grass. SPs are used when targeting midge.

Occasionally a SP may be required for Rutherglen bug control, either at establishment or during grain fill.

Mung beans – FAW is not currently affecting summer pulses to a significant level where specific management is required.

Three agronomists indicated mirids are often a problem at early budding to flowering, and it is typical to apply dimethoate (250 mL/ha + salt) when thresholds are breached. One agronomist mentioned that they often apply 2 applications 7-days apart. A different agronomist mentioned that this is often applied with a fungicide application on the inner Downs.

Once podding commences, crops will mostly receive an application for *Helicoverpa*, where thresholds are exceeded. Most crops will probably receive one application, but this is not always needed. Most agronomists suggested that this would be Vantacor, although one agronomist had a preference for emamectin where possible, however would switch to Vantacor for some jobs where there had been a high frequency of emamectin applied in the preceding weeks.

Occasionally (less than 10% of applications was mentioned) alpha-cypermethrin may be added to the Vantacor application should GVB also require control.

Two agronomists mentioned that Skope (300-320 mL/ha) may be used where *Helicoverpa* and sucking bugs were present at early budding to podding, with this often followed by a Vantacor in about 10-14 days, or Vantacor + alpha-cypermethrin or Vantacor + dimethoate should sucking bugs also require control at that timing.

A small number of crops may get a late methomyl ‘clean up’ for both *Helicoverpa* and mirids, but this is rarely required.

Soybeans – Loopers can be a problem early season in some years and were particularly high in 2021/22. Many years control is not required, but this season applications of Dipel (1-2 L/ha depending on numbers) or indoxacarb (200-400 mL/ha) were required on some crops.

From the late vegetative stage, one agronomist mentioned that a single late-vegetative stage application of a high rate of pyrethroid + salt targeting loopers and GVB is often all that is required in soybeans. However, this year (2022) looper pressure has been very high and a second application at early podding has been required on several crops. Very occasionally (less than 10% of paddocks) a late-season Vantacor application may be needed for *Helicoverpa*.

A different agronomist mentioned that their mid-season program would depend on the pest complex and time of year (i.e. what was recommended under the grains IRMS). This could be either emamectin alone (150-300 mL/ha) or Vantacor (40 mL/ha) when only *Helicoverpa* are requiring treating (choice depends on the IRMS window at the time). Or Skope (320 mL/ha) if the complex is *Helicoverpa*, GVB & RBSB.

For late season sucking bug control (GVB, RBSB), they have been getting effective results with Shield (125 – 250 mL/ha) + salt when covered under a permit, or Skope (as above) providing the application timing still allows Skope to be used (as it has a 6-week WHP). If a further late season sucking bug spray is needed within these WHPs then Decis® (500 mL/ha) + salt will be used.

Chickpea – Most chickpea crops are sprayed at least once targeting *Helicoverpa spp.* (sometimes twice) from pod set to completion of grain fill. Few (if any) other insecticide sprays are needed in chickpeas.

Several different strategies were reported. One inner Downs agronomist suggested that most crops will get a Vantacor at early pod set for *Helicoverpa*. Should a second application be required then typically this will be Affirm.

A different agronomist was preferring Affirm as the first choice for *Helicoverpa*, however would switch applications to Vantacor in higher pressure situations when more residual control is required.

On the western Downs, where soil moisture is adequate and a longer pod fill is expected, often alpha-cypermethrin (300-400 mL/ha) would be applied in late August (where pressure is lower and most likely to be *H. punctigera*), or otherwise Steward (300 mL/ha) is the alternative at this timing. This is then followed by a Vantacor application during pod fill. In years where it is drier, and the crop is expected to finish early, a single Vantacor at early budding may be all that is applied.

Cotton – one agronomist mentioned that they were managing both conventional and Bollgard® 3 cotton. In Bollgard 3, insect control was limited to sucking pests. For mirids, the strategy is to avoid early applications "as the plant can compensate well for early square loss". As young bolls are being set, it is common to require a dimethoate application, with the low rate of 250 mL/ha + salt being used to reduce impact on beneficials. If GVB is present, Starkle (dinotefuran) at the half rate of 90g/ha + salt will be applied.

There is a small area of conventional cotton, primarily grown as a refuge strategy for Bollgard. This agronomist indicated Affirm (1 or 2 applications) at 600 mL/ha is typically the early product of choice for *Helicoverpa* control and mirid suppression. However, if pressure is too high for Affirm then Steward (650 mL/ha) will be used instead. Preference is to hold Steward for later in the crop, as it is harder on *Trichogramma*. 1 to 2 applications of Vantacor (55 mL/ha) will be applied late flowering to boll fill stage, targeting *Helicoverpa*.

Biological agents

One agronomist commented that they are "not really counting native beneficials as it is difficult to do." Their thinking is that if pest pressure is low, and beneficials are there, they can help with control. However if pressure is high, beneficial populations are unlikely to be sizeable enough to make an impact. "We're still learning what are the right pest/prey ratios with FAW." Specifically, *Cotesia* and *Trichogramma* appear to be helping with FAW suppression.

This view was supported by two other agronomists "Previous experience (prior to Bt transgenic cotton) was that if pests are taken out too early, it decimates the food source for beneficials. So, depending on numbers, I try and delay the first spray for FAW by four or five days to encourage as many beneficials as possible. Maize hosts such a variety of beneficials that we need to encourage and utilise them wherever possible. Native *Cotesia* populations were evident in 2021-2022 season and have been effective, although not to the degree where they negate the need for insecticide control. We currently record beneficials as present / absent but would like to start recording quantitative numbers as well."

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

And from a different agronomist "Native wasps such as *Trichogramma pretiosum* and *Cotesia* are considered but it is very difficult to measure quantitively. Parasitism levels are hard to determine. However we work on the theory that any parasitism is good because once they're starting, they're going to build up in the crop. And any chemical application is going to affect them, hence our strategy to reduce chemical use as much as possible."

Another agronomist suggested that, in grains, beneficials are considered as part of the management strategy for some crops (excluding chickpea) with ladybeetles, wasps, damsel bug and lacewings being observed, but not measured. "We haven't considered releases of *Trichogramma* wasps for FAW to date, as there's no hard evidence to suggest that they are especially effective, no recommended pest/prey ratios and they are costly to release." "We still see chemistries as a more effective and cost-effective option at this stage. We use soft options where appropriate. That said, we're also mindful of not being caught out using a soft option and/or low product rate to conserve beneficials, and then being cornered into needing applications of harsher chemistries. Sucking pests are a major issue for some of our crops, not just in grain loss but also grain quality. In mung beans for example, the premiums for higher quality are significant, so whatever pest management approach is taken needs to be rapid and effective. Being such a short season crop, it's difficult for beneficials to achieve an adequate level of control. Obviously if we were managing cotton, it is a different story, and we are particularly focussed on beneficials."

One agronomist suggested that "Occasionally we will release *Trichogramma* wasps, but it's difficult to know if they were successful on FAW populations or not." A second agronomist reflected the same sentiment, while a third was going to try some releases this past summer but didn't due to the extremely wet weather.

Cultural / non-chemical management tactics

All agronomists showed interest in the concept of pheromone traps to assist with management of FAW, but generally were experiencing disappointing results.

One agronomist mentioned that they are not currently using pheromone traps as they are questioning the accuracy of the existing technology being used. But saw potential "if the pheromone was proven effective."

A different agronomist had similar views whereby he had placed traps between two pivots planted to corn last summer (2021/2022) and didn't catch any FAW moths, despite both crops being hit "Which is disappointing, as we were hoping to use the moth flight as a kick-off date for Fawligen. The pheromone used in those traps obviously wasn't effective, but if it was, we would definitely use it as part of a management program."

A third agronomist mentioned "Traps proved useful last year (2020/2021) but the new pheromone doesn't seem to work as well as the old one. Previously we would still get bycatch but would trap FAW as well. Whereas with the new one, we don't seem to be catching many moths unless pressure is extremely high. When it worked well, it was a useful tool to indicate that we needed to scout harder to ascertain grub numbers."

In the opinion of a fourth agronomist "Pheromone traps are a good way to double check what's happening in the paddock, particularly if you are only scouting around 10% of it. We have found that when there starts to be activity in the trap, they are already active in the crop. We weren't catching big numbers of moths in the traps this season but from my understanding, that's fairly typical. This season was a little bit different – we put traps out in August 2021 and had very little moth activity until October/November when the weather began to warm up. At that stage, although we had started to trap moths, we still weren't seeing activity in the early planted crops. Then quickly that turned with populations very evident in crops and they built up rapidly."

Non-chemical strategies that are being used on the inner Downs include earlier planting dates for maize and sorghum (where it fits with other management criteria); increased scouting, particularly early in the crop; maintaining existing beneficial species and continuing to investigate the potential for releasing additional species; and the use of products like Fawligen and Magnet to minimise pressure and avoid a build up later in the season.

In the opinion of one agronomist "Monitoring / scouting is critical from very early in the crop. We are now scouting corn like we would scout soybeans and mung beans. Basically, twice a week from planting. Control needs to be implemented early if numbers are getting high through the vegetative stage. What you don't want is unidentified larvae early in the crop, because from that point it's a case of chasing your tail to try and manage populations that are entrenched in whorls."

Existing resistance, IRMS and impact of FAW on IRMS

One agronomist mentioned "Pyrethroid resistance to *Helicoverpa* has been well document for many years."

A different agronomist working mainly on the western downs, suggest that it "can sometimes lean the other way" i.e. growers 'expect' to see resistance to products like methomyl based on industry testing, but we are "yet to see a methomyl failure in chickpeas." "In some years, it's also surprising how well an SP will work, but this is very dependent on population dynamics. Historically, we worked on predicted emergence date for *H. armigera* in the area which would determine our last SP application date. This worked reasonably well, particularly in conjunction with trapping results to help determine what percentage of the population was *H. armigera*. More recently, the approach we've taken in chickpea is to apply an SP given its low cost, on the understanding that if it doesn't achieve the desired outcome, retreatment can be done quickly. Most growers are happy to take that risk, and some years it works better than expected. It's a strategy that we're comfortable with for chickpea given that we don't see many beneficial insects in chickpea crops anyway. It's a completely different case to mung beans and cotton where IPM programs are more valuable."

One inner downs agronomist suggested that alpha-cypermethrin performance on brown shield bug (BSB) this year (2022) "doesn't appear to be as effective as we would like" and was questioning resistance as a possible reason. However as BSB is only a secondary pest of summer pulses, no testing has been undertaken.

With regard to indoxacarb, one agronomist suggested "Occasionally when numbers are high, Steward hasn't been as effective as expected but that's unlikely to be resistance, more likely attributable to other factors such as application." While a different agronomist mentioned "We haven't used Steward for *Helicoverpa* for approximately four years, following a couple of ineffective applications in high pressure situations in mung beans. We have opted to switch chemistry and save Steward for loopers and instances of very low *Helicoverpa* pressure.

Another agronomist raised GVB as some concern. "We had incredibly high GVB pressure in the 2021/2022 season. Products like Skope would traditionally be used as a one-off knockdown and residual control, but the pressure rebuilt very quickly inside what would normally be a buffer of 10-days or so. Discussions with other agronomists and ADAMA suggested there were similar experiences across the area during the season, and it was extremely unlikely to be caused by resistance."

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

All agronomists mentioned concerns over Group 28 use (*Helicoverpa* in general, due to the broad range of crops used, with FAW adding further to the use patterns), with one agronomist stating, "We really don't have any other options in pulse crops, so it's critical these products are protected." While another added "There are limited effective insecticide options for pests like *Helicoverpa* in pulse crops, which makes it difficult to stick to recommended windows of use in the IRMS."

Two agronomists also included indoxacarb and emamectin in their list of insecticides of concern.

"We are very concerned about overuse of key modes of action, particularly given the spread of crops and industries in the area – grain and horticulture. Overuse, and not adhering to recommended application windows, were the primary causes of resistance issues with the old pyrethroid chemistry and we don't want that situation repeated."

All agronomists interviewed from the Darling Downs were aware of the both the cotton IRMS and the grains IRMS. Where cotton is grown, there appears to be very high compliance (*ICAN note: this higher level of 'compliance' is possibly an artifact of insect control in cotton now being somewhat 'easy' with the number of solutions now available, and insecticide management now only really constrained to management of sucking pests.)*

In grains, there was a more mixed response to the IRMS. One agronomist was fully committed to the grains IMS said "It's critical to adhere wherever possible to recommended windows of use, to preserve chemistries. It's never going to work for everyone when they 'want' to use certain products, but a longer-term perspective is imperative if chemistries are to remain effective. The arrival of FAW has certainly posed challenges for some to adhere to the recommended windows, particularly in the November to January period when pressure can be high – this is where most breaches occur."

Two others were 'trying hard' to align decisions with the intent of the IRMS, while a fourth didn't really see it as workable.

One agronomist commented that "I always try to discuss the strategies and reasoning behind the IRMS with grower clients face-to-face, rather than simply sending a blanket email. Involving them in the decision-making helps generate a much greater understanding and adoption of the approach."

An agronomist from the inner Downs saw the strategy as an important initiative which they are fully implementing, albeit acknowledging that it is a 'voluntary' strategy. The following insights were offered:

- The existing grains IRMS should be regularly published and promoted to help extend awareness and uptake.

Should the strategy be upgraded to also encompass FAW then:

- Resellers could potentially enact product supply restrictions to certain modes of action at certain times of year, but that would simply encourage grower stockpiling
- In terms of tightening the planting window for a crop like corn, it's doubtful that would be formally needed – as FAW seems to be tightening it naturally
- Sustainability of the insecticide options would be an important factor. Basically, we would be mad not to use a plan that was developed by entomologists with input from industry (such as those working in R&D with the chemical supply companies like Bayer, Corteva, Syngenta etc) as it's critical to protect our chemistries. There are very few options available, and the development of new chemistries is so expensive for Australia that we have no choice but to rely on existing products. Many of us are old enough to remember when resistance was so

> bad in the cotton industry that some growers were spraying every three to four days. It was unsustainable and most of us didn't know what was next. It was just fortunate that Ingard® cotton came along.

An agronomist from the western Downs suggested that staying within the current grains IRMS (which has been developed for *Helicoverpa*) was "difficult, but not impossible" when trying to manage FAW in maize. The current grains IRMS has the current chlorantraniliprole 'spring' application window cutting off in mid-November (and subsequently pushing users towards indoxacarb). This is the timing where FAW starts to build quickly in maize, and indoxacarb is one of the weaker insecticides against FAW. However, there was also acknowledgment that maize is a very small proportion of the cropping area. Should FAW be written into the strategy then "We would certainly use the strategy, as long as the application windows line up in the key crops. That's difficult in summer crops given the wide planting windows, but hopefully industry will reach a point where late corn simply isn't grown in this area. There are always other crop options for a late plant. To be effective, an IRMS probably needs to set a planting window for corn, similar to what's done in cotton."

However a different agronomist had an alternative view. While fully supportive of the principle of IRMS (and fully adopting in cotton, and supportive of the principle of a QDAF led IRMS for FAW), this agronomist suggested that there was currently not enough viable *Helicoverpa* insecticides to allow the use of product windows in spring / early summer for *Helicoverpa* when there are still chickpeas being sprayed, plus a range of summer crops and a wide range of planting dates. This agronomist mentioned that they are "not really utilising" the current grains IRMS due to these issues, and this becomes even more complex should FAW be also included in the IRMS.

When it comes to implementing a window based IRMS, this agronomist added that "product use can be controlled to some extent at a reseller level, by restricting what can be sold at a particular time. Although there will still be loopholes as it's impossible to control what stocks are sitting in farm sheds. Education of resellers, consultants and growers is critical, particularly in areas where grain isn't the prominent crop such as horticulture, cane and cotton valleys. There is a responsibility on the chemical companies to help address this knowledge gap and preserve the chemistries."

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- We still need to keep fine tuning our management practices for FAW, using experiences from our company network right across Queensland, with also input from QDAF, private consultants, commercial agronomists and growers
- Improved understanding of the best way to maximise Fawligen. "It has only been successful for us when applied through pivots. We tried it in other paddocks on neonates that had just hatched, and control was less than 60%. Very keen to use this style of product in the early stages of crop growth, just need to improve the way it's applied"
- Better pheromone traps (*ICAN note: the lack of performance of the attractant in the 2021/22 traps was mentioned by all*)
- Ideally there would be some advances in thresholds to assist with monitoring and management decisions
- There could be a role for surveillance technologies like drones and artificial intelligence being used to assess crop damage on a broader paddock scale

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

- Further research on beneficials effective against FAW, e.g. *Trichogramma* wasps and *Cotesia*, to establish whether releases of these beneficials (or other beneficials) can reduce FAW populations and what pest/prey ratios to use (X 2)
- Research into how to build beneficial numbers up naturally earlier in the season
- Further investigation into the naturally occurring fungus
- Require a 'late' option for control of GVB in mung beans that has export MRLs and is 'softer' than pyrethroids.

14.1.3. Wide Bay Burnett (WBB)

For the purpose of this study, the WBB region covered the geographic region from Kingaroy in the south to Bundaberg in the north. Within this region, the South Burnett is an important consideration for selected grain crops (including maize and summer pulses) while the Bundaberg region contains significant areas of sugarcane, vegetables (in particular capsicum and tomatoes) and orchard crops.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	WBB	X			X			Soy / Peanut		X

Expected FAW pressure

FAW has been present for the full past two summers and is thought to have arrived in the Burnett sometime during the summer of 2019/2020.

Agronomists report that numbers drop in winter, start building in Spring and peak in December / January, although one agronomist mentioned that you can still normally find a few in winter. On the coast at Bundaberg, FAW can be found all year, however population numbers increase over summer months.

Maize is the primary crop of concern. Historically, maize crops in the South Burnett have not been regularly scouted, and only occasionally sprayed for *Helicoverpa*. With the introduction of FAW, maize crops are now requiring weekly monitoring from emergence to after silking. While monitoring is ongoing, there are 3 critical timings:

- Protection of the main photosynthetic leaves (approximately V6-V10, depending on variety)
- Sometimes FAW will hit the tassels, which can reduce pollination
- Protection of the silks & developing cobs.

South Burnett growers are not currently paying for this service level of scouting, and agronomists interviewed were interested in understanding what is happening in other areas *(ICAN note: there has been a similar trend mentioned in several interviews, in that agronomists are struggling to work out how fund the time requirement for high levels of monitoring in relatively 'low' value crops such as maize)*.

Interestingly, one agronomist reported that they had a maize crop this past summer (at Coulston Lakes) that was 'forgotten' due to a communication issue between the grower and agronomist and hence was not monitored or sprayed at all (compared to the district average of 2-3 applications). "While it was very 'ugly', it still yielded 'OK'. Which gave our agronomy team some comfort that grain yield is still possible even when control is inadequate. Although, to maximise yield, we are still looking to protect the last two big photosynthetic leaves before cob formation."

Agronomists all reported that several growers stopped growing maize last season, or substantially reduced area. "Planting in the historical November/December window is likely to now require 3 insecticide applications for FAW. So growers need to budget on an additional $120/ha, plus application costs. This has resulted in a significant switch to sorghum or summer pulses where growers haven't been able to sow during the early maize planting window." A different agronomist added "Maize price (grain) and FAW pressure has already seen a large swing away from maize. Maize area is unlikely to come back while the current status holds."

One experienced South Burnett agronomist gave a number of personal observations with regard to FAW, which he stated 'needs validating':

- FAW appear to favour 'young' maize crops and will prefer these if they have a choice over a more 'mature' crop
- FAW numbers appear to drop away substantially in February (despite still being warm). They cannot explain this drop off "apart from there are no longer any young maize crops by this time." (A different agronomist from a different geographic location also commented that they were at a loss to explain why pressure drops off suddenly in February when there is "adequate moisture, host crops and temperature is not extreme. This year was wet in February, while last year was very dry, but the same drop was noticed." This agronomist added that pressure then picks up a bit again in late summer)
- They are finding very little FAW within a few meters of the paddock boundary if there is adjacent vegetation / trees on the paddock boundary. Reason for this is unknown – speculation could be that there are more beneficials being harboured in the native vegetation
- Popcorn varieties appear to get hit very hard
- Agronomists suspect there has been a decrease in *Helicoverpa* pressure over the last 2 summers since the arrival of FAW. While this may be coincidence, they openly questioned if they are seeing 'species displacement', or is it possible that FAW is attracting more predators, which is also impacting *Helicoverpa* numbers? FAW are known to cannibalise each other at early growth stages, so could FAW also be eating *Helicoverpa*? As you will regularly find the two species 'fighting' on beat sheets"
- FAW appear to 'love' white French millet and the *Echinochloa* millets (Japanese, Shirohie). But red panicum millet appears less attractive
- FAW appears to be extremely damaging to Johnson grass (weed) populations.

The coastal Bundaberg region is mixed cropping, consisting of sugarcane and tree crops (avocadoes, macadamia nuts and some mangoes) and significant areas of small crops (tomatoes, melons, capsicum in particular, but also some sweet corn, snow peas and several other small crops). The majority of vegetable production is in spring and autumn – to supply markets with produce in between the Lockyer Valley and Victoria (summer production) and the Bowen/Burdekin (winter production).

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FAW are reported to be present all year, with numbers declining slightly and life cycles extending over the cooler months. There are host crops available most of the year. The main crops being affected by FAW include capsicum, snow peas and sweet corn.

Similar to the South Burnett, one Bundaberg agronomist suggested that *Helicoverpa* pressure "has dropped off considerably since the arrival of FAW, but that is probably not surprising due to the much-increased frequency of insecticide application for FAW."

This same agronomist also noted that in 2022, "GVB pressure is massive i.e. 12/m in tomatoes which they have needed to spray with a SP, and then the same pressure is back again 3 days later. The GVB pressure is so high that they are also stinging sweet corn cobs." The agronomist was questioning if this is just coincidence, or as a result in a large reduction in broad-spectrum OP/SP/methomyl applications across the region due to FAW management?

Management strategies

Maize – Maize, grown both for grain and silage, has typically been an important rotational crop for the Burnett, however the arrival of FAW has had significant impact. Many crops are rain grown (especially in recent seasons where irrigation allocations have not been available due to the extended dry conditions).

Prior to the arrival of FAW, "Historically, only about 1% of maize crops would get an insecticide application for *Helicoverpa*."

Since the arrival of FAW, the key strategy being implemented in the South Burnett to manage FAW in maize appears to be to plant in early spring (as soon as it warm enough i.e. September / October) with good moisture & nutrition. In this scenario, the crop can largely 'outgrow' relatively light FAW populations that are likely at this time. "FAW does not appear to over-winter well in the South Burnett. We can often get away with only 1 or 2 insecticide application for early sown crops. However, to plant early we need late winter / spring rainfall – which often does not happen" (most maize is rain grown in the South Burnett).

"Crops planted later in November / December 'get smashed' during the early vegetative stage and require additional spraying and will still carry more damage. Additionally, 'late' planted crops (e.g. December rain and January planting) regularly have limited soil moisture during vegetative stages without follow up rainfall. As they are moisture limited, they are also likely to be low yielding – and hence growers are reluctant to spray/spend money on them. So the combination of moisture stress, early damage from FAW and minimal spraying is likely to result in a devastating outcome. We have seen 8-10" moisture-stressed maize plants completely killed by FAW, with paddocks needing to be replanted."

A different agronomist indicated that for them, two Vantacor application in maize was the starting point, with most crops then getting a further 1 or 2 Affirm applications "and the crop will still carry damage, which may be too much for a grain crop, but might be acceptable for silage. However, this adds a lot of additional growing cost for growers that have never needed to spray maize previously. In 2020/2021, silage crops typically had 2 x Altacor followed by an Affirm before growers just 'gave up' and stopped any further spraying."

"Many growers are not set up for spraying once the crop gets above about thigh height. This forces later insecticide applications to using aircraft, further increasing costs, if you can even get access to a plane. Additionally the current maize grain price is relatively low, compared to other crop options."

"Collectively, this has meant that growers have dropped maize from the program this past summer Maize growers for grain typically went to cotton (or sometimes pulses). While maize for silage / grazing was switched to forage sorghum for the same use patterns." This agronomist reported that he only had 1 silage maize crop this summer across the whole business.

Sweet corn – While sweet corn and popcorn gets hit hard, the area grown is not large. There is no tolerance for damage to the sweet corn cob.

Therefore, in Bundaberg where some sweet corn is grown, it is sprayed extensively from the vegetative stage, partly to maintain leaf photosynthetic capacity, but more importantly to have numbers "as low as possible" when silking commences. One agronomist mentioned that "Once silking commences, crops will be then on a 3-day insecticide program." This agronomist added that "early in 2022 we pushed out to a 4-day spray interval, predominantly due to bad weather. This was not successful and resulted in blow outs." However, he added that this "may be the 4-day window or may have been compounded with some applications being washed off before having a chance to fully enter the leaf, as it was difficult to always find a 3-4 hour application window without rain."

Vegetables - Capsicum is arguably the main FAW concern for Bundaberg agronomists, as Bundaberg is an important capsicum growing region and the behaviour of FAW can make control difficult. One agronomist reported that FAW neonates "give the stalk of the capsicum fruit a 'love bite' and enter through the stalk almost undetected. They will then spend their entire lifecycle inside the bell and may be undetectable, apart from a slight colour change to the fruit."

Snow peas was also mentioned as a problem crop. The rational by one agronomist was that crops are very fast growing, and growth dilution can be extreme. With FAW generally attacking the new growth that is 'unprotected' from previous insecticide applications.

Tomatoes are a very large crop in the district, but current *Helicoverpa* applications (typically emamectin and Plemax® (indoxacarb + novaluron) rotations) appear to be keeping any FAW under control and they are not specifically managing tomatoes for FAW.

FAW are "Not a problem in tree crops at this point in time."

Sorghum – There is a mix of sorghum for grain, silage and forage. Forage sorghum is typically not sprayed at all, while there is some spraying of grain sorghum during grain set on an 'as needs' basis for *Helicoverpa*. This is not regular, with many crops not sprayed. One agronomist suggested 1 in 4 crops may get treated for *Helicoverpa*. Sometimes this will be Vivus, but often by the time a spray decision is made the larvae are often too advanced for Vivus, and methomyl is often the product of choice.

Irrigated sorghum will be planted in September / October, however rain grown crops will be planted based on timing of spring rainfall to fill the profile.

One agronomist reported that "FAW can do some leaf feeding early season but tend to 'disappear' as the sorghum starts to go to head. Only 2 or 3 blocks of sorghum were sprayed this past summer (with Vantacor). This was mostly for cosmetic reasons 'as grower wanted to do something', but they probably didn't need spraying."

A different agronomist echoed similar thoughts but was experiencing greater pressure. "Forage sorghum is not sprayed for FAW. Maybe 60% of sorghum for silage is getting treated. Grain sorghum is mostly getting 1 Vantacor in the early vegetative stage and then left. Mostly the pressure disappears as the crop maturity advances." This agronomist questioned "It is too early to tell yet if the switch from maize to sorghum will be sustainable. Or will sorghum also become unmanageable." This question in part reflects the newness of this insect pest and in part questions the capacity of FAW to adapt to different host species.

Summer pulses – Agronomists reported that they are not really seeing much FAW activity in summer pulses. "We did see more than usual levels of 'window paneing' in peanuts last season, and also in winter cereals in 2021. This may be due to FAW feeding but was difficult to find the larvae that were causing this."

Typically mung beans and soybeans are scouted regularly from flowering onwards (but not much prior to that).

There are typically two planting windows for mung beans. September / October, with harvest early in the new year. And a second planting window of January with harvest in April. Soybeans are typically planted in October / November and harvested in April.

Peanuts may get occasionally sprayed for *Helicoverpa* "when extreme leaf feeding occurs. Maybe 1 in 8 to 10 years."

Cotton – There are potentially some small areas of irrigated cotton, depending on water allocation (which has been negligible in the past few years). Planting is typically in October, with harvest in April. "We are not finding any FAW of significance in cotton and have not sprayed for FAW."

Important insecticides

Maize – Mostly control is being achieved by 2 Vantacor applications, applied as needed based on scouting. Sometimes this may get the crop through without further insecticides (although will generally suffer some damage). Some very early planted crops may occasionally get by with only 1 application.

One agronomist mentioned that they were finding that Vantacor was working best when applied through the pivot when applying "a few mm / ha. (e.g. 5)"

"Vantacor takes at least 5-7 days for full effect. We would only 'get worried' if you were finding very little larvae after about 10 days."

One of the agronomists mentioned that they had tried replacing the second Vantacor with Affirm, which "Worked ok, but had shorter residual than Vantacor." He mentioned that they could continue to experiment with products and application timing, but it is probably not worth it as "growers are moving away from growing maize altogether."

A different agronomist added that "It is becoming increasingly common to apply a third application during cob development. Some growers have been known to apply a 3rd Vantacor application (acknowledging this is off-label), although more commonly a third application (if applied) will be Affirm or Steward – noting that this is only done for rotation purposes, as Vantacor is strongly the 'preferred' product of choice, with Affirm second and Steward a noticeable third in terms of efficacy. Success Neo is not used as "it is just too expensive to use in field maize."

Vantacor is considered the most effective insecticide. Reasons mentioned were:

- 3-4 weeks residual (which is significantly longer than any other insecticide)
- "Softer' on beneficials than basically all competitors
- Appears to be systemic, in addition to translaminar. "We have found dead larvae right into the centre of the stalk"

- It is also 'cheaper' than other effective standards (and foliar Bt sprays), although has recently had a price rise
- Many paddocks in the South Burnett are small. Growers will typically purchase a drum of Vantacor which will treat around 150 acres. This means growers often have left over Vantacor from the first application, so this will be the product that they will use for the next application (even if the agro recommends a different product).

Due to these reasons, growers are choosing Vantacor for the first 2 applications 'to get the most value' and are reluctant to spend more $/ha on early applications of other insecticides considered 'less effective' in case they don't get to use their 2 Vantacor applications. Rotation is only really happening where a 3rd application is needed.

With Fawligen, one agronomist was "Disappointed in the results. It needs to be timed very well, and growers are not checking crops often enough (and won't pay for agro checking) to optimise applications. Fawligen doesn't persist and build up in the paddock like Vivus does for *Heliothis*."

This was reflected by comments from one of the other agronomy groups interviewed. They had used some Fawligen but concluded "Applications need to be timed perfectly. It will take out a lot of the correct size population, but still leaves some. At $38/ha there are generally other more effective options for better value. It 'may' have a longer-term fit applied early as a band spray (only treating a small % of the paddock) with higher water rates. One of our growers reported reasonable control applying 100 mL/ha (half rate) through the pivot, followed by a second application @ 50 mL/ha and then a third application at 20 mL/ha, which appeared to keep FAW number low over time. There was no science behind the use rates – just a guess."

While the agronomists interviewed were largely using a Vantacor based program in maize, one mentioned that "Some competitor agronomists are still recommending methomyl, or methomyl + Decis (deltamethrin) mixes. Typically those recommending methomyl mixes are the resellers who do not have 'agency' access to FMC chlorantraniliprole products." Where methomyl is being recommended, the advice is to apply at night, as the belief is that the hatchlings feed more on the leaf surface before burrowing to avoid UV light. But generally "results are sub-par, so not much is being used."

Summer pulses – Most soybean or mung bean crops would budget on an application targeting *Helicoverpa* at flowering. This is commonly Vantacor, but one agronomist commented that they are trying to push summer pulse applications for *Helicoverpa* to Skope, rather than Vantacor. Primarily, as a regional rotation strategy, to try and take some of the pressure off chlorantraniliprole. "Skope is 'nearly as good as Vantacor' on *Helicoverpa* while also providing GVB knockdown."

With regard to FAW, one agronomist indicated that we are "Typically only finding low level FAW infestations, 'but they are there'. Generally we not spraying, as often by the time growers are noticing 'damage', the larvae have already 'gone'."

Sweet corn - Typically it was reported that the preferred program was to build on the current use of Success Neo (which was already being used for *Helicoverpa* and WFT) by adding rotations of Proclaim (emamectin) in the vegetative stage. "Prior to FAW, emamectin was rarely used in the district for anything. We believe Success and Proclaim provide the best efficacy on FAW." Some indoxacarb may also be used in the vegetative phase, but in their opinion, indoxacarb is significantly poorer than these other options.

Once silking commences, they move to a tight 3-day rotation of Success, Proclaim and chlorantraniliprole. They don't believe chlorantraniliprole is as good as these others, however they need to heavily rely on it at this stage due to the lack of other available options. Their strategy is to achieve very good control with Success and Proclaim in the vegetative stage and then 'hope' that pressure in the block is low enough for chlorantraniliprole to be able to hold up in the rotation.

This agronomist also mentioned that, since the emergence of FAW which is known to have resistance to broadspectrum insecticides, there has been a concerted effort across the region to drop applications of methomyl wherever possible (in all crops). "Not surprisingly, it is now much more common to find decent populations of microhymenoptera."

Vegetables – Bundaberg has always been a high-pressure area for *Helicoverpa* and western flower thrip (WTF), so Success has been part of the existing program. This has been historically complemented by additional applications of indoxacarb and some use of chlorantraniliprole, predominantly targeting *Helicoverpa*. With the emergence of FAW, some changes have been made to the application program.

Proclaim (emamectin) has been ramped up as an important rotation partner, due to its efficacy against FAW. A respected agronomist commented that he was 'very surprised' to find dead FAW larvae inside capsicum bells 3-4 days after an emamectin application and mentioned that he "didn't expect emamectin to have that level of translaminar/systemic activity."

This agronomist also mentioned that they have largely replaced indoxacarb with Plemax (indoxacarb + novaluron). Plemax is not yet registered specifically for FAW but is registered for *Helicoverpa* and cluster caterpillar (plus other caterpillars) in key vegetable crops and they believe that this is much more efficacious on FAW that straight indoxacarb. However, novaluron isn't registered for use in sweet corn, so Plemax is restricted to use in capsicums and peas etc.

Further, this agronomist is also involved in a contract research business, so they have been regularly assessing efficacy of a range of insecticides against FAW. From their research, they offered the following ranking of insecticide options when used in horticultural crops to target FAW;

- Success can give 90% control of FAW (with good coverage)
- Emamectin or Plemax are around 80%
- Emamectin and Success are the only products to consider where FAW are past the 2nd instar
- Chlorantraniliprole will only provide a 60-70% job
- Indoxacarb alone is less than those above
- Methoxyfenozide 'works ok', but at the current use rate and pricing for *Helicoverpa* in tomatoes and capsicum, this is approximately $180/ha (1.7 L/ha rate) and other options are preferred. However, there was awareness that Corteva are coming to market with a spinetoram + methoxyfenozide product and Adama are intending to launch a 'double strength' methoxyfenozide formulation in broadacre pulses and maize which will be much cheaper that current hort pricing (expecting around $25/ha in pulses). So, more attractively priced methoxyfenozide options are likely to be available soon, which may alter future use.

As mentioned above, chlorantraniliprole is needed to be used in sweet corn due to lack of rotational options (and Plemax is not available). In fruiting vegetables, they are "only using any of the Group 28's where they have had a good knockdown with emamectin first, and then only relying on the Group 28 'for clean-up'."

Biological agents

In the South Burnett, there were comments to the effect that they were "Noticing lots of native *Metarhizium* this year during the 'wet' conditions during January / February." However agronomists were unsure how much impact this is having on FAW populations.

Two agronomists suggested that they sometimes see shield bugs attacking FAW, but generally they didn't see beneficials contributing significantly to FAW management.

A different agronomist was seeking more information on beneficials and their impact on FAW but added "Generally we are not seeing consistent benefit for beneficials in the paddock. Species tend to fluctuate. This year there has been a lot of damsel bugs, while last year there was a lot of red & blue beetles. We are not using commercial releases of beneficials."

Historically, insect control in Bundaberg has been dominated by broad spectrum insecticides, hence beneficials were rarely seen. However, since the arrival of FAW (which already has resistance to these broad-spectrum chemistries), there has been a reported large reduction in methomyl and OP/SP use, which is allowing some build-up of beneficials, however this is still not to a level where they are a major tactic in control programs, "especially as management programs are still heavily reliant on spinetoram and emamectin which will still be quite damaging to microhymenoptera."

One agronomist mentioned that it can be common practice to 'abandon' fruiting vegetable crops after their productive life and often these are not immediately removed (especially tomatoes and snow peas where trellises need to be removed first, before cultivation can occur). In these "blocks that have been 'let go', populations of *Trichogramma* and other beneficials build fairly quickly." However, this agronomist also noted that GVB pressure has been building and has been immense this past summer and autumn and was questioning if this is just coincidence, or as a result of a large reduction in OP/SP/carbamate use.

Cultural / non-chemical management tactics

In the South Burnett, one of the agronomy teams interviewed were monitoring 3 FAW pheromone traps, as part of the QDAF network, although two of these were 'lost' this past season due to flooding & fires. "We don't see much value in them. They are constantly picking up 2-3 months per trap per check almost all year long. But this appears to have no correlation to larvae pressure in the paddocks, which can be much more, or much less."

A different agronomist had another 2 traps, with results also feeding into the QDAF network.

Some dedicated maize growers around Toogoolawah have purchased and installed their own traps.

Grower scouting and finding larvae is a problem in the eyes of one agronomist. "Growers are very 'reactive' when it comes to insect pests. 'Normal' is to assume they won't be a problem, then only seeking to manage once damage is noted. This is somewhat different to weeds, where they will be more proactive e.g. use of residuals. Most maize and sorghum growers are not 'monitoring' these crops, as they have not needed to do this in the past and have previously just 'reacted' to evidence of foliar damage. They can generally find FAW if they look. And if uncertain, they will send pics on their phone to the agros. But many/most are only reacting to visual leaf damage, by which time it is generally too late. Grazing / silage and maize for grain are all relatively low value crops, and therefore growers won't spend big $ on insecticides or monitoring."

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

There was some discussion with regard to the QM FAW attractant + methomyl insecticide with the EE Muirs agronomists interviewed.

- QM FAW is an alternate 'attractant' to Magnet
- Distribution of QM FAW is exclusive to EE Muirs
- The local agronomists have done some initial work in the South Burnett, but have currently stopped supplying to growers, as it is unclear as to the need for formal 'registration' with the APVMA (as it is not an insecticide in its own right, but is recommended to be used with a registered insecticide)
- Label has flexible application patterns (more so than Magnet), but more local work is required to understand how to apply for best results.

There was feedback from other independent agronomists who were interviewed during this research that appeared to support a general belief that QM FAW was a 'better' attractant for FAW, while Magnet was a more generalist attractant (and sometimes also attracting significant populations of beneficials).

In Bundaberg there was little evidence of non-chemical control strategies, apart from intense scouting (at least twice weekly).

Existing resistance, IRMS and impact of FAW on IRMS

In broadacre cropping, Vantacor (chlorantraniliprole) was the major focus for each of the agronomists interviewed, as it is now the main product for FAW in maize along with *Helicoverpa* in several other crops. There appears to be general understanding by agronomists of the need to manage chlorantraniliprole across the region.

One agronomist added that "Not only is it the mainstay of our current programs, but there is also a chlorantraniliprole seed treatment close to commercialisation for maize and potentially other summer crops like sorghum. This is expected to be an attractive option for growers. Additionally, Vantacor is currently only available to stores under an 'agency' arrangement, so not every reseller has access. As a result, retail pricing is somewhat controlled. However, it will soon be off patent, which will further open up product distribution and most likely reduce pricing – which will result in even more extensive use." (*Author note: chlorantraniliprole seed treatment was mentioned, however Fortenza will be cyantraniliprole – however still the same MOA*.)

With regard to the IRMS for grains, one agronomist commented that "DuPont (Kent Bell) did try to establish an IRMS for summer crops back when heliothis was the focus. There was a tech note, but we haven't seen anything since, and there is nothing on the Vantacor label." This agronomist recalled that this Dupont strategy "Allowed chlorantraniliprole use in late chickpea crops, but then no use at all for the spring mung bean window. But could be then used again in post-Christmas mung beans." (*Author note: it appears that strategy may well have been the QDAF 'summer grains' strategy, which may have been picked up and promoted by DuPont at the time*.)

When it comes to growers, the feedback from one agronomist was "Growers are not even thinking about resistance. It is only the agros who are considering it." This agronomist added that "While a resistance strategy is needed in the medium-long term as there is too much pressure on chlorantraniliprole, restrictions on use will just further influence growers to switch to non-host crops."

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

While a different agronomy team added "Most growers understand that they shouldn't use any more than two consecutive applications of any product, but that is about where it stops when it comes to a resistance strategy."

> *Author comment: The general messaging of 'no more than 2 consecutive applications' appears to be prevalent in the Burnett (along with several other regions) i.e. it is 'acceptable' to apply two applications back-to-back – and this is somewhat supported by the label and minor use permits. However the label states that the 2 applications are applied to the same cohort of insects (i.e. applications probably within about 21 days) and not more than 50% of applications in the crop can be the same MOA. It appears that this second part of this label wording is not being considered, and in general, users are trying to 'extend' the period between applications, so as to try to make two consecutive applications cover as much of the maize growing period as possible.*

One agronomist added that "Our concern is that sorghum 'may' become the primary FAW host in the district as growers drop maize out of the program." Two agronomists from a different agronomy group expressed similar concerns "The shift away from corn in the region, due to high FAW pressure, is likely to put more hectares into sorghum and possibly more spraying / impact on *Helicoverpa*."

These agronomists also were concerned that "Some 'less responsible' retailers do not currently have access to Vantacor. With the pending availability of generic chlorantraniliprole, this is likely to lead to even more widespread use."

Both Pioneer and Pacific seeds are currently working towards a chlorantraniliprole seed treatment (Fortenza brand, supplied by Syngenta. Registration submission pending with APVMA) for control of *Helicoverpa* and FAW in cotton, maize, sweetcorn, sorghum.

In horticulture in Bundaberg, there is acknowledgement that FAW have arrived already resistant to methomyl, OPs and SPs and this has forced a reduction of use of these products for other pests as well, so as to not flare FAW.

One horticultural agronomist commented that adoption of Durivo® (chlorantraniliprole + thiamethoxam) seedling drench applied at planting has become a 'convenience' for growers to avoid needing to spray early season pests and has been widely adapted. However, in their opinion, results against potato tuber moth / leaf miner "may be dropping off and might be indicating resistance – but no testing has been done." More generally, this agronomist did not like the concept of at planting applications of insecticides and believes it accelerates resistance, such as the Durivo example above and also imidacloprid against aphids, and hence was not in favour of further expansion of Group 28 seed treatments for FAW – but did acknowledge that they appeal to growers.

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- Understand if there are differences in FAW attractiveness between maize varieties (Are anecdotal observations real?)
    - There have been some reports that Amadeus (HSR seeds) is not getting damaged by FAW
    - Also reports that Fairbanks sweet corn varieties appear to have some level of 'resistance'
    - One grower reported that 1315IT had "noticeably less FAW pressure than P1467 right beside it." (The agronomist thinks he had these varieties in the correct order)

  - In forage sorghum, another observation was that Graze-N-Sile was 'hammered', while adjacent Mega Sweet had much less damage.
- More grower information / communication is required with regard to beneficials (i.e. which are important) and native virus and how to plan for, and utilise, these tools.

14.1.4. Central Queensland / Dawson Callide (CQ)

Central Queensland is a large geographic area dominated by extensive areas of grazing pasture. For the purpose of this study, we concentrated research activity on the key broadacre cropping and cotton regions of the Central Highlands (centred on Emerald) and the Dawson Callide.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	CQ			X			X	Mung	X	

Expected FAW pressure

FAW was first noticed in the Dawson Valley in May 2020 in some sweet corn crops, and then in broadacre corn & sorghum crops in November 2020. Despite this relatively early introduction, this agronomist suggested that populations decline each winter and "We rarely see FAW until mid-late November, but then pressure builds very quickly through December and January."

This agronomist mentioned that "There can be some misidentification between cluster caterpillars and FAW." Which may be influencing levels of detection. "The armyworms are very difficult to separate when small. It's easier to accurately identify FAW by the damage caused, which is different to other grubs in corn. FAW `skeletonise' the leaf and make new leaves turn yellow. It's not difficult to differentiate between FAW and *Helicoverpa*. Difficulty with identification isn't causing major issues as most of the time it is FAW. If treated as FAW, the chemistry will also clean up other grubs."

On the Central Highlands, where there isn't much maize grown, one agronomist first found FAW in sorghum in 2020 and suggested that populations are still increasing each year which "was likely helped by a larger sorghum planting in 2022." Currently they are not spraying vegetative damage in sorghum as they haven't triggered the threshold of 30% leaf removal but consider this may be possible in the future on some crops if pressure keeps increasing. "When it comes to sorghum, hold your nerve – to date FAW doesn't seem to be posing an issue for sorghum yield."

A different agronomist mentioned that "We first saw FAW in sorghum a couple of years ago however, didn't see large infestations until the 2021/22 season. FAW can be an issue in sorghum in the early growth phase, but as they don't seem to affect the head, hopefully insecticide control won't be required in most cases.

We are not seeing large FAW egg lays in cotton. Agronomists feel that "the Bt technology is effectively controlling them." There is work being undertaken to determine whether the use of pigeon pea as a refuge crop may contribute to any resistance build up in the Bt's to FAW, but that's still very much a question mark.

We haven't had large plantings of mung beans in recent years due to the dry season. Currently unsure if FAW will pose much of a problem in mung bean crops, but haven't seen any infestations to date. However if they do hit mung beans then it's likely that the control of other pest species with Altacor will also control FAW. Working in the region's favour is the fact that only very small areas of corn are grown."

One of the agronomists interviewed mentioned that he managed a sorghum and maize (silage) crop last year that was planted in early July and pressure was "higher than ever before" so was questioning if populations subside over winter in central Queensland.

Management strategies

Sorghum –The vast majority of sorghum is sown from late December through to the end of January. Very little sorghum is sown in central Queensland during late winter / spring due to the risk of high temperatures at flowering and the low frequency of years when planting rain occurs to enable sowing to occur at that time. However, there may be very small areas of irrigated sorghum planted in July-September. Harvest is mostly March to June/July, depending on planting date and conditions.

One agronomist mentioned "We had a heavy infestation of FAW in December 2021 planted sorghum. We have seen FAW in sorghum previously, but not such a heavy infestation. After speaking to other agronomists with experience in FAW in sorghum who said they had seen little production impact between sprayed and non-sprayed crops, the decision was made not to spray. While there was significant damage to leaves, there seems to be no damage to heads and therefore yield is unlikely to be impacted. Altacor may have been a control option, but the less industry relies on this insecticide the better, to avoid resistance issues. Research suggests that FAW prefer night feeding, so a large sorghum head in full sun isn't an ideal environment for them."

In the Dawson, FAW pressure in sorghum appeared to be higher than on the Central Highlands, which possibly may be as a result of more maize being grown in the district. "FAW can impact the sorghum plant's tillering. Under overhead irrigation, rot can also set in down in the whorl if it has been damaged by FAW. FAW can do leaf damage at the 5-6 leaf stage through to head emergence, although it's a minor problem compared to maize."

Maize – Some corn has traditionally been grown in the Dawson Callide. One local agronomist commented "FAW hasn't ruined the corn industry in the Dawson Valley yet, but it has certainly dented it." "Damage and potential yield penalties are much worse than in sorghum. It's virtually impossible to control once they're in the cob. If cob damage occurs, moisture can infiltrate and create quality issues."

The planting window has traditionally been from August to mid-February, with the bulk of planting occurring December – January. Although it has been noted that FAW problems are much greater in late planted crops. "We haven't had an issue in the August-September planted crops to date, with FAW only appearing right at the end of these crops."

However, with the arrival of FAW, planting has dropped significantly in recent years – with much of this area switching to sorghum or cotton, which is being further assisted by current relative commodity prices.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Maize for silage is typically chopped 90-100 days after planting, while grain crops can be harvested from January to June, based on planting date. Some 'grain' crops were cut for silage in 2022 due to the predicted ongoing cost of FAW insecticides.

The agronomic advice to maize growers is to "plant early." Aiming for the crop to be 'mature' before the FAW pressure builds in November / December. "If they don't, they'll need to be prepared to silage the crop instead of taking it through to grain if FAW pressure is high. And to include Fawligen into the existing control program. Set up the spray rig properly to ensure adequate coverage. Use the right nozzles and water rates so chemicals can reach the grubs and make sure spray conditions are appropriate."

Mung beans – With the recent run of 'dry' years there has been little dryland mung bean grown on the Central Highlands. Being a quick crop to grow, and with limited irrigation allocations, there has been some interest in irrigated mung beans as they require less water / ha relative to a cotton crop. Irrigated crops are generally not planted until February in Central Queensland, to avoid excessive heat at flowering.

Cotton – Planting typically commences from August 1, with most of the crop planted in August. However late dryland crops may be planted through to the end of December. "Planting dates have been affected by a lack of rain & irrigation allocation in recent years."

Chickpeas – Chickpeas are the main winter crop of relevance with regard to noctuid pressure. Dryland crops can be planted any time from mid-April and until early July, based on available soil moisture. The 'preferred planting window is May. The main harvest period is October.

Winter cereals – One agronomist also mentioned "We suspect that there has been a small level of FAW activity in early planted wheat over the past couple of years. Unlikely to be a major problem given the winter temperatures."

Important insecticides

Sorghum – Insect management is mainly focused on *Helicoverpa*, with most crops getting an early virus spray (e.g. Gemstar @ 100 mL/ha or Vivus 150 mL/ha). Sometimes (maybe 25% of crops) may require a second *Helicoverpa* application (usually methomyl @ 1.5 to 2 L/ha), especially where flowering has been uneven.

Occasionally 'late' crops may require a pyrethroid application for sorghum midge (e.g. Dominex® Duo @ 300 mL/ha).

Rarely, Regent® (6.5 mL/ha) is applied for grasshoppers.

In the Dawson Callide, one agronomist suggested that "We can't justify the cost of applying many sprays in sorghum. We have applied the odd Vantacor spray (55 mL/ha) if FAW populations are very high and having a major effect on the plant's tillering. FAW damage can also cause rot in the whorl in overhead-irrigated crops. We would only do 1-2 sprays maximum per season (for *Helicoverpa* and FAW). Once the head emerges, FAW tend to disappear."

Maize (Dawson Callide) – To date, the typical program in maize has been "not to panic too early", however they are mindful that FAW can build really quickly. Growers are currently being told to budget on a 3-4 spray program, with the first application being applied 3-4 weeks after planting. This is likely to be a full rate of Vantacor (40-55 mL/ha) which may also clean up any *Helicoverpa* present. This is then followed by either Steward (500 mL/ha) or Affirm (900 mL/ha) at tasselling and then a second Vantacor (55 mL/ha) at commencement of silking. “We haven’t used Fawligen as yet but will definitely look to incorporate it into a control program in future.”

This agronomist suggested that each of these applications were only delivering a 2 or 3 out of 5 on FAW and mentioned “Rate is less important than coverage. With boom spray applications, we need high water rates, the correct nozzles and plenty of pressure. Haven’t had a spray job that’s done better than 50% control on FAW, which is primarily related to spray coverage and difficulty with getting the chemicals down into the plants where the FAW are. The most effective applications seem to have been towards the end of the crop when the tassels are high and close to the boom so the chemical dribbles down into the whorls.”

One agronomist on the Central Highlands was managing a single block of corn for silage this past summer. This required management for FAW. The strategy used was Affirm (400 mL/ha) in the early vegetative stage “which was only reasonably effective, but this could have been impacted by application errors”, followed by a mid-season Altacor (70 g/ha) which “was very effective at keeping populations in check and minimising defoliation. However, also may have been helped by the fact that the pressure backed off as the season progressed.”

Mung beans – On the Central Highlands, the strategy of one agronomist was that most crops will receive at least one Altacor (70 g/ha) at early flowering for bean pod borer and *Helicoverpa*. Often a second application is required mid flowering, with a pyrethroid (e.g. Dominex Duo @ 300 mL/ha) commonly added to the Altacor for control of GVB.

A different agronomist suggested that their strategy had been typically a low rate of Affirm (160-300 mL/ha) plus dimethoate (400 mL/ha or 200 mL/ha + salt) for control of *Helicoverpa* + mirid complex applied at budding to flowering. which was generally followed by Altacor (70 g/ha) + deltamethrin (500 mL/ha) at podding. In maybe 20% of years this later Altacor + pyrethroid may be replaced by a lower cost methomyl application. However, this agronomist commented that “Affirm has lost efficacy in recent years due to ‘the nature of mung beans and the nature of the crop’ (rather than resistance issues). We are yet to decide on an alternative.”

In the Dawson, it was suggested that most mung bean crops will require a single insecticide, while a significant number may not be sprayed at all. Insecticide choice will depend on what requires control. This could be a low rate of dimethoate (250 mL/ha + salt) for mirids. A higher rate of dimethoate for thrips (thrips can vector tobacco steak virus. Will only spray if pressure is high as this can take out predators). Steward (400 mL/ha) for *Helicoverpa* or Vantacor (40 mL/ha) if chasing both *Helicoverpa* and bean pod borer. Sometimes dimethoate may be added to Vantacor if mirids are also a problem.

Cotton – Sucking pests drive insecticide use in Bollgard 3. Most crops would expect to require two or three insecticide applications and generally product use rates are at the low end of registered rates.

One Central Highlands agronomist suggested that the first application for mirids is typically Regent (30 mL/ha) applied early. Sometimes a second application is required where mirid pressure is high. Moving into mid-crop (flowering / early boll set) crops will generally get a Transform (100 mL/ha) for control of mirids and aphids, plus suppression of RBSB and GVB, or MainMan® (500 g/kg flonicamid) at 120 g/ha for mirids and aphids. In higher mirid pressure situations both applications may be required. Occasionally (less than 10% of crops) a miticide may be needed for broad mite Agrimec® (18 g/L abamectin) @ 300 mL/ha. Later in the season, some crops (less than 10%) may require an Admiral® Advance (100 g/L pyriproxyfen) @ 500 mL/ha for whitefly, or Pegasus® (500 g/L Diafenthiuron) @ 800 mL/ha where there is a whitefly / aphid / mite complex requiring treatment.

A Dawson Callide agronomist suggested that their plan was typically dimethoate early. Typically this will be a low rate when targeting jassids, GVB, cotton stainer or cotton flower bug, but they may go to 800 mL/ha if they are also trying to control heavy populations of thrips.

Very occasionally (significantly less than 15% of paddocks) they may need to switch to Shield® (200 g/L clothianidin) @ 125-250 mL/ha or a pyrethroid if GVB are the dominant pest and requiring robust control but are very aware this this has the potential to flare silverleaf whitefly, broad mites or mealybug.

Rarely (less than 1 in 2 - 3 years) they can sometimes find very high *Helicoverpa* pressure damaging squares in Bollgard 3. If an insecticide is required, they have the option of Vantacor or Steward or Affirm.

Chickpeas – One agronomist suggested that their strategy involved most crops receiving an Altacor (70 g/ha) during early podding for *Helicoverpa*. In dryland crops this may be enough residual at that time of year to not need any further applications. Many irrigated crops (and some dryland crops) will get a second application at late podding. The second application is likely to be either be a low rate of Steward (300 mL/ha) or Affirm (300 mL/ha).

A different agronomist had been historically using Larvin® (375 g/L thiodicarb) as the first application, however this has mostly been replaced by Affirm (300 mL/ha) in the past year for about 75% of jobs and Altacor for 25% of paddocks. In some years (maybe 50%) a second mid-late season application may also be required, which will be Altacor (70 g/ha).

In the Dawson Valley, it was suggested that most are trying to use Steward in chickpeas (for *Helicoverpa*) and to keep Vantacor for mung beans in summer, when pressure is higher. Typically one application of Steward (300 mL/ha) is all that is required, but rarely a crop may require a second application which will typically be Affirm (300 mL/ha) or Vantacor 30 mL/ha).

Biological agents

In cotton, the inbuilt protection in Bollgard 3 varieties is form non-pesticide control of FAW. Specifically, the Vip3A protein was mentioned by one agronomist as expected to be able to control FAW.

One agronomist mentioned that they were acutely aware of beneficials, in particular the generalist predators that target a range of insect pests (e.g. damsel bugs, spined predatory shield bug) and parasitic wasps and egg predators. "When considering spraying in cotton, the first two thoughts are mealybug and whitefly - because we lost significant areas of crop to mealybug when it first arrived in the district. So, in terms of beneficials, my primary concern in cotton is preservation of the ladybird complex. With whitefly, parasites have been a very important mechanism in the past. Although it is still an issue, whitefly has become easier to control. If looking to control pests like *Helicoverpa* or FAW, parasites are likely to be one of the key beneficials in this area, particularly in crops like corn which has a large canopy."

In the Dawson Callide, the general advice from one agronomist was "Where possible, we try to hold off sprays to ensure predators have a food source. Experience with cotton has shown that sometimes chemistries can be the problem – for example chemistries that took out beneficials had the effect of flaring whitefly populations. Whitefly is rarely a problem in cotton now."

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Cultural / non-chemical management tactics

One agronomist was using pheromone traps for both *H. armigera* and FAW "as another source of decision-making information" but was unsure how useful they were for FAW. They commented; "however, we would use these in the future for any growers wanting to plant corn on the Highlands while still working out the best management strategies for corn." This agronomist also saw significant benefit in trying to restrict growers to plant maize (silage) or sorghum in the cooler months, where FAW pressure is likely to be less, and use Vivus as their frontline management in sorghum to preserve beneficials. In chickpea, they are not seeing FAW pressure to date, but are constantly trying to delay applications for *Helicoverpa* to only spray when pressure exceeds the economic threshold and try to adhere to the grains IRMS wherever possible.

Another agronomist mentioned that they are not using pheromone traps. "With only small areas of corn grown in the region, FAW hasn't been a significant enough issue to date to warrant pheromone monitoring. If more corn was grown in the region, they certainly could be useful. If FAW has a negligible effect on yield in sorghum and growers become conditioned to seeing a level of leaf defoliation without wanting to spray, trapping probably isn't as important. Most sorghum crops can take 25-40% defoliation of leaves before yield is affected. Even in the badly affected crop this year, leaf defoliation was probably only around 15%." This agronomist also mentioned that they continue to encourage growers to avoid weedy paddocks and green bridges, which may host FAW. Many growers are attuned to weed / green bridge removal as a key component of insect management.

While 'pupae busting' isn't required in cotton crops under the Bollgard 3 management plan for Central Queensland, pigeon pea trap crops are still cultivated in for *Helicoverpa* management. It is unknown what effect this may also be having an impact on FAW.

One agronomist mentioned that adherence to 'planting windows' had always been extremely important in Central Queensland. "In the case of corn, it's a very narrow planting window in CQ for agronomic performance. If it's planted any later than January/February, it takes forever to come off. If it's planted earlier than January, growers tend to have issues with pollination at silking."

In the Dawson, it was suggested that panting maize 'early' (August/September) may become an important tactic against FAW, however this will require a change in mind set from growers who typically consider December as the best planting window for maize. The combination of early planting and running "a targeted IPM program of products like Fawligen and Vantacor" may allow maize to continue to be grown. This agronomist suggested that it might also be practical to get irrigated sorghum growers to switch to an early planting window (September) to reduce FAW vegetative pressure.

Existing resistance, IRMS and impact of FAW on IRMS

Helicoverpa resistance is known to be present in older chemistries i.e. pyrethroids, OPs, carbamates. One agronomist said this is confirmed by experience and observations over the years. "It all changed with the introduction of Bt technology in cotton, so we don't use these chemistries for *Helicoverpa* control any more. We haven't seen any issues with the newer chemistries introduced since the late 1990s/early 2000s and haven't seen any insecticide resistance to insecticides for sucking pests."

A different Central Highlands agronomist suggested that there were no clear, confirmed cases of resistance with the newer chemistry, although they keep abreast of industry resistance monitoring. Some drop off in performance of Affirm was mentioned by this agronomist, along with a comment that when they were previously using Steward "there were more survivors than expected in *Helicoverpa*." "But it is debateable if this was due to resistance or not."

An agronomist from the Dawson Callide shared similar views “Surveying of *Helicoverpa* from the Dawson and Callide Valleys in recent years has detected very small levels of resistance to Steward and Vantacor. With regard to FAW, “My gut feel is that a couple of sprays haven’t been as effective as expected. Could be related to the new formulation & mixing issues, rather than resistance. We have discussed with FMC.”

There was general acknowledgment of the importance of managing resistance to the newer chemistries. In the Dawson, where FAW appears to be having a more direct impact at present (most probably due to a higher incidence of maize crops), one agronomist suggested “Vantacor is a very important chemistry for bean pod borer in mung beans. So overuse in other crops like maize is concerning.” The potential overuse of Steward (for *Helicoverpa*) is also on their radar.

On the Central Highlands, the arrival of FAW as a major pest would be a problem in the eyes of one agronomist, as it would place even more pressure on chlorantraniliprole. “Altacor is such a reliable insecticide for Central Highlands growers – it’s robust and has good residual.” This agronomist was also concerned about what is happening with chlorantraniliprole use in the Burdekin, an adjacent production area. Should overuse of Group 28 insecticides in the Burdekin for both FAW and *Helicoverpa* result in resistance in *H. armigera*, then this could potentially migrate to the Central Highlands which would be highly problematic in pulse crops and sorghum, despite CQ not really growing FAW sensitive crops.

Compliance with the cotton IRMS is high with each agronomist interviewed, however one mentioned “The cotton industry IRMS isn’t as critical as it was years ago. Now most growers are using Bt varieties are only applying a couple of sprays a season. Generally the chemistries used are rotated as a matter of course.”

One agronomist suggested that they were “Following the grains IRMS as close as possible” however two other agronomists commented that they try to follow the grains IRMS, but “There is an issue around the timing of Vantacor in mung beans. The recommendations aren’t appropriate for the planting windows and the bean pod borer challenges faced in the Emerald region. However, as mung beans are not a massive crop for the region, there isn’t large areas being treated regularly with Altacor.” This agronomist added “Should maize be grown in the Emerald region, it would be planted in January. Which would mean it would be likely to be sprayed at the same time that mung beans are being treated with Altacor.”

A second agronomist mentioned “Suitability for the pests we are trying to control at the times we need to control them will drive adoption of any IRMS.” “Windows of use for some of the products in the grains industry IRMS didn’t align with the needs in CQ. For example, it recommended not to use Vantacor on mung beans between February-April, which is the main time we need it to control bean pod borer. Vantacor is one of the only effective chemistries we have for bean pod borer aside from Affirm. Steward has been registered recently but we’re reluctant to use it as we’re unsure how effective it is compared to Vantacor/Altacor.”

A further comment along a similar line was “A grains IRMS incorporating FAW needs to be practical for the individual regions but at the same time, there needs to be integration between regions and their windows of use if it’s to achieve its aim of preventing resistance build-up. The issue and uptake will lie in whether the IRMS allows growers to continue using their most valuable chemistries when they most need them.”

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- It's a numbers game. So if FAW populations can be reduced, there's a much greater likelihood of adequately managing them and their impact on production. Any option such as pheromones, viruses and diseases or nematodes which has the potential to reduce numbers should be pursued by industry
- Would be good to see biological options developed (e.g. a sprayable fungus). However, whatever is pursued needs to be effective and, importantly, cost effective
- In an ideal world, availability of 'Bt corn'
- More robust formulation of a product like Fawligen
- An effective seed treatment – only issue is that they often don't last long, but may assist in the early stages of the crop.

14.1.5. Bowen / Burdekin (BB)

The Burdekin agricultural region, centred on the town of Ayr, is a topical region supplemented by extensive irrigation – allowing for almost 12 month of the year production. Cropping is dominated by sugarcane, but also includes grains and legume crops plus some vegetable production.

Bowen, to the south, is a lower rainfall environment, with 'cropping' mostly constrained to irrigated vegetable production around the Delta and associated river systems, mostly during winter months.

In addition to the Bowen and Burdekin areas surveyed, there is also a significant area of sugarcane (with some summer pulses as a break crop) grown to the south of the Bowen / Burdekin basin, extending from Sarina in the south to Proserpine in the north, and including the Pioneer Valley centred on the town of Mackay. This area was not specifically targeted for interviews in this research as the crop mix grown is not primarily conductive to FAW and these crops are adequately covered by other regions surveyed along the Queensland coast.

There is extensive rain grown beef cattle pasture outside of these two farming valleys, which was not part of this study. Two agronomists mentioned that there are significant areas of forage sorghum or maize grown by these graziers, and much of this would never be scouted or sprayed for insect pests – so is quite likely to be contributing to the overall FAW population. One of these agronomists mentioned that some of their grazier clients are spraying silage maize during the establishment phase (first 3-4 weeks) and increasing sowing populations as a strategy to address damage where maize is still being grown for fodder. Some have switched to forage sorghum or mixed legume crops for grazing.

While there are a significant number of retail and independent agronomists in the district, there were several comments made by agronomists interviewed suggesting that a significant percentage of these beef cattle graziers do not have an 'agronomist' providing advice.

This appears to also apply to several 'cane farmers' who only see rotational crops as a forced necessity between cane crops. Several of the agronomists interviewed indicated that these growers often have poor attention to timeliness of pesticide applications and are the ones most likely to make unprofessional product choices, with their poor level of understanding and management of FAW likely to be adding to the overall district pressure.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Horticultural growers and those growers who are 'focused' on maximising the value of grain production in their rotation were perceived by interviewed agronomists, as likely to have professional agronomic advice regularly provided.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	BB	X	X	X	X	X		Soy, mung		X

Expected FAW pressure

In both the Burdekin and Bowen regions, agronomists reported extremely high fall armyworm pressure. Fall armyworm arrived in the district in the summer of 2019/2020, with pressure increasingly strongly during the 2020/2021 summer.

In Bowen, pressure this season (2021/2022) was mentioned to be relatively similar to last summer, "which is extremely heavy". Several agronomists in the Burdekin suggested that pressure 'might' have been slightly lighter in 2021/2022 compared to the year prior. Possible reasons for this included a significant reduction in maize area sown in spring, or the 'drier' summer this year.

Two agronomists mentioned "you always see a spike in egg lays around the full moon."

In the Burdekin, FAW pressure continues throughout the year, as there are always host crops being grown. For example, during spring / summer there will be significant areas of summer pulses and sorghum being grown in addition to grass pastures and forage crops, while large areas of sugarcane are also in permanent production. As these crops lose their attractiveness to FAW in late summer / autumn, winter grown maize and alternative vegetable host crops are typically being planted. The Bowen / Burdekin region is the 'winter' production bowl for much of Australia's sweet corn, tomato, capsicum, and cucurbit vegetables.

Agronomists reported that significant FAW pressure (requiring treatment) is experienced almost 12 months of the year, with just generation life cycles taking slightly longer to complete over the cooler months. It is common to see pressure move from one paddock that is becoming unattractive to FAW (as the crop is drying down), to an adjacent block that has a younger and more attractive host crop.

Maize and sweet corn and capsicums appear to be the predominant crops favoured by and most severely affected by FAW, although peanuts, soybeans and some other vegetables were reported to be holding significant FAW populations.

Several agronomists mentioned that there has already been a major shift away from maize in the Burdekin. This is predominantly due to increased costs associated with FAW. This trend away from maize has also been driven by the relatively poor price for maize ($280/t in 2021) and the high cost of nitrogen fertilizer in 2021/2022.

Two agronomists mentioned that they feel that growers are becoming more comfortable in adapting to 'live with' FAW. One of these indicated that growers who have struggled with the cost or frequency of insecticide applications have already shifted their production system, specifically dropping maize for grain from the rotation.

While there are very large areas of sugarcane grown through the Burdekin and a small area of rice, agronomists reported that both sugarcane and rice appear relatively unattractive to FAW, with populations only typically being found in these crops where the cane or rice has a heavy grass weed 'problem' (barnyard grass was specifically mentioned by two agronomists). One agronomist commented that there is an APVMA emergency use permit (PER89384) for sugarcane that allows for the use of 157 gai/ha of chlorantraniliprole as an in-furrow application, followed by a foliar application of 28 gai/ha and "There are reports that some growers are applying these massive (in-furrow) rates as a foliar application to low numbers of FAW in sugarcane, despite FAW typically doing no major damage to cane at all."

'Reef regulations' pertaining to growing sugarcane now force cane growers into maintaining ground cover on fields between sugar crops. Those growing grain crops in this period are generally trying to manage FAW and other pests (see below), however, the alternate 'low input' strategy is to plant a cover crop (e.g. cow pea or similar) or just let the paddock grow full of weeds, so as to keep ground cover in place and therefore meet their reef regulation obligations for maintaining ground cover. These 'low input' paddocks are not treated for any insect pest and were perceived by agronomists as creating the potential for a huge insect migration into horticultural crops when they are removed in late summer in preparation for cane planting.

Barnyard grass (a weed) was mentioned as a preferred host for FAW, and therefore where this was present in high density in any crop, it was likely that FAW will be found.

Management strategies

Grain crops

Maize – Historically there have been two main planting windows for maize. April – June (more common for grain crops, with harvest pre-Christmas) and November – December (more common in beef / grazing). A common strategy was to grow maize during a break between cane crops. This rotation has typically been either cane – mung bean – maize – mung bean – cane; or cane – maize – soybean – cane, depending on when the cane block is taken out of production. Mung beans are a shorter option and may allow 3 crops within the 18 months out of cane production.

With the increased FAW pressure in maize (and high cost of nitrogen fertilizer in 2022), many growing maize for grain have already dropped maize from their program, while those who did still grow maize in 2021 are reconsidering the fit. Historically there was little need to spray maize for insect pests, however a maize crop for grain will now require at least 4-5 insecticide applications and may still suffer up to 50% crop loss.

In addition to the cost of insecticides, consensus appears to be that maize will require scouting twice a week from emergence to at least silking.

One agronomist mentioned that "you cannot sit and wait and see if FAW populations develop over time, or if natural beneficials will be able to suppress them (like you can often do with *Helicoverpa*). You must move with an insecticide as soon as you find FAW."

One agronomist was still managing a 'considerable area' of popcorn as some of these growers are locked into longer term contracts.

As an alternative to maize, there has been some adoption of two or three back-to-back pulse crops (e.g. cane – mung bean – soybean – mung bean – cane) in the break between sugarcane, but this is recognised as a poor agronomic choice. Agronomists interviewed were still very unclear of what the 'new' rotation will be for the 18-month period between cane where (winter) maize is no longer a viable option.

Pulses – While pulses do hold FAW populations, the pressure is not as intense as in maize. Most crops are regularly scouted, either weekly or twice per week.

Planting windows for mung beans were typically mid to late August and then again in February – March, while soybean planting windows were July and then again between Christmas and mid-January.

One agronomist saw an advantage to mung beans over other pulses, as the short crop duration (as little as 55-60 days in the Burdekin) reduces the need for the number of insecticide applications in general.

Grain sorghum – Historically, not a lot of grain sorghum has been grown, however there is more interest as an alternative option to maize, as generally FAW pressure is less. However, sorghum is not well adapted to 'winter' production, which is the position previously occupied by maize in the Burdekin.

Planting will be typically August to late September where irrigation is available, or January – February especially for dryland crops.

One agronomist mentioned that they are currently carrying 30-40% vegetative damage in sorghum prior to head initiation, and this does not appear to be impacting yield. Once head initiation has commenced, it is generally *Helicoverpa* that is doing more damage than FAW. "FAW don't really seem interested in sorghum, however you will 'sometimes' find FAW eating heads."

Millet – Interestingly, two agronomists both reported that they are not seeing FAW attack millet crops in the Burdekin (although these crops were attractive to *Helicoverpa*). Whereas agronomists from the Atherton Tableland and the South Burnett reported millet to be a preferred host of FAW.

Horticultural crops

Sweet corn – The majority of sweet corn grown is grown in Bowen by a small number of 'family owned corporate' businesses, with a large number of very small growers making up the bulk of the remaining sweet corn production. The large 'family corporates' are supplying the major supermarkets for 12 months of the year and have production bases spread across the main growing areas in Australia. For these Queensland sweet corn producers, the main alternate production area is southern Queensland (Lockyer Valley).

Planting of the Bowen sweet corn crop commences in Mid-February to March and continues to around September / October. This results in the harvest window starting in early-May and running until early to mid-summer (Christmas), while the Lockyer Valley production peaks in summer and continues into autumn. As these businesses desire to have continual supply into the supermarkets, they stagger planting dates to spread harvest as much as possible. It was reported that these growers are planting sweet corn blocks every few days and are often harvesting most days of the week.

These small number of corporate vegetable farming operations are highly competitive between themselves and as a result, can often be extremely protective of their sensitive information. One agronomist said: "Every horticultural farmer is out for themselves." Such attitudes potentially makes area wide strategy coordination more difficult. To balance this, the majority of the most at risk crop of sweet corn, is grown by a very small number of producers – a fact that could be used to simplify communication and training on a crop and region specific IRMS for sweet corn.

Several of those interviewed during this research who were either currently consulting to these organisations, or had done so in the past, indicated that these organisations require consulting agronomists to sign non-disclosure agreements (which continue after they cease working for the organisation). This was noticeable in our ability to extract detailed information from this segment. One senior agronomist who was recommended to be interviewed declined to be surveyed, another who had previously worked for one of these large corporates "probably shared more than they should have" and a third, who is currently consulting in this area, was deliberately 'vague' in the level of information and detail provided. A fourth was willing to share reasonable level of detail.

The damaged caused by FAW is more extensive than *Helicoverpa*. Typically *Helicoverpa* do not cause extensive damage to the crop during the vegetative stage, so the majority of *Helicoverpa* spraying has previously been targeted at cob protection. If *Helicoverpa* get into the cobs then they will mostly feed at the tip of the cob, so lightly damaged sweet corn can have the tips of the cob cut off and the remaining sweet corn cob can still go into the pre-pack market. A specialist sweet corn agronomist mentioned "Prior to FAW, *Helicoverpa* was the primary driver. We hardly even consider this anymore now that fall armyworm is here."

Fall armyworm are causing extensive vegetation losses, requiring early spray applications to maintain the photosynthetic capacity of the plant. Then, once entering the cob, they tend to feed all the way down the cob and typically emerge toward the base of the cob when ready to pupate. This results in complete loss of the cob. In addition to entering at the top of the cob, FAW larvae can burrow directly into the cob along the length of the cob.

"With the high and constant pressure we get, you cannot go soft on this insect pest even though we would like to. You have to go hard! e.g. if you over rely on Fawligen, too much damage will occur leading to substantial economic losses. I would far prefer to be using softer and less aggressive management strategies than I am, but at this stage we are doing what we have to do to get the crop through to harvest."

One agronomist mentioned that there was a noticeable increase in FAW egg lays on the full moon, and also that 'silking' appears to be the most attractive sweet corn growth stage.

The combination of an extremely attractive host crop (sweet corn); high market value of the crop; staggered planting dates and a desire for production for approximately 8 months of the year arguably makes sweet corn production in Bowen the epicentre of FAW management in Australia. Reports suggest that a single sweet corn crop is likely to get at least 6 to 8 passes prior to harvest (often more), which is around double what was previously being applied when *Helicoverpa* was the main pest. Some sweet corn blocks have been sprayed up to 14-15 times in extreme situations.

"Growers are starting to question the economics of sweetcorn production, but are continuing to grow this crop as 'it's what they do'. On a per hectare basis, we used to spray 3-4 times per crop for

Helicoverpa. We are now spraying 8 – 12 times, so the cost for insecticides has increased at least 3-4 fold. It is probably more than this because the cost of insecticides has also increased now that FAW is our primary pest."

This can mean, when application costs are also included, that the cost of FAW on sweet corn production may be in the order of an additional $500-$1000/ha per crop, compared to when only *Helicoverpa* required management. While this sounds extreme, one agronomist mentioned that this level of insecticide input is 'financially sustainable' due to the high value of the crop. "Growers are still currently wearing unacceptable levels of damage even with this intensity of spraying. So the value of the crop losses is still far outweighing the additional cost of insecticides."

This was also supported by the local entomologist who mentioned that "an insecticide program to manage FAW in sweet corn may now cost up to $1500/ha. But this needs to be put into perspective in that the crop is likely to cost $5000/ha in establishment costs alone and is expected to return a gross income of over $30 000/ha. So avoiding a 10% yield loss will more than cover the additional spraying cost."

If a corporate farm can develop a FAW management strategy that can 'cost-effectively' supply high quality produce to their supermarket customer, then this has major commercial advantage to them, and hence these organisations are extremely 'protective' of their individual strategies which have been largely developed by their internal agronomy teams.

Other vegetables – while there are a wide range of other small crops being grown in the district (e.g. tomatoes, melons, cucurbits, green beans etc.), the main crop commonly mentioned as being targeted by FAW (in addition to sweet corn) was capsicum. Typically vegetable crops such as capsicum are transplanted sequentially from March to May.

In particular, it was reported by several that small FAW larvae appear to enter the young capsicum fruit under the calyx (possibly because this is a very difficult part of the plant to get effective spray coverage) and move inside the stem and into the developing fruit. Once inside the young fruit they can often complete their full development stages, remaining inside the induvial piece of fruit for their full lifecycle. Insecticide control is considered effectively impossible once they have entered the fruit. One agronomist reported finding FAW pupae inside capsicum bells – with presumably moth emergence delayed until the rotten fruit falls from the bush and breaks down.

However, the local entomologist interviewed did openly question if all the damage that is being assigned to FAW was only coming from FAW? In his experience from trial work, it was not uncommon to also find *Spodoptera litura* (and possibly *Helicoverpa)* contributing to this type of damage. However, the agronomists interviewed appear to be confident the damage was mostly from FAW.

Important insecticides

Maize – Maize for grain was the major challenge identified by several agronomists. While yields are relatively high, the crop value (in 2022) was not adequate to support the increased insecticide costs required and this is seeing several growers question its place in the program.

This resulted in at least one agronomist acknowledging that their current management strategy was to 'go hard and early' with broad-spectrum (and cheap) insecticides (methomyl, pyrethroid and organophosphate combinations). While this was accepted as not being sustainable, they didn't have the confidence that a 'softer' program was possible "within budget" for these lower value crops.

However, other agronomists interviewed had a very different program for maize. One strategy was to try and 'ride out' early vegetative damage without spraying, but start an aggressive insecticide program from around the V12 growth stage (particularly in maize crops being managed for hybrid seed production). A typical program would be something like:

V12 growth stage – Vantacor (via high clearance ground rig)
Tasselling – Steward (via high clearance ground rig)
Silking – Vantacor (by plane)
Cobing – Steward (by plane)
If further spraying is required – methomyl

This agronomist mentioned that it was "rare to spray any insecticides on maize, prior to FAW."

The strategy of a third senior agronomist was:

> Affirm very early, to get the crop through to above V6 and then nothing until about V15 in grain crops. Crops will suffer a lot of damage and look messy.
> Once tasselling starts it is critical to protect the crop to ensure pollination. First spray will normally be Steward, which is 'OK' unless you get rain or overhead irrigation within 5 days. Then 1 more Altacor 'should' get through to harvest. Fawligen is added to Steward and Altacor applications.
>
> For sweet corn or popcorn, the main insecticide program needs to start earlier i.e. around V10 (as tasselling starts about 3 leaves earlier and there will be large FAW at tasselling if the program isn't started by V10). This may result in an extra 2 insecticide applications in sweet corn.

Pulses – One agronomist suggested that a standard insecticide program for mung beans and soybeans would often look something like a methomyl + deltamethrin broad-spectrum application in the vegetative stage. This is chasing a broad-spectrum complex of FAW, *Helicoverpa*, loopers and supressing sucking bugs. Salt will be added if green vegetable bug is present. Sometimes in soybean a second vegetative application will be applied, due to the longer growing season compared to mung beans. The alternative to methomyl + deltamethrin for this early 'broad spectrum' spray is Skope.

This is typically followed by an Altacor/Vantacor at early flowering / pod set, where approximately 3 weeks residual control of lepidoptera pests is expected. After which the grain should be getting hard enough that further damage is unlikely. Sometimes a further methomyl application may be needed immediately prior to harvest to knock down sucking bugs. So typically a 2 (or sometimes 3) spray strategy can be achieved in mung beans, while an additional application is likely to be required in soybeans.

A different agronomist was prepared to carry more early vegetative damage in soybeans, accepting up to six FAW/m without spraying. Should numbers exceed this threshold, then either Affirm or Steward would be applied to vegetative soybeans. Then most crops would get Vantacor at early flowering (with Shield tank mixed if sucking bug control is also needed). Hopefully that would see the crop through to harvest, with the potential of a late methomyl being required to knock down sucking bugs pre-harvest to reduce grain sample contamination. "On some crops a further Steward or Decis 'might' be needed following the Altacor, where pressure is ongoing."

A third agronomist was more concerned about early vegetative damage in soybean and mentioned that "FAW can decimate soybean seedings from the first trifoliate leaf." Their strategy involves an extremely early Steward application, primarily to protect the main terminal. After establishment they are accepting vegetative damage until flowering commences.

In mung beans they may get some early cluster caterpillar pressure around the 4-5 leaf stage. If this requires treating, they will choose a soft insecticide.

The next application in both mung and soybeans will be at the commencement of flowering and will normally be either Affirm (if FAW only), or more likely Skope where sucking bugs (esp. red banded shield bug (RBSB)) are present. This agronomist suggested that Skope was preferred over Shield for RBSB, as the Shield label says no applications to flowering crops, which is when it is needed. RBSB is generally more prevalent than GVB.

> *Authors comment: Following these interviews ICAN checked relevant product use patterns. Shield (clothianidin) is not registered for use in summer pulses, however use in mung, navy and soybeans is currently covered by a minor use permit (PER86221 effective October 2024) for control of RBSB and GVB. As indicated above, the conditions of the Shield permit do state 'DO NOT apply to crops in flower.' Skope (acetamiprid + emamectin) is fully registered for use in summer pulses for a wide range of insect pests, including GVB, RBSB, Helicoverpa and others. The Skope label contains a general statement 'DO NOT spray crops while bees are actively foraging.' Therefore, early evening / night applications of Skope may be in compliance with the label if used on flowering crops.*

Should any further applications be required in summer pulses then this agronomist indicated that the next spray will be 'hard' i.e. Vantacor + Lannate + Decis. One of these applications is usually adequate in mung beans, however a second may sometimes be required in soybeans.

Sorghum – The accepted 'industry threshold' for FAW was reported to be 30% damage in vegetative sorghum, however one agronomist reported that they are currently running with 40% and sometimes 50% leaf loss without the need for vegetative sprays – however they were aware of others using up to two Vantacor applications under similar situations.

In the opinion of two experienced agronomists, insecticide use in grain sorghum is still more important for *Helicoverpa*. The strategy was based around a single application of Vivus at flowering / early grain fill, predominantly for *Helicoverpa*. One agronomist mentioned that occasionally they have added Fawligen to the Vivus application should high numbers of FAW be present and would also have methomyl as a back-up strategy should late season clean-up be required. The other agronomist mentioned that they were of the opinion that Vivus alone had 'some' activity on FAW but typically this application would be a Vivus + Vantacor application and was finding that this 'often' was the only application required.

Sweet corn & capsicums – Typically, due to extreme pressure in sweet corn, feedback was that most crops will be getting at least 2 applications per each effective MOA, and some key MOA groups will be used up to the maximum number of allowable applications. See Table 15 for the maximum number of applications per insecticide group permitted under labels or permits.

One agronomist suggested that, where possible, emamectin is targeted to younger crops (protecting vegetative material), with chlorantraniliprole preferred for protection of the cobs. Best results with emamectin are being achieved with a directed spray right over the top of the row, using very high water volumes to get the insecticide deep into the whorl.

Another specialist sweet corn agronomist suggested that their program was not based on crop growth stage, as they have crops at every growth stage on the farm at the same time and hence the 'farm' is treated, rather than an individual 'block' being treated. So their approach is a MOA rotation strategy. Applications are being made almost weekly and all effective modes of actions are being used throughout the crop. As a minimum, their sweet corn crops may receive 3 applications of both Success Neo and Proclaim and one application of Coragen, with Fawligen or Fawligen + Vivus being added to several of these applications. For crops being grown under the highest FAW pressure, application frequency could be up to 11-12 applications in total i.e. 4 x Success Neo; 4 x Proclaim; 3 x Coragen, with several of these tank-mixed with Fawligen (typically sweet corn crops under this level of pressure will be getting 8 Fawligen applications @ 100 mL/ha through its life).

This agronomist rated Coragen as a 4.5 (out of 5) for FAW control, Success Neo (at the low rate of 200 mL/ha) and Proclaim as 4 out of 5 and Fawligen 1.5 to 3 out of 5, depending on application set up and frequency of application. They are not using indoxacarb "as it doesn't work on FAW". He also mentioned that they are consciously trying to limit the number of Coragen applications as they see this as their strongest tool and hence needs protecting the most. However, they are aware that they are currently placing extremely high reliance (and selection pressure) on emamectin and spinetoram.

Due to the heavy pressure in sweet corn and the lack of alternative MOA for rotation, Success Neo is being used against FAW in Bowen / Burdekin (more so than most other regions interviewed). Growers realise that while it "works well on FAW", Success is the most expensive option available ($140/ha for 400 mL/ha) and can be quite damaging to some beneficials, so feedback from several was that "it's not the first preference when choosing an insecticide" and may often only be used where they have 'run out' of other rotational options. However, one agronomist was regularly using it (up to 4 times per crop) in their sweet corn program at the low label rate (for *Helicoverpa*) of 200 mL/ha which, in their opinion, was "just as good as higher rates, but saves a lot of cost."

Indoxacarb is recognised as not as strong as the other insecticide MOA on FAW, but is still being applied by some under permit, due to the need for MOA rotation in sweet corn.

Some methomyl is still being used by some growers and was reported to "work ok" providing coverage is excellent and the application is well timed. Although agronomists recognise that it will be flaring sucking pests by knocking out beneficials.

Flubendiamide (Belt®) does not have a registration or permit for any use in sweet corn (the label specifically excludes sweet corn), although it is registered for *Helicoverpa* control in some other vegetable crops including capsicum. However one agronomist did mention Belt being used in sweet corn.

Of those interviewed, it was unlikely that Fawligen would be relied on for control alone. However it was not uncommon for Fawligen to be added to other insecticide applications in sweet corn. As mentioned above, one specialist sweet corn agronomist was regularly using up to 8 applications per crop of Fawligen (or Fawligen + Vivus if *Helicoverpa* are also present) in mixtures with other insecticides and added that "standalone Fawligen efficacy on fall armyworm is generally regarded as inadequate for commercial purposes in Bowen. This is a factor of insect pressure and efficacy. If there are 80 eggs in a raft and 50% mortality, there is still a lot of damage and insects left in this crop. The efficacy of Fawligen is variable and depends on application coverage. If applied in high water volumes and applied regularly, efficacy is better than if applied irregularly and with lower carrier volumes/coverage. Application via a pivot irrigation system provides best efficacy with this product. Fawligen is often added to other products."

In the opinion of two agronomists working extensively in sweet corn, "control is still not adequate with the tools we have, even with constant spraying."

In capsicum, three agronomists had shared similar experiences i.e. once fruit begins to set then the program is a constant rotation of flubendiamide, chlorantraniliprole, indoxacarb, emamectin and some spinetoram and methomyl. "It is unlikely to be possible to use any form of IRMS. You need to go hard and early to stop anything getting into the bell."

There was some mention of foliar Bt sprays also being used in capsicums, but most likely in mixtures and not as a standalone application.

Biological agents

Metarhizium is generally considered too be to slow to work in high value crops such as sweet corn and vegetables and hence is not considered a viable tool, although there was some interest to further understand if it could be additive to an insecticide program.

In grain crops, one agronomist mentioned that you can "sometimes see different native viruses including metarhizium impacting FAW populations later in summer", while another mentioned "we have noticed activity of native metarhizium on other *Spodoptera* species and I'm highly interested in potential for FAW management. Under right conditions (high humidity) it has wiped out populations."

One agronomist mentioned that they had tried spray oils directly banded over the whorl of young vegetative maize. While it "had some effect, the efficacy was not probably enough to warrant continued use."

There were different opinions with regard to native beneficials. One agronomist mentioned that native beneficials are not considered at all when it comes to FAW (however they were previously with *Helicoverpa*). "The time lag before they are up to speed is too slow. Basic strategy is once you detect FAW in the crop, you get them out ASAP."

While a different Burdekin agronomist reported that you can find "heaps of predatory bugs, lady birds and lace wings. And these are taken into account when scouting and choosing the insecticide." However this agronomist was not using any quantitative counts or specific ratios. This agronomist had also tried commercial release of *Trichogramma* in winter 2020 maize crops (targeting both *Helicoverpa* and FAW) however they were "not really effective and didn't establish and I suspect they were being knocked out by heavy insecticide use in adjacent horticultural crops."

A third very experienced and knowledgeable agronomist offered the following experiences;

- *Trichogramma* – Currently making releases in sweet corn for *Helicoverpa*, but don't believe they are doing much (if anything) on FAW
- *Telenomus* - Egg parasite. Literature suggests it may be better than *Trichogramma* on FAW
- Pirate bugs - General predator. Working in NNSW but appears to be too much FAW pressure in the north to keep up. And are too expensive as they are very difficult to raise for commercial release
- *Cotesia ruficrus* - General parasitoid. Has been useful in southern Qld & northern NSW. Steve Madden is rearing them for armyworm in winter and that is working in NNSW. However doesn't believe it is doing much against FAW in the north. Native Cotesia may be a different species in north Qld.
- *Trichopoda* – Helping on GVB, but requires a pollen refuge.

A fourth specialist sweet corn agronomist commented that he "would like to see more activity to locally reared and released beneficials that specifically target fall armyworm on a large scale. We feel that locally adapted natural enemies will perform better than ones selected and reared outside the region. Insects need to be adapted to the tropics." This agronomist also added that "In *Heliothis* days, we scouted the number of parasitised versus non-parasitised eggs. We don't do this with fall armyworm as there are simply too many FAW and the pressure is too high to bother."

Natural Solutions Australia https://naturalsolutions.com.au/about/ is a commercial insectary recently established in Bowen by Jamie Jurgens (local vegetable grower). One agronomist reported "They intend to rear most commercialised species, but are not currently doing whitefly parasitoids."

Cultural / non-chemical management tactics

There were mixed views on the benefit of pheromone traps. Some agronomists considered that they we not of much use in the district, due to the expectation that FAW are always present and "huge' numbers of moths can be captured almost all year.

There was some use in Bowen, particularly early in the season and especially in more remote sweet corn blocks, as a way to determine when heavy monitoring is required during winter. One Bowen agronomist suggested that trap numbers used by many are often inadequate and a lot more are needed to have confidence in the information. And of those traps that are present, several are only checked infrequently. "We need many more traps and these need to be checked twice weekly. If this were done, it would be possible to evaluate the effectiveness of moth kill strategies such as 'attract and fill' (Magnet + methomyl) done on an areawide basis. The traps that are currently out there are being run by DPI and "can ¾ fill a 5L bucket each week when pressure is high in early summer."

In the Burdekin, Nutrien were initially maintaining their own network of traps, but this has now been incorporated into the broader QDAF monitoring program across Queensland.

A local entomologist in Bowen was conducting research into pheromone attractants. "Male pheromone traps are able to capture massive quantities of moths – however correlation with egg lay is not high. They are useful to detect activity moving into a paddock, but not much use in population reduction."

"We still need to do more research with female attractants for population reduction. We don't yet understand if they are attracting young, but not yet mated females. Or females full of eggs and ready to lay? We were doing some work with the attractant QM FAW, but the Department Director requested that we stop this work, as QM FAW is it not registered with the APVMA (but is available commercially). We also have another attractant in trial work (but not yet commercially available)."

Growers are still experimenting with the concept of Magnet + an insecticide in sweet corn. The concept appeals to many, due to the ease of use and relatively low cost – "even if it only reduces pressure and cannot be used as a standalone option." One agronomist reported that some growers are applying strips every 100m or so; some are just treating perimeters of blocks; while others are setting up a drip nozzle at the end of a conventional boom that is applying other broadcast insecticides.

The concept of Magnet, coupled with Entrust (spinosad) is of particular interest to those attempting to grow 'organic' sweet corn in Bowen, as organic producers have very few other options outside of NPV.

In grain crops, one agronomist has been using Magnet + methomyl on some farms with reasonable performance. "Some growers are only using around the boundary of paddocks (many paddocks are very small), while others are using strips every 50m on larger paddocks. You can find a lot of dead moths of all species (including FAW) after application, but also significant mortality to beneficials, especially lady beetles when using methomyl." This agronomist was strongly interested in research into alternate insecticides. Has tried Altacor and Affirm with Magnet and they seem to have some efficacy (but visual observations only and not any trial work). Discussed this may be a place for spinetoram – as it is currently too expensive to be used broadacre in grains crops and has some adulticide activity.

This agronomist has also had some experience with QM FAW, an alternate attractant to Magnet. Their experience was that QM FAW was visually significantly better than Magnet in attracting FAW i.e. many more dead moths. QM FAW is only available via EE Muirs and there is some confusion over the 'registration' status (i.e. does the attractant need to be registered, or just the insecticide partner?).

Existing resistance, IRMS and impact of FAW on IRMS

One Burdekin agronomist interviewed was regularly sending FAW samples to NSW DPI (Dr Lisa Bird) for coordinated resistance testing.

All those interviewed recognise that current insecticide use for FAW is placing extreme selection pressure on several products, but in particular the Group 28 MOA. "Chlorantraniliprole is currently being heavily used in maize, sorghum, soybean, mung bean and vegetables for FAW, while also being used for cluster caterpillar and *Helicoverpa* – so there is also a resistance concern for these pests."

There was no evidence of any formal IRMS being utilised in the Bowen / Burdekin, outside of label and permit restrictions on the number of applications, although some of the agronomists interviewed proactively mentioned information contained in 'The Beatsheet'. There was general support in principle for the 'concept' of an IRMS that would limit the exposure to Group 28, although all those interviewed were struggling to see how this could be practically implemented in the Bowen/ Burdekin region, due to the 12 month of the year use patterns. There was commentary along the lines of "Growers would be generally accepting of the idea of a non-use period of Group 28s, as long as this was not when 'they' wanted to use it."

Similar views were shared by a local entomologist and a leading sweet corn agronomist. "There are probably not enough tools in the tool box now for management in sweet corn. Restricting any product to a 'non-use window' is only going to place more pressure on the other insecticide MOAs."

One broadacre agronomist mentioned that their position was to try to avoid any consecutive chlorantraniliprole applications and where possible, limit applications to only once per MOA per crop. However they noted that this was generally not possible in maize crops for grain and not possible at all in vegetables (when controlling both *Helicoverpa* and FAW). This agronomist did make the comment "However, should I be using chlorantraniliprole more frequently if others are, and therefore it will be rapidly 'broken' anyway?"

In the Burdekin, all agronomists were still trying to determine what will be the 'new' break crop strategy for sugarcane, now that FAW are entrenched and winter maize has become uneconomical to grow (at $280/t for a 10-12 t/ha yield). Sorghum is not really considered a replacement as it does not like growing over winter and will only yield 'up to 6 t/ha', at similar value/t as maize.

Grain crops

One agronomist mentioned that they had heard stories of growers applying up to double the permitted application rate of chlorantraniliprole on pulse crops. However, for the growers they are managing “a well targeted application at full label rate consistently gives good control for approximately 3 weeks and this should be enough if you apply it correctly, even via the plane.”

Similarly, other agronomists reported growers spraying crops such as cane and vegetative soybeans and sorghum with multiple applications of chlorantraniliprole, when “there is generally no need to spray at all in these situations.”

In addition to the obvious pressure being placed on Group 28, one agronomist was also concerned with regard to the pressure being placed on methomyl.

Another agronomist mentioned that some resistance exists to both methomyl and pyrethroids in sucking pests, so typically when they are used it is always as a tank mix of the two, which normally still works (as confirmed by experience, and not testing). This same agronomist also reported that they are seeing resistance to pyrethroids in *H. punctigera,* while industry resistance testing has shown low level resistance to indoxacarb in both *Helicoverpa* and FAW from the Burdekin “which is concerning.”

Horticulture

The primary ‘resistance management strategy’ in sweet corn is the number of applications permitted by the product label. As growers are directly operating under quality assurance programs of the major supermarkets, label compliance is generally good. (*ICAN note: It should be noted that ‘maximum’ number of applications on the label may often be set in relation to residue limits in the produce and may not be sufficient as a strategy to delay the selection of resistant individuals.*)

As horticultural blocks are staggered in their planting dates (to extend the harvesting window), it is more common in these crops that a spray tank of insecticide may be applied to adjacent blocks of sweet corn at different growth stages. From a resistance management perspective, this means that growers are more in-tune with the need to rotate modes of action across the farm for successive applications, rather than considering matching a particular insecticide to a specific crop growth stage. First applications of Group 28 insecticides commence in Bowen in March to early April and run continuously until early November.

Each of the agronomists working in sweet corn mentioned that they are equally concerned with both selection for resistance from ‘overuse, but also that the currently available FAW management options (and their existing frequency of application as per the label) are still not adequate in producing ‘damage free’ sweet corn under the FAW pressure experienced in Bowen. One agronomist commented that “The best growers who are trying to do the right thing and use less insecticides are currently the ones who are being financially penalised the most, due to severe crop damage.”

Outside of ‘new’ insecticides, are there options for FAW management that you would like to see pursued?

- More information on native beneficials and their usefulness. Including the effects of ‘heavy’ spraying frequency for all the key modes of action
- A similar product concept to Durivo (i.e. seedling treatment) for sweet corn at planting – but not a Group 28 (like Durivo or Fortenza)
- One agronomist (who was acutely aware and ‘on-message’ with resistance management and the need to consider beneficials) commented that “There is very little information available via the research community on how to optimise performance of ‘hard’ insecticides e.g. methomyl & SPs – both for performance and managing resistance”

- A different agronomist shared similar thoughts and was seeking more information on correct timing and application strategies for all insecticides (including the older chemistry). There is very little information available (via the research community) on how to optimise performance of 'hard' insecticides e.g. methomyl & SPs – both for performance and managing resistance. Use of these is still very important late in the crops and can therefore take pressure off the softer chemistry
- There was a request for additional grower extension on recognising FAW in capsicums in particular. FAW neonates will immediately burrow into small fruit and it is very difficult to detect their entry point. It often looks like minor mechanical damage i.e. a bit of rubbing. To the inexperienced grower, they don't even know FAW are present until they are mature and exit fruit to pupate. By that time the fruit is rotten inside, although sometimes it will show as uneven colour (blush)
- More information is sought on vegetative thresholds in sorghum. The agronomist requesting this is currently prepared to accept 40%, and maybe 50% leaf loss which doesn't appear to be reducing yield (while the current threshold is 30%). In their opinion, the existing threshold in vegetative sorghum needs more extension, as they believe too much spraying is going on in vegetative crops
- One agronomist specifically mentioned great quality information being provided via The Beatsheet and specifically valued the support provided by Hugh Brier & Melina Miles and hoped this would continue. This agronomist also suggested more extension (especially to those not directly talking to Melina / Hugh) on insecticide rotation and best use (i.e. what order to use insecticides in order to improve efficacy and preserve beneficials. Training workshops are needed "Similar to the detail provided by ICAN in the herbicide space"
- Drift management – there is awareness of drift with herbicides, but most 'don't care' with insecticides (and this can be particularly problematic especially around adjacent vegetable crops close to harvest)
- We need more control choices (both chemical and non-chemical) in order to implement a sustainable program. There is not enough alternatives to be able to reduce selection pressure on any options we are currently using
- Withholding periods
    - Shield cannot be used once flowering commences (when we want to use it)
    - Skope – 4 weeks for mung beans, 6 weeks for soy limits use to mid-season
- Alternate softer insecticide to methomyl is needed for attract & kill technology. Methomyl is killing many beneficials
- Registration of QM FAW, as it is more effective than Magnet in attracting FAW
- One of the agronomists mentioned that he thought he remembered reading somewhere that resistance mechanisms are different in FAW moths to caterpillars. If correct, then how does this information impact what they should / should not be doing with attract & kill technologies that target adult moths?
- One agronomist reported a situation where a previous crop had been ploughed in and a new emerging crop was immediately attacked by large FAW at emergence – as there was not enough time for an egg lay and larvae to reach that growth stage. This agronomist believes that FAW have potential to live underground and feed and develop on vegetative material and then come above ground when there is something to feed on. (A similar observation was reported in subsequent interviews in the South Burnett)
- A sweet corn agronomist was particularly interested in the concept of area wide management to reduce overall FAW pressure. "Integrating area wide management will be

critical for success. If we don't act to control this pest in an areawide manner, we will be relying on frequent applications of a limited number of insecticides, as we are currently doing. And that is not sustainable." Although noting that this would be very difficult to implement in sweet corn where there is intense competition between growers and a general lack of desire to collaborate. Currently "Every horticultural farmer is out for themselves"

- "Ideally there would be areawide management targeting adults, based on a broad network of pheromone traps to provide early warning of when moths are active in the area. This would be supported by an areawide strategy to attract and kill moths which would also be supported by regional rearing of targeted beneficials for fall armyworm and widespread release of same."
- Education of growers and advisers on effective spray programs (along with coordination of growers with very separate and personal profit objectives) would be required to engage in an area wide management strategy. Targeting education at agronomists would cover the larger growers in large part, but there are many smaller growers. Priority issues are how we act collectively in an area wide IPM manner. This will be made more complicated by the individualistic nature of growers in this industry
- Identification of locally effective natural enemies for fall armyworm with local rearing and release on an areawide scale. I feel that an area wide management strategy targeting reduction of adult moths is the only option I can see for longer term success
    - How can we, as a grower community, mass rear and release beneficials?
    - For *Helicoverpa*, we used to do widespread *Trichogramma* releases plus areawide Magnet and methomyl
- A broader network of pheromone traps that are inspected and reported twice weekly, is needed. Coupled with areawide deployment of attract and kill strategies as triggered by moth activity in traps, along with rearing of locally adapted beneficials and mass releases
- More targeted products and better attractants to use in attract and trap strategies would also be beneficial. It is understood that several companies may have such products. Companies mentioned were Smart Green and OCP (organic crop protectants)
- Metarhizium would also have a place in area wide strategies
- We also need more chemistry with different modes of action from those we currently have. It's essential to reduce the selection pressure placed on the three main chemistries currently used.

14.1.6. Atherton Tableland (AT)

Atherton Tableland is a high rainfall 'tropical' production region, which is geographically small but cropping diverse - incorporating a mix of grain crops, tree crops and fodder (including maize) for dairy production. The high rainfall and warm (but not excessively hot) environment results in almost continual production across the full calendar year.

Some agronomists interviewed on the Atherton Tableland also consulted to properties to the west of the Tableland, where rainfall drops rapidly, and 'cropping' is limited to rain grown summer cereals (sorghum and some maize) typically for stockfeed. While some were also part of businesses that also service the 'wet tropics' region on the coast (i.e. Tully / Innisfail) which is very much a sugarcane monoculture.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
Qld	AT	X		X	X			X		X

In addition to these pre-selected crops, feedback from agronomists on the Atherton Tableland shared their experiences with management of FAW in improved pastures (most commonly this was Rhodes grass *Chloris gayana*). Some also mentioned the presence of FAW in orchard crops.

Expected FAW pressure

FAW can be considered endemic on the Atherton Tableland, after arriving 3 summers ago. All agronomists reported that it can be found all year round, just that development lifecycles slow over the winter months.

One agronomist suggested that numbers still appear to be increasing each year.

Key crops are now being actively managed for FAW, whereas before the arrival of FAW, key 'grain' and 'fodder' crops were only monitored and treated 'occasionally' for other caterpillar pests.

Maize – While all agronomists reported maize to be the primary host of FAW, there was diversity in agronomist response with regard to both cropping systems and management.

One agronomist who claimed that "they manage the majority of maize crops on the Tableland" suggested that the preferred maize planting window is November to Christmas, with most of the grain harvest finished by March. In a relatively 'dry' year such as 2021, they indicated that they were able to keep the maize planting window condensed, which provided significant benefit in subsequent FAW management, as crop growth stages were more uniform across the district. Conversely, the previous November-December 2000 was 'wet' which saw planting extended and therefore additional management problems resulted with coordination of foliar sprays. Predominantly crops managed by this agronomy team were going through to grain as opposed to silage production.

This agronomist reported significant egg lays are often seen in front of a weather change. Their belief is that once in a maize block, FAW is happy to continue cycling within the same crop, with numbers continuing to build as the crop progresses - from both the next generation and extras 'flying in'. They have also noted a change in laying behaviour each year in maize. In the first year of FAW, eggs were mainly laid on upper leaf surface; year 2 on underside of leaf (which is more difficult to hit with sprays) and in year 3 they are now laying in the whorls.

A senior agronomist from a different business reported a significantly different experience. Maize crops under his management were primarily being grown for dairy silage / green cut and therefore he reported that planting "was continuous from about August 1 to March 1", so as to have an ongoing harvest for most months of the year.

This agronomist mentioned that several of these growers supplying the dairy industry are typically beef graziers planting some of their paddocks to maize for their dairy cattle neighbours, and often the planting and harvest of these maize crops was done by contractors. Prior to FAW, most of these maize crops were not treated for insect pests, as any low-level *Helicoverpa* damage was ignored, especially when the crop is cut before grain maturity. So the system was very low input for the land holder (contract planted with only fertiliser and seed costs, rain grown, and then contract harvested). With the continual FAW pressure, several of these growers are now questioning their desire to grow maize for the neighbouring dairy farm and are starting to withdraw and leave paddocks under grass pasture for their own beef cattle operation. This is causing the dairy industry to reconsider where they will be able to secure their long term feed supply. The agronomist suggested that it may be possible to switch the dairy feed to a mix of sorghum and summer pulses, but there is considerable work that needs to be done in this space to develop new feed rations using inputs with different nutritional values.

A third agronomist from a different organisation was typically dealing with lower rainfall properties to the west of the Tableland reported that these growers (small in number) are consciously moving away from a mix of maize and sorghum (mainly for grazing) to a program much more heavily dominated by sorghum as a result of the FAW pressure in maize.

Peanuts – Traditionally, many crops would only get 1 application for *Helicoverpa*, however 2-3 may occur in heavy years. These sprays will also be controlling FAW, but with the increased pressure since the arrival of FAW, many crops are now getting up to 4 insecticide applications.

FAW damage is a combination of early leaf removal plus damage to flowers and pegs. FAW do not appear to be targeting pods.

First insecticide application is commonly going out with the first foliar fungicide spray. Crops are sprayed with fungicides about every 10 days, so there is plenty of opportunity to include an insecticide as required. Insecticide choice is often methomyl (where sucking bug control is also required), or Vantacor if only lepidoptera control is required.

One agronomist was of the opinion that pressure in peanuts was from moths flying in and laying eggs only, and not from continual lifecycles turning over with the paddock when peanuts are grown i.e. when moths pupate from peanut paddocks they appear to be dispersing and looking for a more preferred host.

Soybeans – One agronomist reported ‘little pressure to date’ in most of the soybean crops they manage. Another agronomist reported that they are trying to keep spraying of soybeans to a minimum and finding predatory bugs are helping this objective. If spraying is required it is often Steward, as this will have more activity on sucking bugs that are also likely to be present.

Rhodes grass – Grass pasture, in particular Rhodes grass, was also identified as key host for FAW. Grass pasture (Rhodes) is grown for grass seed production, hay and for use as mulch for local orchards. Each of the agronomists interviewed mentioned that they can find significant levels of FAW in the Rhodes grass pastures at all crop growth stages, especially during summer months. However, young crops in the establishment phase, are of highest concern.

Typically they have never needed to check grass pasture for caterpillars, so it is still coming as a surprise to some growers when pastures are being severely damaged.

Many grass pastures are still not really being scouted. However the agronomists interviewed are starting to closely monitor newly establishing plantings. As they are now scouting grass pastures more frequently, these agronomists reported they are often finding mixed populations of FAW plus northern armyworm (*Mythimna separata*) and *Helicoverpa*.

One agronomist mentioned that it is common to plant Japanese millet in combination with the Rhodes grass. The millet is used to provide quick ground cover and give protection for the slower establishing Rhodes grass i.e. the millet will be at 5 leaf when the Rhodes grass will be 2 leaf. Both of these species are “getting smashed early by FAW”. So there is often a need to spray to get the pasture established. There was general reluctance to articulate what insecticides are being used, due to lack of registrations or permits – however it was implied that Vantacor/Altacor, or in some cases pyrethroids, are probably the products of choice.

Other – one agronomist reporting finding FAW egg lays in passionfruit and two mentioned avocadoes “*But typically these do not come to anything. However, at least in avocadoes, there is reasonably high use of chlorantraniliprole for other caterpillar pests, so that is probably keeping FAW at bay*”.

Another agronomist reported finding some FAW in potatoes, but indicated they appear to be generally controlled by the existing *Helicoverpa* management strategy being used.

Nobody mentioned sugarcane as an important host for FAW.

Management strategies

Maize - All agronomists identified that maize crops will be continually under pressure from FAW, from emergence right through until at least silking, as they are predominantly being grown over the summer months when FAW is most active.

The most critical growth stages for maize were identified as protection of relatively early vegetative growth (otherwise too much photosynthetic leaf area is lost, and development is delayed); and then again to protect the young cob. For crops being grown for grain production, cob protection may be required well past silking. Typically agronomists reported that they are ‘carrying’ a significant amount of leaf injury from approximately V6 to at least V10 growth stages, in order to avoid frequent spraying.

Grain sorghum – One agronomist, who was working in the drier regions to the west of the Tablelands, reported a swing from maize to dryland sorghum due to increased FAW pressure. Previously they could have got a sorghum crop through on a single well timed Vivus (some years not sprayed at all), but currently they are not using Vivus at all due to FAW pressure. They will carry up to about 10 FAW/m (and a lot of leaf defoliation) in the vegetative stage before spraying. Full monitoring needs to begin at head initiation. Generally they are finding that they can get a sorghum crop through to harvest with a Steward application at early head emergence, followed by a single Altacor/Vantacor. Prepared to accept up to 10% yield loss if it means they can get through without spraying.

Important insecticides

Chlorantraniliprole (Vantacor, Altacor) was consistently reported as the most ‘useful’ insecticide treatment against FAW. The key differentiating factor is the extended length of residual control, compared to other insecticide modes of action (rather than any significant increase in efficacy over competitive insecticides).

As FAW larvae are reported to be very sensitive to UV light, they seek to rapidly entrench themselves into hidden feeding sites as soon as possible after hatching. This includes moving deep into the whorl of a young maize plant; or using the silks to gain entry into the developing cob. One agronomist reported that you can often find FAW hiding under soil clods during the day and also indicated that most insecticides appear to work best when applied late afternoon / early evening. Possibly this is due to FAW avoiding UV light and feeding more at night?

Once entrenched, obtaining direct spray contact with the larvae, or where it is feeding, is almost impossible. So the key to effective insecticide control is to have the insecticide residue on/in the leaf prior to FAW hatching, so that control can be achieved as soon as the neonate commences feeding. With continual egg lays, a long residual insecticide such as Vantacor/Altacor applied prior to hatching appears to be giving the highest levels of control, and hence application timing is slightly more forgiving than with other insecticides.

In maize on the Tableland, the consensus was that probably the 'best' application timing for Vantacor/Altacor is early cob formation where a single application may give up to 3 weeks residual control, possibly extending right through to silking. Most appear to be trying not to apply any further applications after silking, although this is not always possible under sustained pressure. If conditions are 'wet' at this key growth stage, then a combination of natural beneficials and, in particular, native metarhizium are 'sometimes' enough to avoid the need for further late sprays post silking.

Where a further 'at-silking' insecticide application is required, one agronomist reported that they were getting good results from Affirm at this stage 'as you can get coverage where the FAW are laying'. A different agronomist mentioned that sometimes methomyl may be used for an at-silking application when there are monolepta beetles also present, as these beetles can feed on the silks and hence disrupt pollination.

While this extended residual control (compared to other insecticides) also means that Vantacor/Altacor outperforms other insecticides in the early vegetative use timing, the more aware users are looking to use an alternate mode of action at this early timing, for rotation to delay resistance. As there is very fast crop growth at these early crop growth stages, the length of extended residual protection from Vantacor/Altacor is somewhat compromised by rapid crop growth dilution. This means that there is less difference in length of residual protection between Vantacor/Altacor and other insecticides at this growth stage, and hence more acceptance by growers to use a different mode of action at this growth stage.

Often this earlier timing may be as early as the V2 growth stage and may be a program of two Altacor/Vantacor applications applied 21 days apart (as promoted by FMC – see below) i.e. a V2 application followed by a V6 application. Where chlorantraniliprole is not used early, indoxacarb (e.g. Steward) is often favoured due to price and perceived 'softness' on parasitoid wasps, although it is generally understood that 'efficacy' of Steward is inferior to some other options. Emamectin (e.g. Affirm) is sometimes also used for these early applications.

Spinetoram (Success Neo) is generally understood to be extremely effective on hatching FAW populations, however the expense generally prevents use in crops such as maize. At $129/ha for a single application (excluding application costs), Success Neo was not being used in 'grain' crops.

There was mixed feedback on the use of pyrethroids. One agronomist was not using any pyrethroids at all on high value crops, however did mention that in the early stages of the FAW incursion several growers were applying pyrethroids outside of advice given by their agronomist. A different agronomist reported that his growers had used reasonable levels of pyrethroids over the two summers past but have mostly given it away this past summer due to poor performance. A third agronomist reported that there is still significant use particularly in lower value crops e.g. crops being grown for fodder rather than grain, although this will provide knockdown only, and no useful residual control.

Under high FAW pressure on the Atherton Tableland there was no discussion around application rate for insecticides being used to target FAW. Where an insecticide is used, it will be applied at the maximum registered (or permitted) use rate. In all situations, users were looking for 'increased' efficacy (where possible) from all products when they are selected for use.

Each agronomist commented that FMC are supporting / promoting the consecutive applications of Vantacor/Altacor https://www.fmccrop.com.au/download/insecticides/Tech_Notes/fmc_vantacor_brochure_final.pdf with the proviso that these are being applied to the same 'generation' of insect pest. [*Discussion ensued as to whether there are distinct 'generations' of FAW in northern Queensland where there is no diapause? Or are we dealing with field populations with continual overlapping generations?*]

As a result of this, one agronomist reported they have been applying Vantacor at 'double' the maximum application rate to young maize and recording this in their spray records as two separate applications at full label rate, applied 3 weeks apart. They believed that this higher initial starting application rate was giving better knockdown and extended length of residual control, compared to the double application strategy. In their view, this would not be expected to result in additional resistance selection pressure (relative to the FMC position of two applications), nor should result in increased crop residues, as 'harvest' will not be occurring until well after the insecticide has 'run out' when this strategy is used at early vegetative growth stage. Only one respondent reported this.

This same agronomist indicated that they were often adding ProGibb (gibberellic acid) to pyrethroid and some Vantacor sprays, when applied to young maize and grass pasture crops. Their belief is that the GA will enhance early season leaf growth, and this can be useful to try to have the crop 'outgrow' the vegetative impact from FAW feeding.

While there was no 'standard' insecticide program, some options presented were:

	V2	**V6-8**	**V10-V14**	**Tasselling**	**Silking**
Lower yield potential 'dryland'		Steward	Vantacor		Vantacor only if needed
Light pressure	Steward or Affirm	Vantacor	Vantacor		Affirm only if needed
Heavy pressure	Vantacor	Vantacor			Affirm or methomyl
Heavy pressure	Alpha – cypermethrin + ProGibb	Double rate Vantacor + ProGibb			Emamectin

Biological agents

Fawligen - Each of the agronomists interviewed suggested that they are not finding a suitable fit in their management program. Reasons given included:

- Fawligen does not persist on the leaf surface (compared to the translaminar products) and will get washed off (high rainfall area, with many crops also having overhead irrigation)
    - Therefore applications need to be timed precisely at egg hatch. This requires twice weekly scouting in order ensure application timing is correct

  - There is not enough crop value in dryland maize to justify that intensity of scouting
- It doesn't build and spread in the environment, like Vivus does in sorghum. Therefore, to get it to work effectively, requires multiple applications e.g. weekly @ $20/ha per application
- Application is also critical. Appears to need ~400L/ha spray volume.

Foliar Bt sprays – two different agronomists both mentioned that they believe foliar Bt sprays are 'adding to' knockdown of other insecticides, despite both being told not to expect any significant activity on FAW. Neither were using foliar Bt spray solo or using these extensively (as they have been told that they are not worthwhile).

Spray oils – One agronomist has tried BioPest oil ($10/L). But believed it only works on anything that is directly hit by the spray deposit (which is almost impossible with FAW).

Beneficials – A range of native 'beneficials' can be found attacking FAW. These appear to be widespread, but inconsistent. Shield bugs and spine bugs were often mentioned as generalist predators. One agronomist was noting the impact of pirate bugs (*Orius sp*.) in soybeans in particular and would actively try to avoid spraying when these were present.

Beneficials are generally being 'considered' when making insecticide choice, but this appears to be more gut-feel than working on any specific counts or predator/prey ratios. One agronomist had tried commercial releases of *Trichogramma* and felt that they may have had some activity, but it was very hard to quantify, and they are probably unlikely to use going forward, while a second agronomist was using up to two releases per crop and was "hoping they are working".

One agronomist mentioned a preference for Steward over Vantacor for 'early' applications in maize on the belief that Vantacor is more damaging to native parasitic wasps and flies. He mentioned that he had insect count data to support this position and this information had been passed onto Melina Miles.

Two agronomists reported that it was not uncommon to find native metarhizium, which can build to useful levels late in the season with dense canopies and high humidity. Although it doesn't seem to persist in open (young) crops, and especially if conditions are hot and dry. It was hoped that, over time, this may become an important tactic as users become more familiar with the conditions required to maintain infection levels and this may be able to reduce late season applications.

A different agronomist reported that they were of the belief that the current BASF commercially available metarhizium formulation (Green Guard, sold into plague locust markets) has activity on FAW. However BASF has told them that they have limited availability of this product and is only formulated once per year.

Cultural / non-chemical management tactics

A comment that was raised by each agronomist is that growers on the Tableland have never directly paid for crop scouting. For crops where regular scouting has been required in the past, the retail-based agronomists have typically been able to cover this cost via margins on product sales. Each agronomist commented to the fact that this existing model is now most likely unstainable with the frequency of scouting required for effective FAW management. While this discussion was common across all crops, it was seen to be particularly problematic in low value 'grazing' crops (which have generally never been scouted previously), where the grower is already pushing back against the cost of insecticides required and the increased application costs of multiple insecticide passes, without additional charges for 'scouting'.

Potassium silicate – One agronomist reported that they have been adding potassium silicate to early vegetative sprays in maize. The principle is that it is abrasive and may wear out the insect mouth parts. This senior agronomist interviewed reported he was "not sold on the idea" but commented that one of the other agronomists in their team uses it regularly.

Pheromone traps have been tried, but generally not considered of much practical value, as moths are present all year.

One agronomist mentioned that they have looked into light traps (i.e. commercial scale bug zappers). But these cost ~$15 000 each and are needed at 1 per 5ha – so are considered uneconomical. A different agronomist reported that paddocks "close to towns" are getting hit the hardest and questioned if the moths being attracted to street lighting?

There has been some experimental use of attract and kill technology. One agronomist reported trialling the use of Magnet alone, Magnet + methomyl and Magnet plus Bulldock (beta-cyfluthrin) in 20m strips across a maize paddock. "We certainly found plenty of dead FAW months in the treated strips and could also find moths feeding on the Magnet only. However the FAW population overwhelmed the treatments. We decided that this could not replace the need for broadcast insecticide applications, so hence are no longer using it." There was some mention that many growers were uncomfortable with the concept of 'attracting' moths to their crop.

Existing resistance, IRMS and impact of FAW on IRMS

No IRMS strategies are currently in practice on the Tableland.

One agronomist mentioned that volunteer maize control has become 'essential' for population management.

Each agronomist interviewed was very conscious of the pressure being placed on chlorantraniliprole. Almost every maize crop will be getting (at least) two applications, while chlorantraniliprole is also the foundation insecticide in just about every other crop. Therefore it is being applied 'in the district' just about every month of the year. One agronomist mentioned that this is a similar situation to Sivanto Prime for whitefly control – in that Bayer only recommend 2 applications per crop, but with the diversity of cropping and planting dates, this can see Sivanto Prime often being applied up to 15 times per annum on a single farm.

The agronomist who had been experimenting with applications of 'double rates' of chlorantraniliprole and reporting better control was questioning if this was evidence of changing tolerance / reduced sensitivity to this product?

Another agronomist mentioned that they have included chlorantraniliprole seed treatment in 'management' trails being conducted by Melina Miles (QDAF) on the tableland. There was understanding that the potential availability of a Group 28 seed treatment, in addition to current foliar applications, will further increase selection pressure on this MOA.

There was no real obvious solution identified as to how an IRMS could be effectively implemented due to the ongoing annual pressure and crop rotation. One agronomist mentioned that the only way an IRMS 'might' be effective in reducing applications would be to physically withdraw product from the supply chain for a period of time each year. It was mentioned that Bayer currently do this with Lunar fungicide in bananas, whereby the local territory managers collect all unused stock from resellers on 1st May. While this doesn't prevent users from 'stock piling' product on farm, it does show intent to operate an IRMS. Discussion was had that chlorantraniliprole is about to become 'generic' so the opportunity to implement a withdrawal strategy such as this may have already passed.

There was some consensus that 'if' maize can be shown to be able to be sustainably grown on a 2-3 spray strategy then many current growers will continue to grow the crop. Those that have needed to spray more than that have probably already switched to alternate crops. Timing of insecticide applications is also important. Late season application requires aerial application (@ at 40L/ha and approximately $40/ha per pass). Strategies that can avoid/reduce the need for aerial application are likely to be beneficial in supporting ongoing maize growing in the region.

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- Chlorantraniliprole
    - One agronomist (mentioned above) has been applying chlorantraniliprole at 2x the current maximum label rate in maize and believes this delivers significant increase in performance / length of residual and would like to see this progressed to a label change
    - Another requested registration / permit (e.g. MRL's and grazing WHPs) for Vantacor in Rhodes grass pasture
- More work is still required to understand FAW lifecycles and host crops. One agronomist stated that QDAF have been "too slow to respond" and agronomists have needed to work it out for themselves
- One agronomist was looking for more information on FAW thresholds in maize
    - How much damage can be taken to the 'solar panels' and not affecting grain yield?
    - Does this vary with time of year? i.e. is it more important to protect leaves in winter when there is less photosynthetic activity?
    - Should thresholds vary with dryland v irrigated crops? Grain v forage crops?
- Application
    - One agronomist mentioned that there is possibly the need for application workshops for users, in particular aerial application in maize
    - Another mentioned that many growers are still very 'backward' with their application equipment, with many old sprayers and nozzles still being used "Typically applications are around 200 L/ha (may be up to 1000 L/ha in some hort crops), but nobody talks about droplet size"
    - QDAF have started to do some work looking at adjuvants (e.g. Nu-Film – a pine resin 'wetter') to see if retention can be increased
- 'Shorter' maize varieties may allow the use of more high clearance ground rigs, which may lead to better coverage
- One agronomist commented that he believes that there is global literature which says that there is a particular gene in some maize varieties that make these more attractive to FAW. Therefore there is a need to understand different varietal susceptibility
- Mating disruption pheromones – there was a question from one agronomist if there was any work being done on the introduction of sprayable mating disruption pheromones in Australia for FAW? These are used in other countries and for other insect pests. This agronomists' understanding was that a 'program' is typically in the order of thousands of dollars per hectare – and hence not applicable for broadacre crops

- Metarhizium
  - More research into the natural Metarhizium, that appears to be quite effective under certain climatic conditions. Can it be produced for commercial sale?
  - Is anyone looking at permits and supply of international sprayable Metarhizium formulations? One agronomist believed there are several commercial products available in India "but they might not have any registrations"
- Potential for insect tolerant varieties (GMO solutions) was discussed with two of the agronomists
  - Local maize companies in Australia are not 'owned' by the US / Asian companies which have the current IP for GM solutions in corn. Further, the maize germplasm typically grown on the Tableland is unique to that location
  - Also, there was a belief by one agronomist that resistance management strategies for GM maize require a 30% refuge – which would be unacceptable to these generally small paddocks.

14.2. New South Wales

14.2.1. Northern Rivers (NR)

The Northern Rivers geographic region is a relatively high, summer dominated rainfall area located on the far-north NSW coast and centred on the townships of Grafton and Lismore on the coast and Casino in the hinterland. Coastal production is typically irrigated sugarcane with summer pulses as a break crop; whereas the hinterland is a more diverse mix of summer pulses (mostly soybean), summer (sorghum, maize) and winter cereals (wheat, barley) grown for either grain or grazing.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
NSW	NR	X			X			Soy		

Expected FAW pressure

FAW was first identified in maize in the 2020/2021 summer and appears to dissipate each winter. As per several other regions in southern Queensland and NSW, agronomists on the Northern Rivers reported that 'early' maize crops are not getting much damage from FAW, however pressure ramps up quickly in December and January.

Maize appears to be the only crop requiring management for FAW currently. "We haven't seen too much of a yield issue to date, because our control strategies have been successful." However, one agronomist interviewed was aware of a local crop (not their client) where FAW had decimated the maize crop approximately 30 days from emergence."

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Management strategies

Maize – Relatively small areas of maize have typically been grown for both silage and grain in the Northern Rivers. Some early crops are planted from late September, but the main planting widow is traditionally around December (with some continuing into January). Harvest is May to August.

Agronomists acknowledged that early planting dates are likely to be the best tactic to avoid having maize attractive to FAW in December and January when pressure is highest. However, as maize is mostly grown on rainfall, there is often not adequate soil moisture for planting in late September / early October. Advisers felt that should FAW pose too great of a risk, growers will switch from maize to soybeans as opposed to planting maize very early (perceived as out of season).

Early crops may give the potential for winter double crop options in some situations. This double crop opportunity, in combination with the arrival of FAW and associated increase in insecticide costs is driving a rethink on preferred planting date by some. Additionally, relatively poor grain maize prices in recent years, along with marketing & supply chain storage logistics, has seen several growers switch to silage production – where the impact of FAW is somewhat of less consequence, relative to maize for grain.

Prior to the arrival of FAW, growers would budget for 2 *Helicoverpa* applications, but often got away with one application. With the arrival of FAW, 2 or 3 applications are now required.

One agronomist mentioned that ideally maize crops require scouting every 3-5 days. But this past summer, with extensive wet weather and flooding, this was lucky to be once per week for most crops. As a result, spraying frequency increased, with several crops needing the maximum 2 Vantacor and indoxacarb applications each, with Fawligen + Vivus being applied in between "to try and keep the FAW at bay." As the number of applications per mode of action is limited to 2, this agronomist suggested that maximum label rates will always be used when chasing FAW.

Growers are still learning to identify FAW in the very early instars. Incorrect identification can potentially lead to poor choice of Fawligen versus Vivus for early season applications, which for some is further reason to want to use Vantacor, as correct identification is less critical.

Sorghum – Sorghum is often also grown for forage/silage, typically planted in October to late December / early January and cut from February to late April. Forage crops may be grazed or cut and baled until the first frost.

To date, insect management is still centred on *Helicoverpa*, with most crops only receiving a single Vivus application. "We haven't seen FAW in sorghum."

Summer pulses – Soybeans are commonly planted from November to the end of January (depending on variety), with harvest approximately 120 days later in April and May. "Not many growers will plant in October/November because it's a risky hail period at establishment."

One agronomist reported only finding the odd FAW in soybeans "but haven't had to spray any bean crops yet." However, suggest that most growers will budget on 2 *Helicoverpa* applications and 1 application for sucking pests. "*Helicoverpa* wasn't a particular issue in the 2021/2022 season, however loopers were. Can also have issues with grass blue butterfly and cluster caterpillar, which may alter control the program slightly."

A different agronomist suggested that getting access to planes / helicopters can be difficult and expensive in the Northern Rivers, which leads some growers to avoid spraying soybeans post row closure. These growers are prepared to sacrifice some yield to insects as a trade-off for less insecticide and application cost due to the logistical issues around getting a plane / helicopter, and the belief that ground rigs do too much physical damage to the crop post row closure. However this agronomist suggested "Drones are opening new opportunities for growers in terms of application options particularly as paddock size is often relatively small."

Important insecticides

Maize – One agronomist was using Fawligen (200 mL/ha) as the product of choice for early vegetative applications, which "Can be quite effective (3-4 out of 5) when targeting low FAW pressure and larvae are very small (1^{st} – 2^{nd} instars). We add Optimol as a feeding stimulant and apply in high water rates by ground boom, using medium droplet size." Typically 1 vegetative application is applied.

A different agronomist, who was only managing a very small area of silage maize, was using either Fawligen (150 mL/ha) + Vivus Max (150 mL/ha) plus Amino Feed UV, or alternatively indoxacarb or Altacor for combination populations of FAW and *Helicoverpa* in pre-tasselling vegetative applications. Typically two applications will be made by ground rig, before the crop gets too big.

Once the crops reach tasselling, standard practice for all appears to be an application of Vantacor (55 mL/ha + surfactant), applied by air where FAW are present. A second application may often be applied to some crops at silking / grain fill, if warranted.

Sorghum – As most crops are only grown for silage, *Helicoverpa* management is often only a single Vivus (150 mL/ha) applied at early head initiation. This is "very effective on *Helicoverpa*, and can achieve up to 80-90% control, even on 3^{rd} instars."

Another agronomist suggested that most forage sorghum crops for grazing / green-cut will not be treated with insecticides at all, including for *Helicoverpa*.

Soybeans – Management is for loopers, *Helicoverpa* and sucking bugs.

Looper pressure was particularly high this past season, with some crops getting a very early application of either Dipel or indoxacarb alone, or a mix of Dipel + indoxacarb. In many years, specific looper control is not required. Where indoxacarb was used, they generally try to keep the rate low, so as to not overly affect lady beetles.

A different agronomist suggested that their early vegetative strategy was often to apply Vivus (150 mL/ha) relatively early for *Helicoverpa*, with sometimes Vantacor being used instead of Vivus for the first application where *Helicoverpa* pressure is well above threshold and the crop is being set back too much. This agronomist mentioned that they are trying to encourage growers to use Affirm instead of Vantacor for vegetative applications where the pressure is too high for Vivus "As we have been relying too heavily on Vantacor."

Typically all crops will then get a Vantacor (40 mL/ha) at flowering / early podding for *Helicoverpa* and a late pod fill application of Skope (320 mL/ha) for green vegetable bug (GVB) and red brown shield beetle (RBSB) (which will also clean up any late *Helicoverpa*).

Some growers are also applying fipronil with the seed for lucerne crown borer @ 2L/tonne of seed.

Organic soybeans growers will use Vivus (150 mL/ha) + Dipel (2 L/ha) for all applications.

Biological agents

One agronomist mentioned that a native virus has been knocking FAW populations this year, especially with the wet conditions this summer.

Beneficials are not typically measured quantitatively, but experience and constant scouting allow beneficials to be factored into decision making. Predatory shield beetle can be very effective on *Lepidoptera* larvae (including FAW) in soybeans (and maize to some degree).

“Native *Trichogramma* and lacewings occur in soybeans, with some growers releasing them in maize to target general *Lepidoptera* larvae – although it’s difficult to quantify the effectiveness, it certainly seems to have some impact on populations.”

Lady beetles and hoverfly can be effective against aphids.

One agronomist mentioned that their current program is soft (Vivus / Fawligen / Vantacor), so has minimal impact on beneficials “but if a product like Lannate (methomyl) was used, then FAW would be back very quickly, and beneficial numbers would be severely affected.”

Cultural / non-chemical management tactics

Early planting of maize is seen as a major tactic. “The earlier the better when it comes to maize planting. However we are still finding that we need to treat for FAW regardless.”

One agronomist commented “Some people are using Magnet + Lannate to try to target FAW in maize, but we haven’t found Magnet particularly effective in this area, given corn crops aren’t close together – so we don’t typically recommend it.”

There is some use of pheromone traps for monitoring. “We have found they work very well in some paddocks, while in others the traps are lucky to attract a single moth, yet the maize crop is being chewed out by FAW. Potentially they can be a useful tool, especially for timing peak egg lay with the release of beneficials.”

Another agronomist mentioned that while they didn’t have their own traps, NSW DPI traps were close by “So we kept in touch with them regarding results. Pheromone trapping can be a useful tool, but unless you have your eye in, it can be difficult to accurately identify moths and therefore draw accurate conclusions about populations.”

In soybeans, one agronomist mentioned “We have been holding off spraying *Helicoverpa* on ‘threshold’ numbers and ‘threshold’ damage (instead waiting until 40% leaf damage) before applying insecticides, to allow beneficials to build up. Then we’ll use a softer chemistry like Vantacor.”

Existing resistance, IRMS and impact of FAW on IRMS

Formal IRMS are not currently used in the district. “We are not really using any resistance management strategies in the crops managed – it’s been very hard to get the whole area onto a workable strategy. Just relying on own understanding of, and support for, integrated management strategies to rotate MOAs and avoid overuse.”

Another agronomist added “We are not aware of particular strategies per se, but certainly mindful of not exceeding the maximum applications per season on the label / permit. Also, while the same tools are available season-to-season, the insect pressure can vary significantly. For example, although there was heavy looper pressure in 2021/2022 soybean crops, that hasn’t been the case in the preceding five years, which has meant we aren’t regularly using those chemistries against that pest.”

One agronomist reported that anecdotally they believe Steward applications have not been as effective as expected “But it’s hard to attribute it 100% to insecticide resistance. Could also be issues with rates, application error etc. We have been using more Affirm in past two years with good success."

As per most of the regions surveyed, Vantacor was the product mentioned of being of greatest concern to resistance selection. "We never previously used it in maize to control *Helicoverpa*, but now that FAW is here and it's approved for use in maize, there's a real concern over resistance build-up." While another agronomist suggested "Altacor/Vantacor could pose an issue if people want to continue growing corn and are tempted to overuse the chemistry given its effectiveness. However most growers and advisors are aware of the need to protect a tool like Altacor/Vantacor. Some agronomists considered using a mectin in the rotation to control FAW in 2021/2022 but plans and results were affected by flooding."

On the flip side – one agronomist suggested "not much maize is likely to be grown in the district until there are more cost-effective tools in the kit, or something changes. Assuming this is the case, the rate of resistance could stall in this area for a few years".

Feedback on potential resistance management strategies was along the lines of, "Integrated control strategies to reduce the reliance on Vantacor are required, with a focus on targeting all stages of FAW, not just the grub stage. For example, in maize, we have been using pheromone traps to monitor moth numbers. When egg lay is present, some growers have released *Trichogramma* and lacewings – although it's difficult to quantify their effectiveness, they certainly seem to have had some impact on populations. Also the use of products such as Fawligen when thresholds permit, rather than going straight in with Vantacor. This helps reduce pressure on Vantacor. A fungus that's been present in the grubs with the recent wet weather has also been enormously successful in reducing FAW numbers."

However, this agronomist also added that should a formal IRMS be proposed, "It must be easy to implement otherwise it won't be adopted. Adoption would be improved if there was an incentive to do so, such as in price or market access. Possibly needs to be a stewardship program that's conditional if using particular chemistries. Any strategy also needs to be cost effective. There's no point in bringing out a new product that costs $100/ha because no one will use it. Price is why there are older cane growers (in areas like Wardell) still using SPs and OPs for grub control - because they are cheap. While that's happening, there's not a great deal of motivation to implement a resistance management plan."

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- This year, with the wet weather, a native fungus has been knocking FAW populations. More research is required on this. It has been attacking FAW from 1st instar to 4th-5th instar stages.
- Assess the effectiveness of strategies employed in other countries where FAW has been present for some time. (X2)
- A method to identify FAW in the neonate stage that is quicker than sending them away and waiting for confirmation.
- Further research into the tolerance of different maize varieties to FAW pressure.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

14.2.2. Gwydir Namoi (G/N)

The Gwydir and Namoi valleys cover a large area of northern NSW west of the Great Dividing Range. Extensive vertosol floodplains and slopes support mixed grain crops and large areas of dryland grazing.

Much of the grain production is rain grown and is a diverse mix of summer and winter crops towards the east; with a winter crop dominant program (wheat, barley, chickpea and some canola and faba bean) towards the west as rainfall declines. There can be significant areas of irrigated cropping along the river systems following years of above average rainfall and resulting water storage, with cotton often being the primary beneficiary of the available irrigation.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
NSW	G/N	X		X			X	Mung	X	

Expected FAW pressure

One agronomist reported that they have only encountered FAW at 'concerning levels' in maize, although these were mostly "below threshold". However they have found it occasionally in sorghum and cotton (egg masses, but no larvae found – indicating that the transgenic traits in cotton are probably effective). The first observations were in 2020, and it has only been found 'in summer' to date. This agronomist reported that numbers were higher in 2020/2021, than in 2021/2022 – both in paddocks and in pheromone traps.

A Liverpool Plains agronomist mentioned they found it for the first time in a 2022 corn crop (pressure of 1 larvae per cob), however as corn is a very small crop for them, not finding FAW in preceding seasons was not surprising to them. This crop had been treated with methomyl and Vivus and control was poor. As FAW was still 'new' in this region, the agronomist mentioned that identification was still very difficult for their team at the first few instars, and they are predominantly using foliage damage patterns and presence of egg rafts as their identification tools.

A third agronomist reported only finding significant presence once in late planted maize crop for silage and this was under threshold and was not sprayed.

Each of the agronomists suggested that it appears that populations are not currently building much in summer and are 'dissipating' over winter.

Management strategies

Maize – Typical planting date is from 1st to 20th September (approximately two weeks later on the Liverpool Plains), as soil temperatures are beginning to rise, with harvest from early February (with harvest a month later on the Liverpool Plains).

There is the option of a second window (December / early January plant), but two agronomists mentioned they would actively try to get their growers to avoid this where possible. A third mentioned that they only have one client who plants late, and this is for silage and not grain.

Prior to FAW, maize crops wouldn't be scouted for insect pests at all until about 1 week prior to commencement of tasselling. "If FAW becomes more problematic in future corn crops, we will have to start charging clients to scout corn crops in the same way we charge more for scouting cotton. We envisage that once a corn crop gets to about 30 cm high, we may have to start weekly monitoring."

One agronomist mentioned that *Helicoverpa* is still the main problem and FAW numbers have not caused "big problems yet". However their current *Helicoverpa* program is probably also suppressing any FAW.

One agronomist mentioned that maize area had declined significantly in recent years (prior to any threat of FAW and that the baseline area for maize was already small), predominantly due to poor grain price, with cotton being a more attractive proposition for many.

Sorghum – typically planting begins early September and is completed by the end of October, otherwise crops may be flowering during heat waves. Harvest will be from mid-February through to April (a month or more later on the Liverpool Plains), depending on planting date. A second window exists for sowing from late December – mid January. Late sown crops are harvested in May-June.

"Sorghum requires a bit warmer soil temperature for establishment than corn."

Insect management is focused on *Helicoverpa*. One agronomist added that it is now fairly uncommon to need to treat for sorghum midge (probably < 10% of crops), and this is typically only when there are 'late sown' crops that are getting infested from populations moving out of earlier sown crops that are drying down, or crops grown in lower lying areas where there is often Johnson grass populations.

Cotton – planting typically commences around 1st October and will be finished by mid-November, although dryland may continue be planting until mid-December should there be late planting rainfall. Picking will commence mid-April and be completed by the end of May.

Mung beans – there are two planting windows, depending on crop rotation and soil moisture. Spring planted crops will go in during October and be harvested in January where there is adequate soil moisture at planting. Alternatively, late-season crops will be planted in December to mid-January and be harvested in March/April. The summer sowing window is the primary window, as there is more likelihood of a full soil moisture profile, or sometimes this will be a double crop after winter crop harvest.

Chickpeas – usual planting window is mid-May to mid-June (sometimes later), with harvest October-early December. Later planting is likely to require more frequent application of insecticides for *Helicoverpa* control.

Winter cereals – one agronomist mentioned that the need for insect spraying is highly seasonal. Many years no applications are needed, but in years where control is required, spraying can be quite extensive. *H. armigera* can attack young seed heads (October). When control is required, methomyl is usually the product of choice, due to the proximity to harvest.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Insecticide sprays in barley usually target common armyworm, with most spraying very close to harvest to stop head lopping, although if populations are very high, this can occur earlier in the season. Typically alpha-cypermethrin is used. In most seasons, most crops are not sprayed.

Important insecticides

Maize – One agronomist reported that their typical program for a maize crop (for grit) will be two Vivus applications for *Helicoverpa*, one at about V8 and another about V12. Then an Altacor/Vantacor at silking, targeting both *Helicoverpa* and in case any FAW may be present. This will be accompanied by a Magnet + methomyl perimeter spray. The selection of Altacor for the at silking application, and the use of Magnet as a prophylactic perimeter spray are both currently in response to the 'threat' of FAW and are increasing the cost of growing corn.

In the absence of FAW, other agronomists were trying to manage *Helicoverpa* in maize using a 1-spray strategy. For one agronomist, this was 2L/ha methomyl + 70 to 100mL Vivus Max applied via the plane at silking to prevent *Helicoverpa* entering the cobs, although "Timing is critical and difficult to get right as the crop does not silk evenly." Sometimes 600 mL/ha abamectin is added if two-spotted mite is also a problem. This agronomist has already experienced a failure with this strategy when FAW were present and mentioned that, should FAW require application in the future, they would probably require something like Vantacor +/- methomyl +/- Fawligen. This agronomist mentioned that they are not currently using much Vantacor (only in a few mung bean crops). They also suggested that 'arrival' of FAW as a significant pest may force a shift away from methomyl in general and may also require 'early' applications of Fawligen e.g. with post-emergent herbicide sprays. However FAW pressure currently does not warrant this.

Another agronomist was currently relying primarily on Vivus alone at silking, often applied via overhead irrigation (e.g. through the pivot) for *Helicoverpa* control. Occasionally (10-20% of applications may have alpha-cypermethrin or methomyl or Vantacor added, although this is not common.

There does not appear to significant use of Fawligen in the district. But one agronomist did mention that they expect to need to substitute Fawligen for Vivus applications, or use a mix of the two, should FAW become established in the region.

Grain sorghum – The current program is generally a Vivus application at early flowering, targeting *Helicoverpa*.

One agronomist mentioned that methomyl may also be added for additional midge control (where needed), while another was adding SP for this purpose.

If Rutherglen bug is present (Liverpool Plains), then occasionally the agronomists may also add a full rate of SP, or sometimes 500 mL/ha of chlorpyrifos.

Cotton – Cotton is effectively not sprayed for *Helicoverpa*.

A typical sucking pest spray program for one agronomist is 1 to 2 Transform early season, targeting mirids, followed by 1 to 2 Regent mid- to late-season, also targeting mirids. Occasionally a mid-late season Paramite® (etoxazole) or Agrimec (abamectin) may be applied for mites.

A different Liverpool Plains agronomist started with a single fipronil for mirids, but then switched to Primal® (acetamiprid) or Skope (emamectin + acetamiprid) for further mirid applications as the acetamiprid will offer some level of suppression of SLWF, while the fipronil will only flare them.

Generally acetamiprid is adequate to keep SLWF numbers suppressed, and they find that they don't require specialist whitefly products like Admiral or Pegasus that are required in the hotter regions.

Mung bean – one agronomist reported that their strategy was typically two applications of Altacor/Vantacor + pyrethroid, targeting both *Helicoverpa,* stink bugs and mirids. The first applied at budding, with the second applied approximately 10 days later. Occasionally Skope may be used as an alternative to the Vantacor / pyrethroid mix.

A different agronomist is finding that they can typically get by with a single broad-spectrum application of methomyl when targeting *Helicoverpa* and GVB, with dimethoate + salt often added where mirids are also present. A third agronomist also saw that encouraging more use of methomyl in a relatively 'short' season crop could be an option to reduce selection pressure on chlorantraniliprole.

Chickpea – A single late season Altacor/Vantacor or Steward may be all that is required for *Helicoverpa*. Pyrethroids are often avoided, as by the time spraying is required there is generally a significant proportion of *H. armigera*.

However, on the Liverpool Plains, both agronomists mentioned that a two-spray program is more likely to be needed (one agronomist mentioned an average of 1.7 applications). Typically one will be Altacor @ 70 g/ha, with the alternative application being either a SP (only if the first application is 'early' and they are confident that only *H. punctigera* are present), or Steward where mixed populations of *Helicoverpa sp*. are present. One of these agronomists felt that there could be useful benefit in delaying resistance by encouraging more frequent use of Steward and Vivus in chickpea and less use of Altacor/Vantacor.

Canola – One agronomist managing canola was finding that it was typical to need late season application for *Helicoverpa* "every hectare, every year." This is typically a full rate of a SP plus a low rate of Vivus (50 mL/ha) for *Helicoverpa*, plus sometimes Pirimor® (250 g/ha) will be added if aphids also require control. Diamondback moth (DBM) control is 'ok' but pressure appears to be increasing and it is expected that this may soon require a shift to Affirm.

Of interest, a different senior agronomist, passed on the following observations. A property he was managing in the Inverell district in 2021/2022 had sorghum, maize, sunflower and soybean all growing in adjacent paddocks and all were planted at similar timing in spring. There was sporadic FAW in combination with *Helicoverpa*. Insect management were:

- Sorghum – 1 Vivus spray only required
- Sunflower – 1 Vivus spray followed by 1 'conventional' insecticide (believed to be Vantacor). This was the shortest crop, so didn't need any further insecticide applications.
- Corn – FAW pressure was sporadic. 2 Fawligen applications were applied, followed by a low rate of Vivus
- Soybean – Last year, on this property, insect pressure was light in soybeans and the crop only received 1 GVB application, and no *Helicoverpa* applications. This year pressure was much higher, with 5 foliar applications being applied 'to date', with the crop still requiring 30-40 days more protection at that time.
    - Regent was applied in-furrow for lucerne crown borer
    - First application was Bt, targeting loopers
    - 1 dedicated *Helicoverpa* spray (Vantacor)
    - 3 GVB applications, starting as 'soft' as possible and progressively getting 'harder' (Shield, Skope, SP)

Biological agents

One agronomist placed very high importance on natural beneficial populations as well as targeted release of commercially supplied beneficials as an important strategy to minimise insecticide use, and therefore reducing potential for resistance selection. “We will be releasing *Trichogramma* wasps early (av. 2 capsules/ha from the air) and staying soft using Vivus for both FAW and *H. armigera*. There is a good paper from Brazil on the benefits of this approach. *Cotesia* is the beneficial species we would really like to have, but as yet, Bugs for Bugs are not yet breeding this species for commercial sales, but we are currently breeding it up for our own use. In cotton, we have been releasing beneficials (*Eretmocerus hayati*) for > 8years to SLWF and this has reduced insecticide use by >80%.”

> *ICAN Note: A goggle search indicated several research papers on Trichogramma on FAW from South America. Of particular interest, was a recent paper* (Jaraleno-Teniente, Lomeli-Flores, Bujanos-Muniz, & Rodriguez-Rodriguez, 2020) *https://www.mdpi.com/2075-4450/11/3/157/htm that showed that Trichogramma pretiosum has some control (av. 29% parasitism), however this was variable with sometimes no parasitism being recorded. In this same paper they reported much higher levels of parasitism (av. 70%) with T. atopovirilia.*

In addition to commercial releases, this agronomist is scouting for and counting beneficials in summer crops and this information is included in decision making. “We have well-defined rules of thumb how these beneficial insects relate to pest species.” In addition to the parasitic wasps, pirate beetles, damsel bugs, big eyed bugs, lady beetles, red and blue beetles are all important. “Beneficials are a primary insect management strategy for us in a growing range of summer crops. These need to be used within an IPM environment where soft insecticides are used wherever possible. In winter, we have also used wasps which target aphids in canola in 2021 and will be increasing our research in this area in 2022. The species involved include *Diatella rapai* and *Aphidus colemani*. These target canola aphids, GPA and cabbage aphid. We will often add in *Trichogramma* wasp for control of *Helicoverpa* species. *Diadegma* may also be added for DBM in canola.”

A different agronomist was valuing native beneficial populations in cotton “as it is a long season crop and there is time for them to build up”, however was placing little importance on them in other broadacre crops and was not using commercial releases. “We regularly see substantial numbers of beneficials in grain sorghum and other crops, but there is very little evidence that a particular predator will be present in numbers sufficient to substantively change a spray decision in crops other than cotton. Occasionally shield bugs in mung beans may be of benefit with low / sub-threshold populations of *Helicoverpa.*” A different agronomist mentioned that beneficial insect numbers tend to increase in wet years and decrease or remain static in drought years.

A fourth agronomist was counting beneficials in both cotton and grain crops and acknowledged that while there are some accepted ratios in cotton, these are not as well defined in other grain crops. He also indicated that there is currently no ‘soft’ insecticide for Rutherglen bug or midge in grain sorghum and this requires an SP application, which can severely disrupt / destroy beneficial populations, and hence makes the concept of maintaining beneficials much more difficult to adopt, not just in sorghum but also in adjacent crops on the same farm / region.

There is extensive use of Vivus in several crops, but particularly sorghum.

One agronomist mentioned that in ‘wet’ years, native viruses may build up in *Helicoverpa* populations and hence this may negate the need for Vivus applications in sorghum in some circumstances.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Cultural / non-chemical management tactics

One agronomist was operating 3-4 pheromone traps as part of the NSW DPI monitoring network, with information (and ID if needed) being sent to Lisa Bird. "Pheromone traps are very useful as they help determine when adults are present or not. It is a prompt to scout at risk crops more intensively." A second agronomist, while not directly managing any traps themselves, mentioned a similar response with regard to the benefit of the NSW DPI network "as an early warning. It prompts us to look harder and when we find larvae and be more confident to treat them as likely FAW, rather than *armigera*."

Another very experienced Liverpool Plains agronomist was not currently using pheromone traps as they don't believe they have significant FAW populations 'yet'. This agronomist was also not aware of any coordinated monitoring programs [e.g. https://thebeatsheet.com.au/key-pests/fall-armyworm/faw-pheromone-traps/#nsw], stating that "They would be great value if there was a local network that was actively monitored by NSW DPI. This would help us and growers to know when we needed to start scouting more intensively in at risk crops." This suggests to the authors of this report, that the extension of the network trapping results may need further resourcing as this agronomist 'should' be aware of the existing network.

The combination of early sowing of corn and sorghum, Magnet (or the FAW equivalent when available) + methomyl, aerial releases of beneficials and early applications of Vivus (in sorghum) all build a viable management program in the eyes of one agronomist. Additionally "Trap crops have a role in large area crops such as cotton, but we do not have sufficient area grown of corn to create a big enough problem to warrant use of trap crops."

One agronomist mentioned that Magnet + methomyl in cotton was an important part of the industry management package for transgenic crops. In cotton, where 3 x Magnet + methomyl applications per crop is combined with the first defoliation being applied by the end of March, growers can avoid the need for pupae busting as part of their Bollgard 3 accreditation requirements.

Existing resistance, IRMS and impact of FAW on IRMS

Industry testing has highlighted pyrethroid resistance in *H. armigera*, and this is taken into account when spray decisions are made in spring and summer. The cotton industry is seen as "excellent" in providing industry advice on resistance levels in cotton.

Both alpha-cypermethrin and methomyl can fail to control *H. armigera* at times, with escapes being found.

Additionally, one agronomist reported that Lisa Bird and the cotton industry are reporting that "*armigera* resistance is developing to both Steward and Altacor." He mentioned that there are some reports of agronomists and growers 'cutting rates' of Altacor, and this would not be helping. However, his experience was that Altacor and Vivus were still working well.

Specifically with regard to FAW, one agronomist reported that he was aware that there was already resistance to OPs and SPs and this would need to be considered, should FAW become established in the district.

Two agronomists mentioned concerns over potential for resistance to chlorantraniliprole in general "Concern is in chickpeas and mung bean as it works so well and is thus overused. We also use it in corn. This has implications for sustained use in corn if we need it there for control of FAW, however we do not grow any substantial area of corn." There is also potential overlap of application timing between late chickpea applications and early vegetative maize.

One of these agronomists was also somewhat concerned with the pressure being put on Vivus.

One agronomist mentioned that the published grains industry IRMS was closely followed with regard to decision making. However another said they were "Largely unaware of the detail in the grains IRMS, and hence it was not really considered." While a third commented "There is a grains IRMS, mainly focused on Altacor, but it does not get a lot of press. While we generally try to follow it, awareness (particularly amongst younger agronomists) is thought to be low."

In cotton, the IRMS is much more well-known and followed. One agronomist commented that the only real variation to the published IRMS was in relation to SLWF, where there may be more applications, based on product availability and population density, with products selected based on cotton growth stage rather than calendar dates. While another mentioned that the "refuge management segment could be better followed by industry, as sometimes items such as water management & irrigation scheduling in refuges is below an acceptable standard." A third mentioned that the cotton strategy "was used as a guide only to decision making."

When it came to developing IRM strategies in general, one experienced agronomist commented that strategies such as the cotton IRMS will be supported where there is good science that underpins the strategy (which requires a major commitment to ongoing and annual insect collection and testing, to measure changes in sensitivity over time). However any strategies that suggest "lower thresholds of use which could put the crop at risk of damage" are less likely to be supported.

Another agronomist echoed similar thoughts, in that flexibility is required to make different decisions across a range of crops and therefore a multi-crop strategy is likely to be more difficult to implement, compared to the single 'cotton' IRMS. Significant restrictions on either chlorantraniliprole or Vivus applications would make compliance increasingly difficult, as these products are heavily relied upon. In the eyes of this agronomist, a better approach would be to "to avoid consecutive sprays of the same chemistry, particularly when consecutive generations of insects may be involved."

In the view of two experienced agronomists, product labels need to reflect the best advice on IRMS. Labels are generally followed more closely than 'strategy' documents and are probably the best opportunity to get grower compliance with resistance management. Where labels allow a significantly higher number of applications than a 'strategy' recommends, then it is often difficult to get some growers to restrict applications to less than what the label allows.

Younger agronomists or growers that have not had substantive exposure to an IRMS (or have not lived through the bad old days of major insect resistance problems) are less likely to understand the logic behind, or need for, crop or product 'windows'. This agronomist suggested that compliance with a non-use 'window' would be hard to achieve without a strong lever to implement it, i.e. it has worked in the past with GMO cotton, as there was closely monitored compliance with several aspects of crop management as part of licence conditions for this crop.

There was mention that any multi-crop IRMS would require to be supported by "a substantial high priority education program, which includes training on insecticide modes of action and associated IRMS tactics, activities and options. In particular, this would need to target younger agronomists. Ideally any IRMS would encompass an area wide management strategy, but that can be complex and difficult to implement."

In traditional 'grain' crops, one agronomist suggested that the best strategy may be to have industry try to enforce crop planting windows, rather than product use windows. Having uniform planting is likely to concentrate applications of any product. For example, it is possible to plant maize early in the season, as soil temperatures start to rise, or there is the potential to delay for a later planting date. Should FAW establish in the district, then these later plantings would require the heavy use of chlorantraniliprole.

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- One agronomist suggested that it might be useful to bring back the concept of DNA-based identification kits (similar to the 'Lepton test kits' from the 1980s) to be able to differentiate the two main *Helicoverpa* species and FAW in the paddock. "It's almost impossible to identify FAW neonate larvae and differentiate these from *Helicoverpa*. We don't want to waste the entomologists time every time we need to identify an insect in every crop!" A second agronomist also saw value of this for on-farm testing by agronomists, which "would greatly assist identification and enable us to adopt a targeted response more confidently." He mentioned that he believed NSW DPI had been using a DNA-based kit for 'early instar identification', however was of the opinion that "they have now run out of money for this."
- One agronomist (who did not appear to know of the QDAF / NSW DPI network of pheromone monitoring stations) suggested that a network of industry monitoring stations "would be important to establish" to detect the presence of FAW in the region. A second agronomist, who was aware of the NSW DPI network and had been receiving updates, was wanting this continued and ramped up "to provide early warning awareness. It's a prompt to scout at risk crops more closely and would be highly beneficial."
- "Potential for GM corn?" was suggested by one agronomist.
- One agronomist mentioned that should FAW become established then they would seek guidance from other agronomists with much more experience in FAW management e.g. those working in the Burdekin. The expectation is that scouting will need to increase significantly in host crops; there will need to be more attention / understanding of which beneficials are important and what thresholds they can control; Fawligen will probably become the first choice sprayable control; with Vantacor the back-up – hopefully limited to no more than 1 application. To support this:
    - More information will be required on key beneficials and working thresholds
    - Communications and training activity on managing FAW using softer chemistries and beneficials would be highly desirable
    - Magnet plus methomyl is an option I want to know more about. Our experience with this is limited.
- While one agronomist interviewed was regularly applying commercial releases of beneficials from the air, a different agronomist was wanting more information on this. "I suspect this will work but need more knowledge and understanding about the reliability and economics of use. As use of insects in this manner is largely prophylactic, we will need to have some certainty of impact. This will require a change of grower thinking to a more proactive budgeted approach, rather than the current reactive one."
- RGB management in grain sorghum is a hole in the system on the Liverpool Plains, as it is often sprayed with an SP in bad RGB seasons as there is no 'soft' option. As sorghum is a big crop in the region, this can destroy any chance of maintaining beneficial populations. The use of methomyl in mung bean this is less of an issue, as mung bean is only sown on a relatively small area.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

14.2.3. Riverina (RIV)

The Riverina is a diverse agricultural region in southwest NSW. Rainfall is winter dominant and hence most extensive areas of cropping are typically dryland wheat, barley, canola and pulses (mostly faba beans, lentils, lupins) rotations.

Additionally, there are significant areas of permanent irrigation. This supports a range of summer cropping, including vegetables, grapes, cotton, rice and some maize production.

The Riverina was specifically included in our research as it is the most 'southern' region growing significant acreage of maize and rice, so we wanting to explore the extent of southern migration of FAW and how this is influencing management relative to more northern regions where FAW may become endemic.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	Sweet corn	Sorghum	Sugar cane	Rice	Cotton	Summer pulses	Chickpea	Vegetables (excl sweet corn)
NSW	RIV	X				X	X			

Expected FAW pressure

FAW was first noticed in sweet corn grown over the 2020/2021 summer. One agronomist suggested that, in their opinion, sweet corn gets hit much harder than traditional 'maize' varieties.

While FAW has been present, they are not currently having significant problems. "FAW hasn't posed a major issue in the area to date. Pressure is much lower in the early crops – no doubt there is generational build-up post winter the later crops are planted in summer." FAW pressure "definitely dissipates with the cold winters. Populations need to re-establish each year." This agronomist added "Mice currently give us more problems in maize than FAW."

In southern NSW, one agronomist suggested that "FAW identification is still a work in progress. There can be issues with instar identification when small which can lead to management issues given this dictates what products are used in the early part of the season. That said, monitoring grub numbers is one of the most important keys to seasonal management as this will give an insight into how pest pressure and management is likely to play out. Having an accurate idea of pest presence and numbers early in the season can help with overall management planning for later in the crop/season."

Management strategies

Cotton – Planting starts approximately 1st October as soil temperature becomes adequate, with growers preferring to have the crop in the ground by October 20. Harvest is typically the last week of April and into May.

With Bollgard 3, insect management is almost exclusively for sucking pests, in particular mirids.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Maize – Maize is grown mostly for silage, however there are some grain crops. The silage planting window is generally tight, in mid-October, with crops being cut in late February to early March. Grain crops may be planted from around 20 September to about the second week in November and harvested late March to early April.

According to one agronomist, management of FAW has "been about learning not to over-manage FAW. Our insecticide management was very much on the front foot in 2020/2021 following the public hype about the potential risk to crops, especially maize. But once we began to understand the correlation between pest presence / pressure and crop damage, we found we could wind back insecticide programs to reduce the pressure on chemistries." This was helped by moth numbers appearing to be lower in 2021/2022 season than the previous year.

It was stated that "The difference between *Helicoverpa* and FAW is that with *Helicoverpa* there will often be only one grub in the top of the cob and it's difficult for them to move down into the husk. They tend to only feed on the small grains at the top of the cob, which doesn't normally contribute much to grain yield anyway. So *Helicoverpa* aren't a major issue in corn in terms of yield reduction. However FAW can enter through the sides of the cob and can therefore consume more grain. We didn't see any damage to the sides of cobs in 2020/2021, so the Altacor applied at tasselling for *Helicoverpa* must have cleaned up any FAW.

Sunflower and safflower – Sunflower planting typically starts around September 20, as soil temperatures begin to rise. But can extend into December "with most growers aiming to be finished planting by Christmas."

Most crops will require management for *Helicoverpa*, and often for Rutherglen bug, with typically 1 or 2 insecticide applications required.

Safflower is generally planted in August, with harvest in January. As the key application timing for *Helicoverpa* control is earlier than the other 'summer' crops, often growers can get away with a single pyrethroid application targeting *H. punctigera*.

Rice – A regional entomologist particularly focused on rice added "FAW has not been an issue as yet in rice after 2 seasons of FAW presence. No FAW has been detected in rice, despite being detected in nearby maize crops. Maize and sweet corn are the preferred host crops. I'm unaware of any detections in other horticultural crops in the region." "However, we know that populations are already resistant to SP and OP chemistries, which could be a potential issue as there are very few registered insecticides for rice outside of these MOA groups." While it hasn't been needed locally, there was an emergency permit for Altacor in rice and "it was good to have it there if needed." "FAW could be the 'Trojan horse' needed to get a modern softer insecticide into rice."

FMC are reported to be registering chlorantraniliprole in rice for common armyworm. "FMC have done chlorantraniliprole residue trials in rice. Geoff Cornwall would be the person to talk to. If this was to go ahead, then the rate to be used on common armyworm is likely to be lower than for FAW."

Important insecticides

Cotton – Cotton is the main summer crop requiring insect management, but predominantly for sucking pests. A typical program consists of:

Phorate (3 kg/ha) or chlorpyrifos (1 L/ha) or sometimes fipronil (20 mL/ha) as an in-furrow application for wireworm. Choice of product depends on how the grower is set-up.

Approximately 70% of paddocks will get an early dimethoate, applied around the end of October/early November for thrips, with activity coinciding with winter crops 'haying off'.

Mirids then become the major pest of concern, with an aggressive program usually required. An application of fipronil (40 mL/ha) + salt is typically the first application, applied at squaring in early-mid December.

This is then likely to be followed by Transform (100 g/ha, but sometimes 150 g/ha under heavy pressure) at early-flowering (Christmas to Jan 10).

At cut-out (last week of January) it is typical for crops to receive Skope (350 mL/ha). This will also control any *Helicoverpa* that might be present at that time. And, while not on the label, the emamectin in Skope will also clean up any late mites that may be present.

Maize – Prior to concerns with FAW, a typical program for maize for grain or silage may be limited to either phorate (3 kg/ha) or chlorpyrifos (1 L/ha) applied in-furrow at planting for wireworm and an at-tasselling application of Zeal® (etoxazole) for two spotted mite (350 mL/ha).

In 2020/2021, most crops had an Altacor applied by air at tasselling "Which must have worked well as we didn't see much cob damage." With less pressure (in traps) this past season, and more experience in FAW management "We didn't spray at all for FAW in 2021/2022, only saw the odd one."

Sunflower – To date they have not found FAW in sunflower. However, an insecticide is generally required at early budding for *Helicoverpa*. Depending on when the crop was planted this will either be:

- Trojan® (50 mL/ha) on early planted crops where *H. punctigera* is the target. This will also control Rutherglen bug (RGB).
- For later planted crops, where *H. armigera* are expected, they will often switch to Altacor (70 g/ha), with Trojan being tank mixed if RGB also requires control at that stage.
- Where pressure continues, a second later application may also be required. At this growth stage it will generally be Altacor + Trojan, targeting both pests.

Safflower – Typically most crops will receive an alpha-cypermethrin (300 mL/ha) in late November / early December targeting *Helicoverpa* (believed to be mainly *H. punctigera* at that time of year) and mirids. This is often to both protect the crop, but equally to prevent mirids from migrating out to new summer crops as the safflower starts to dry down.

Rice – To date FAW have not been found, however approximately 40% of crops will get a late season chlorpyrifos or alpha-cypermethrin application for common armyworm and the occasional *Helicoverpa*. If more than 1 application is needed in any individual crop, then the insecticides will be rotated.

Biological agents

In cotton, there is acknowledgement and desire to preserve native beneficials and use 'soft' chemistry wherever possible. This is now the 'accepted norm'. One agronomist suggested that "beneficials used to be measured quantitatively in cotton, but this is no longer done." This is likely reflecting the lack of importance / consideration now with managing *Helicoverpa* in Bollgard 3 cotton.

With regard to beneficials for FAW, the view of one agronomist was "Native beneficials are likely to be helpful, but if FAW is present in significant enough numbers we will apply products and rates that will give us the most effective control." However, they went on to mention that as Vantacor is likely to be one of the main products used, then this is quite soft on beneficials anyway.

Cultural / non-chemical management tactics

One agronomist was using their own pheromone traps and mentioned that "in a season such as 2021/2022 when very few moths are trapped, this determines the prioritisation for crop monitoring by agronomists."

For maize, the belief by one agronomist is that FAW preferentially target sweet corn varieties over maize. To utilise this to their advantage, they are considering the idea of planting a row of sweet corn every so many meters (spacing not yet determined) within the main grain/silage maize crop, as a sacrificial attractant row – and feel that this may be a viable strategy in southern NSW under relatively low FAW pressure.

They are also conscious of the desire to 'plant maize early' wherever possible. Not only does this result in less FAW pressure during the vegetative growth stage, but there are additional benefits in that the crop does not have the same water demand when growing in slighter cooler conditions.

While not a tactic specifically for FAW, they are encouraging growers to cultivate paddocks as soon as possible after harvest. This is done typically for land preparation for the following crop (planters cannot typically manage the high volume of standing maize 'stubble'), as most of the maize grown under irrigation is in a 'double crop' farming system. It is perceived by one adviser interviewed as therefore likely that this cultivation may provide some 'pupae busting' benefit.

Existing resistance, IRMS and impact of FAW on IRMS

In the view of one broadacre agronomist, current insecticide resistance is mostly *Helicoverpa* resistance to SPs and aphid resistance to dimethoate, with both these confirmed by field experience and industry testing.

Additionally, they have also experienced poor field results / failures with the mectins against mites. Some samples have been sent away for testing but results so far have not confirmed major resistance.

One agronomist, working heavily in cotton, suggested that the cotton industry IRMS was "Closely consulted and generally followed to the letter." While there was no specific mention of the QDAF developed 'grains' IRMS, they did add that the "philosophy of the cotton IRMS was adapted for other pests in other crops."

As per several other regions, chlorantraniliprole (particularly Vantacor) was specifically mentioned as a product of concern for resistance selection, primarily in *Helicoverpa* but also should FAW establish, "because it's so effective, has residual and is soft on beneficials and therefore is widely used."

This agronomist did see potential for a broader IRMS "Similar to the program implemented in the cotton industry, but wider to encompass all relevant summer crops." Noting that this agronomist was not aware of the existing grains IRMS. "Possibly such as strategy needs to incorporate a specific window of use for Vantacor, or a reassessment of the number of sprays per season in individual crops which would encourage greater rotation of chemistries. Depending on how the resistance mechanism in FAW operates, there may be refuge crops which could have a place in an IRMS for FAW." They further added that any IRMS encompassing FAW "would need to be practical, work in the field and give effective control of the pest. If an IRMS was developed and implemented, a feedback loop between growers/advisors and entomologists will be critical to ensure it is delivering the desired results or identify if it needs amending."

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- Not at this stage (X 2) – as FAW isn't a major problem for our region, so therefore it isn't high on the expenditure priority list.
- We will need regular updates on resistance levels from other regions and crops that are having problems with FAW. FAW is mobile and we should assume that resistance levels will apply between regions and crops.
- Need a range of insecticides registered that include newer MOA's, as SPs and OPs are likely to be already compromised. In rice it appears that this process has started.

14.3. Northern Territory (NT)

Cropping around Darwin in the Northern Territory is characterised by many small land holders growing a variety of crops. For many, English is not their first language.

There is some larger scale cotton and forage production operations towards Katherine and the Douglas Daley region.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
NT	all						X			X

Expected FAW pressure

Helicoverpa armigera and *Spodoptera* species (several) pressure is 'huge' within the Darwin rural areas, however pressure is much lower around Katherine. It is also expected that there will be large numbers of sucking pests over summer (jassids and leaf hoppers), which are a major vector of plasma viruses.

FAW entered the NT quickly after first incursions in Queensland. It was first detected in the Douglas Daly (Tipperary Station) with 8-10 moths per week identified in the traps. By the time the first larvae were recorded in crops they were catching 70+ moths per trap.

They can now be found everywhere "and they will eat everything, including chillies."

The main crops where FAW is impacting production is sorghum grown over summer, however populations (requiring management) can be found in winter grown melons, Rhodes grass pasture and irrigated millet cover crops in winter plus a range of other crops. 'Conventional' (non-GMO) cotton that is grown as a refuge for the GM varieties has been significantly damaged.

In other horticultural production systems, FAW damage appears mainly limited to sweet corn, however the area grown in the NT is very small and production is limited to one 'organic' grower. There have also been reports of FAW getting into Okra flowers, but again very small area of crop are involved.

Management strategies

Grain sorghum is mainly grown in the 'lower' rainfall regions away from the coast (e.g. Douglas Daly). Areas of crop grown are relatively small. Planting is typically before the wet season kicks in (Dec-Jan), with harvest from March to May, depending on weather. There is some forage sorghum grown under pivots during winter. Sorghum is a low input crop. Forage crops are rarely treated and hence FAW can be regularly found.

There are small areas of rice grown under irrigation during the dry season. Planted April – May and harvested late October.

Cotton is mainly grown over summer (planted mid-December to mid-February) in the 'lower' rainfall areas of Douglas Daly and Katherine. Rain grown crops may be ready for picking in May – June, while those grown on supplemental irrigation are typically picked in June – July.

One agronomist also mentioned that a 'cover crop' (millet or sorghum or cowpea) would be planted in November and planned to be sprayed out the day before cotton planting, when about 30cm. This cover crop also becomes part of their cotton insect management program.

Reports indicate that the triple-stack GMO cotton varieties are withstanding FAW pressure, although one agronomist mentioned reports that a 'conventional' cotton grown as a refuge strategy had been extensively damaged (flowers).

Melons are transplanted to the field from March to July and grown 'over winter' in the NT, so as to supply the southern markets with 'out of season' production from June to September.

Important insecticides

Sorghum – Lorsban (chlorpyrifos) has been tried by one agronomist against FAW with poor results.

One agronomist reported useful results (3 to 4 out of 5) with multiple abamectin applications providing growers can get "Good coverage on smaller instars. FAW egg lays can be continuous in grain sorghum. If it's wet, then gaining access to spray can be difficult, and aircraft cost money."

A different agronomist mentioned that when FAW first appeared, forage sorghum was getting hit hard early and many sprayed vegetative crops 3-4 times across the wet season. "However, now with several seasons experience, we generally no longer spray and usually the crop grows through the damage. We do however get concerned if damage gets into the crown early and we do try and keep the flag leaf clean. We usually don't spray at this stage, but we would consider it. For budget purposes we might have a grower prepared to apply either two applications of methomyl, or perhaps one group 28 such as Altacor/Vantacor, however most crops will not be sprayed." Typically Altacor was reported as providing higher a level of control than methomyl. This agronomist has tried Fawligen, "However it breaks down fairly fast with heavy rainfall and is only active up to the second instar."

During 'summer', forage is cut every few weeks and there is a belief that this rapid growth can largely outgrow FAW damage. One agronomist was more concerned with winter forage crops (under irrigation) where FAW numbers were perceived as having longer to build.

Cotton – The majority of insect management in GM cotton is for sucking pests. Mirids are a problem right up until at least cut-out, with generally 2 or 3 Regent (fipronil) applications required. Many crops may also get an Intruder® (acetamiprid) application should both aphids and mirids require control. Low levels of GVB, silver leaf whitefly (SLWF) and aphids can be found occasionally, but it is rare to treat these.

Noctuids are generally well controlled by the transgenic crop, however protection against cluster caterpillar (*Spodoptera litura*) can fall off if there is a period of cloudy weather "However Vantacor smokes them".

Cluster caterpillar can also be quite high (10/m^2) in the preceding cover crop and may pose a threat to emerging cotton. So sometimes these may be sprayed with a pyrethroid when the cover crop is terminated.

The main agronomist dealing with cotton in the NT indicated that FAW is rarely seen in transgenic cotton, or pigeon pea refuge, and is therefore not sprayed for.

Vegetables – One agronomist reported that programs of 2-3 applications of methomyl was still not providing adequate control of FAW across a range of crops.

A different agronomist mentioned that growers "Are generally very cautious about caterpillar populations in melons (and mangoes) and as a result, we stay soft wherever possible, using a lot of higher cost products with low impact on beneficials. In cucurbits/melons we limit ourselves to a maximum of two Group 28 sprays. If only *H. armigera* is present we will use Vivus, and switch to the Group 28 if multiple pest species are present at a key period e.g. flowering or early fruit set. We rotate Vivus (*H. armigera* only) with Delfin (sprayable Bt) for other applications. We also release parasitic wasps." (*Author note: both Coragen and Altacor were mentioned, however only Coragen is registered for horticultural uses*).

Biological agents

The industry agronomist interviewed had planned to do some trails with Fawligen, but this has not yet happened. There were reports from Kununurra the previous season that programs based on Fawligen, Magnet and sprayable Bt's were working.

Some growers are aware of native beneficial insects. Key species are *Trichogramma* (*Helicoverpa* and FAW), Tachinid flies (FAW) and spiders (general pests). One agronomist commented "You can often find 'lots' in sorghum if growers avoid SP's, OP's and methomyl. They appear to be relatively tolerant of abamectin applications. Many beneficials are hard to scout. Education on how to scout for beneficials and how to integrate them into a program is needed."

Another agronomist mentioned "Parasitic wasps are very handy on chewing pests. We often see high levels of parasitism both in larvae and in eggs. Parasitic wasps are a powerful tool as they can also target larger grubs and mop up survivors from insecticide sprays - providing you stay soft."

Commercially raised beneficials are not released in forage crops, but melon growers do use some releases of commercial beneficials (species not stated) targeting cucumber moth, *Helicoverpa* and armyworm, however some mentioned that the distance from the suppliers of live insects is often problematic.

In cotton, one agronomist mentioned that they were "Happy to have, and leave untreated, a population of up to 2 spotted mites and aphids /m^2 in cotton crops. This provides the beneficials with a food source. Predation by spiders (10-15 spiders in most beet sheets) and wasps is high. We also get big eye bugs and lady beetles. We don't have many secondary pest problems in cotton, but I go 'soft' with insecticide choice, as we do get mealy bugs and I do not want to flare those. Regent at low rates, acetamiprid and Vantacor are all 'soft'. We use 'soft' chemistry first and rarely need to go 'hard'. No pest / prey ratios are used, but if we were to have a problem with mealy bugs, we might look at a release of beneficial lady bugs."

Cultural / non-chemical management tactics

The industry agronomist interviewed saw pheromone traps as highly useful and was installing them around trials they are running, to detect not only FAW but other noctuids as well. However there was a belief that growers are not using traps. In particular, they can be very useful in detecting flights into sorghum crops being grown in the lower pressure regions.

For commercial crops, one agronomist mentioned that they were using pheromone traps initially to detect the start of pressure and hence the need to ramp up scouting, however they are no longer using them as FAW are constantly present.

In okra, there were reports of Magnet + methomyl providing useful results. However, another agronomist mentioned that they had tried Magnet + methomyl in other crops "with only average results" and expected that high and frequent rainfall was a factor in the 'average' performance obtained.

One agronomist mentioned that they are experimenting with chilli wax/powder added to insecticide applications. The idea is that this is an irritant that "burns and agitates insects leading to more insecticide exposure."

Existing resistance, IRMS and impact of FAW on IRMS

Historically the main resistance concern has been pyrethroid resistance to both *H. armigera* and *Spodoptera* sp. across a range of crops.

One agronomist reported that there can be up to 17 generations of *Helicoverpa* per year in the NT and mentioned that while this can be problematic for management, it may be somewhat beneficial for resistance management as there is likely to be several generations each year where there be effectively no spraying occurring (no commercial crops being grown at that time) which may be providing substantial dilution of any resistance genes.

OP and carbamate cross-resistance in both cotton and green-peach aphid has been reported from cotton crops around Kununurra, so the advice from Paul Grundy (QDAF) was to avoid use of dimethoate (for aphids and mirids).

In cotton, there is generally good compliance with MyBMP and the industry IRMS strategy for decision making. The cotton agronomist mentioned that cotton crops follow the industry strategy "to the letter". However it was also added that the days of 'product application windows' have gone, with product rotation being much easier and much more likely to be adopted by users.

The non-cotton agronomists interviewed were particularly concerned around the potential for Group 28 resistance "as we rely on them heavily." However the cotton agronomist had a somewhat different view in that in their opinion, there are very small areas of 'crop' being sprayed in the NT, and these crops are mostly geographically dispersed, so there will be 'huge' populations of FAW in the non-crop environment that will never be sprayed at all. "A few 10-100 ha blocks of crops won't need or drive a resistance strategy."

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

There does not appear to be any 'local' IRMS, but agronomists are aware of information from Hort Innovation, AusVeg and CottonInfo. In vegetables (predominantly sold into fresh markets) and forage crops there is little consideration of industry wide issues such as IRMS. One agronomist called this "NT casualness", while another reported "No. This is the NT!"

There is also a relatively low percentage of these crops serviced by agronomists (compared to other regions surveyed). Combined with the diverse languages in these areas, any IRMS targeting this segment will be difficult to communicate and likely to have poor adoption, unless there is a specific crop which is being decimated and those growers 'might' pay attention. In the opinion of one industry agronomist, a vegetable IRMS is probably required, but this will need to be communicated within a broader IPM strategy and will likely to require "hands on demonstrations of using beneficials, staying soft, trapping, scouting and identification." A different agronomist indicated "Adoption and compliance will depend on the practicality of the recommendations. Commercial outcomes are necessary for the growers. We put a lot of work into correctly identifying pest spectrum and the correct time to act in relation to beneficial insects, as well as understanding host plants for beneficials."

Two agronomists interviewed saw the importance of staying soft where possible and maintaining beneficials (both endemic and released) as a key to delaying resistance. While both also saw the need for a greater focus on scouting eggs and timing of insecticide sprays, targeted to egg hatching/early instars.

One of these agronomists mentioned "While there are no formal IRMS followed, my personal IRMS is to look after Group 28's! For example, in cucurbits (melons) we are very beneficial friendly and release parasitic wasps and rotate Group 28's with Delfin. We also limit ourselves to 2 sprays of Group 28. We will use Vivus if only *H. armigera* are present but will switch to a Group 28 if a cross-section of pests exists at a key period such as flowering or early fruit set."

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- What beneficials are there that will work and help control FAW? At which growth stages? Where do these beneficials live in our system and how can we promote them?
- Many beneficials are hard to scout. Education on how to scout for beneficials and how to integrate them into a program is needed.
- More understand of how to use products like Magnet and the biologicals such as Fawligen.
- Grower training in IPM, monitoring (including incorporation of pheromone traps), pest and beneficial ID and use of softer options. Ideally this would start with the key crops first i.e. sorghum.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

14.4. Western Australia

14.4.1. Ord Irrigation Area / Kununurra / Broome / Carnarvon

Due to the low number of agronomists operating in northern WA, all interviews were combined.

Current crop matrix

Interviews were targeted at the following crop segments.

		Crops								
		Maize	**Sweet corn**	**Sorghum**	**Sugar cane**	**Rice**	**Cotton**	**Summer pulses**	**Chickpea**	**Vegetables (excl sweet corn)**
WA	ORD	X	X				X	Soy / Mung		X

Expected FAW pressure

The first known observations of FAW were March 2020 in early sown corn crops, some 12 months after the initial incursion into Queensland.

Maize and sweet corn are the primary crops for focus. "Some growers are no longer growing sweet corn, as it has become too hard to manage the FAW." Maize is the main focus for FAW at Kununurra, with little sweet corn being grown. Sweet corn is the main focus at Broome and Carnarvon (along with a few sweet corn growers 100 km north of Perth).

Pressure appears to reduce over the wet season. "When we sow corn crops in April/May, FAW numbers are low and take time to build up. In the second week of April 2022, trap numbers are only 0.5 – 1 /trap." As a result, FAW is generally less of an issue in early sown corn crops (April – May), with numbers starting low each year and then building up over winter and into spring. Pressure is more likely to be an issue in later sown maize crops e.g. June sowings.

A local entomologist added that FAW pressure in pheromone traps plummet over the summer 'wet season'. "I suspect this is due to the lack of a concentrated food resource over summer" as there are not many 'crops' being grown at this time and FAW populations most probably disperse into the vast native environment.

"FAW are highly mobile and move around. In October and November, many crops are harvested and at the same time pupae are emerging to find a poor supply of food crops on which to lay eggs. I perceive this is a trigger for dispersal, leading to insects being found in traps up to 70 km away. Dispersal appears triggered by both competition and resource availability. We do not as yet have data on what they feed on during the wet season, but I have seen them in Rhodes grass quite frequently. I suspect there are other pressures on the population in the wet season such as elevated levels of predation by natural enemies."

Similarly, one agronomist mentioned that FAW can still be found in grasses over summer, in particular Rhodes grass and millet. While the local entomologist added that in a recent study, we were able to show that "FAW can complete their lifecycle on grass pastures but did not thrive outside of sorghum and maize crops. For example, in sorghum and maize they produced a large number of larvae of a large size, while in pasture species fewer larvae were produced and these were smaller." "While there is generally not a very significant area grown to either Rhodes grass or millet, there is some impact in these crops. But probably not at a level requiring management."

There are small areas of grain and forage sorghum grown, with pressure mostly only in the vegetative stage.

Cucurbits (pumpkins) have a very wide planting window (February to July) which can mean ongoing pressure for many months, with some growers still not using scouting and just 'calendar spraying'.

"FAW identification is hard when larvae are small, but we are getting better at it. Agronomists are generally good, and no issues exist with identification and implementation of appropriate management strategies. Often we have *Spodoptera litura* present along with a range of caterpillar larvae, so often we spray based on the total larvae load and differentiation between species becomes less of an issue.

Management strategies

Maize – Maize is typically grown in the winter 'dry' season, being planted from April to end of June and harvested September to end of November. One NT agronomist also commented on grit corn crops that they were managing in Kununurra, plus some sweet corn south of Broome and mentioned that the gritting maize crops generally follows early-season cucurbits in the rotation.

One agronomist suggested that their current management strategy is to;

- Sow corn early. Don't plant 'late' crops. This is achievable with minimal impact on yield, however the main downside of concentrating sowing is that it concentrates the harvest, placing pressure on the logistics of handling large quantities of grain
- Monitor crops and respond to scouted pressure
- Spraying 8 – 10 times is a waste of money
- Target key sprays around tasselling
- Target Altacor at tasselling in corn. Keep Fawligen up my sleeve in case pressure is high either prior to or at tasselling.

Sweet corn – Close to Perth, sweet corn planting commences in late August as soil temperatures rise and will continue on a continual basis through to late March. While in the Kimberly / Broome sweet corn planting starts in March and runs through to August. This is designed to provide continual supermarket access. Winter grown sweet corn can be a relatively long season crop (120 to 135 days) at that time of year.

In the first year of FAW arrival (2020) both growing regions were hit with heavy pressure i.e. 200+ moths per pheromone trap per night in crops around Perth, while in the north there was 15-20% damaged cobs. Since that first year, "numbers have dissipated substantively and has not been a problem in crops grown since that first incursion year and similarly, it is also almost disappeared/not appeared in pheromone traps in subsequent years. There is no obvious reason as to why."

Cotton – Cotton is typically planted from mid-January to April, with picking late July to early October.

All cotton is Bollgard 3, and one agronomist commented that "We have seen massive egg lays of *H. armigera* and occasionally one or two make it through to become a medium-sized larvae. Despite finding egg masses of FAW in BT cotton, we have not yet had to spray for this pest. Sometimes we also find *Spodoptera litura*, in cotton but we have not had to spray as yet.

Mung beans – Mung beans are the main 'summer' pulse crop, with the main planting window being February to March, with the odd crop being planted in May to July. Harvest is typically May and June, although the late crops may not be picked until September.

Sorghum – Only small areas of grain sorghum are grown around Kununurra (< 100 ha). Where grown, it is typically planted late April or May and harvested August to September.

Pest pressures are rarely at levels that require intervention in grain sorghum, although some growers did spray in the first year when damage was seen. A local entomologist added "It may be that the pest does not like tougher older leaves on grain sorghum, or the younger leaves on an older plant."

Forage sorghum (for grazing) is often grown as a perennial crop. Planting is typically April to June, with a paddock often remaining in production for 2 or 3 years, with most growth occurring over the wet season.

Pumpkins – Extended planting from February to July, with harvest from June to November. The extended planting window means the spraying is also extended.

One agronomist mentioned that more scouting / monitoring is required "to get growers away from a calendar spraying mentality, which is still the case for a few growers."

Important insecticides

Maize – A typical program for FAW in maize for grit or stock food has been Steward (400-500 mL/ha) in the vegetative stage, however one agronomist mentioned that "It generally has poor efficacy, which may be more due to application than the product." This agronomist rated it 1¾ out of 5.

Pre-tasselling vegetative control has been complemented by Magnet + methomyl, which have continued post- tasselling, however this same agronomist mentioned that performance of Magnet + methomyl was "Highly variable, and often poor and we will be using far less of this in the future."

This comment re Magnet was confirmed by a local entomologist "We had hoped to see more benefit from using Magnet, but there is little evidence showing it is effective and data suggests it is only poorly effective. Some fields have had up to 8 applications of Magnet plus methomyl. The impact on FAW populations has been substantially poorer than was hoped for."

One agronomist suggested that "90% of crops will get an Altacor (90 g/ha) application at tasselling for both FAW and *H. armigera*. Efficacy is reasonable (3.5 out of 5), although application coverage may detract from observed efficacy." Some crops may require a second application.

If pressure is low then sometimes Fawligen (100 mL/ha) has been used, however this agronomist only rated it 2.5 out of 5. Where pressure is higher, Altacor will be used, or sometimes Altacor + Fawligen. "Recent data suggests that a 200 mL/ha rate of Fawligen is substantially better than the 100 mL rate, and we will look to move to the higher rate in future."

Where Success Neo has been applied, it was rated similar to Altacor, but "it is too expensive, and is only rarely used."

The local entomologist interviewed provided the following comments re comparative efficacy of insecticides:

- Steward increases its value somewhat when used later in the vegetative phase, but we are unsure why this trend exists. The ability of Steward to suppress FAW declines faster than Altacor (i.e. Altacor provides longer period of population suppression – especially when used

later in the season than does Steward). While Steward gives good knockdown, it's persistence (particularly early-season) is poor. Could this be improved? Would better application coverage assist?
- Altacor used later in the season provides longer useful suppression of the population than when used earlier season in corn
- The relative efficacy of Fawligen increases two weeks after application
- Implications are that Fawligen is good and best used early to suppress a low-level population, followed with Altacor or Steward
- To date, in WA, there has been very poor correlation between expenditure on total insecticide applications and corn yield in the presence of FAW, i.e. more applications don't necessarily lead to yield increases. It's far more important to select the right products and apply them at the right timing, than to spray on a schedule.

Sweet corn – Chlorantraniliprole (both Coragen and Altacor were mentioned, although only Coragen is registered for sweet corn) and it appears to be the primary insecticide for both FAW and *Helicoverpa*, with crops getting two applications typically to protect the cob.

One agronomist mentioned that translaminar movement of chlorantraniliprole can result in approximately 10 days residual under these conditions.

Historically, sweet corn crops would have had an earlier Vivus application, targeting *Helicoverpa*. However, in one agronomist's program, this has currently been replaced with Delfin (sprayable Bt) as it is expected to be better than Vivus on the mixed FAW, *Helicoverpa* and cucumber moth populations. Most crops they manage also get a methomyl application for knockdown at commencement of tasselling.

A different agronomist suggested that they "Don't have a specific FAW strategy yet, as we are unsure if it will turn up or not based very high pressure one year and 'nonappearance' last season." Their program last year was almost exclusively focused on *Helicoverpa*, so was 2 or 3 applications of Vivus Max in the vegetative stage, followed by 1 or 2 Proclaim from tasselling and 1-2 Group 28s during cob fill. Most commonly 5 sprays would be the normal for armigera – 3 x Vivus + one Proclaim and 1 Group 28. "If FAW does turn up, we will consider switching away from Vivus to Fawligen. Subsequent sprays are likely to be similar to what we are currently using, but if pressure from FAW is high, spray number is likely to increase, particularly with Group 28 chemistry."

Mung beans – Not current finding FAW in mung beans and insect control is predominantly for sucking pests. Early in the crop, it is common to apply a low rate of dimethoate (250 mL/ha) + salt for mirids and aphids. Most crops then typically get a late application of Shield for mirids and shield bugs. One agronomist indicated "This year we intend to try Starkle as it is cheaper and may replace the more expensive Shield if efficacy is good."

Cotton – All cotton is Bollgard 3 and is being managed primarily for sucking pests. A typical program will be one or two early applications of fipronil for mirids, with sometimes a Transform required if both mirids and aphids require control. Crops will generally get a Transform late season (again for mirids and aphids), although sometimes this may be switched for acetamiprid. "We have not yet used Starkle or Skope (for mirids and shield bugs) but we do plan to try these."

Pumpkins – Early season, most crops will get 1 or 2 applications of methomyl to control *Helicoverpa*, *S. litura* and cucumber moth, with a further 1 or 2 applications of a Group 28 (either Coragen or Belt) later in the season during fruit fill for the same pest complex.

Aphid control is highly variable (0 to 4 applications per crop) and will be either Transform, Versys®, or sometimes MainMan. "Transform can be a bit hot on bees, so some growers prefer other products."

Biological agents

One agronomist suggested "We monitor for beneficials and target the use of soft chemistry, especially early in the crop. Predatory shield bugs like hot weather and often decline in the middle of our key growing season (winter). There are a lot of spiders here, and a few parasitic wasps and ecto-parasites that are often seen on larvae. Tachinid flies are also present and can often be seen on larvae. Lady beetles are also a predator for aphids. While mirids are a pest species, they can also be beneficials as they eat *Helicoverpa* eggs."

"We tend to spray on the pest threshold rather than an established pest/beneficial ratio. Beneficials are however scouted and recorded."

The majority beneficials are background native populations. "We have tried releasing *Trichogramma* wasps, but it is difficult to determine their level of impact. We have also released wasps for aphids and mealy bug control. We are very interested in learning more about *Cotesia* and its efficacy/impact."

"We assume native beneficials will adapt to FAW presence, but the process is occurring slowly. We need more beneficials, but FAW is proving to be a cryptic pest. They often hide and cannot be found as they are in entrenched feeding positions, particularly as larger larvae. This may also make them harder for beneficial insects to find and parasitise."

The local entomologist interviewed provided the following assessment of beneficials in maize:

- *Cotesia* are effective on FAW larvae
- *Trichogramma pretiosum* can target FAW eggs, however commercial releases have resulted in mixed reports of success
- Predatory shield bug, lady beetles and spiders do attack all stages of FAW, while damsel bugs and lacewings are more active on larger instars. We see more of these insects where there are higher FAW numbers, so we assume that they are feeding on the FAW.

Cultural / non-chemical management tactics

A leading agronomist and entomologist both suggested that planting dates need to be considered. In their opinion, maize planting is likely to be condensed to the early part of the season so as to make FAW management simpler.

Vegetables (pumpkins) are likely to be more problematic with growers wanting to spread harvest for marketing and logistical reasons, which will then require spraying over many months.

Pheromone traps are considered very important "to provide growers and advisers a feel for what's happening. However a challenge is that early infestations in particular can be very patchy and the presence of adults in traps does not correlate well with field pressure, particularly early season. We can have zero moths in the traps and a neighbouring field can be invested, or the reverse. Field surveillance still remains a critical requirement for effective decision-making.

A local entomologist commented that FAW numbers in pheromone traps have been consistently higher in Carnarvon than Kununurra for the whole of the past two years. It is also noted that the area of sweet corn is mostly concentrated around Carnarvon, with relatively little sweet corn being grown in Kununurra – it is not known if these are linked. “Broome has only had limited FAW pressure, but trapping has been less intense so there is some uncertainty.”

Existing resistance, IRMS and impact of FAW on IRMS

One agronomist reported that there is “100% resistance” to dimethoate in cotton aphid.

Group 28 resistance in FAW was raised of a significant area of concern by two agronomists interviewed. “We grow 5000 ha of corn per year, and Altacor is applied on all of it. We also use Group 28 chemistry in cucurbits, as Group 28s are the only ones with efficacy that are registered/approved for FAW larvae control.”

Where cotton is grown, there appears to be good compliance with the industry IRMS. “In other crops, we try to stay as soft as possible and select chemistry to preserve beneficial insects. We try to target windows for particular products e.g. Group 28 use in corn at tasselling and where possible, rotate between chemistries (where options exist).

This agronomist above suggested the following strategies to try to minimise overuse of chlorantraniliprole:

- Stick with label rates
- Try to keep Vantacor within a tight window around tasselling in corn. This will go for about six – eight weeks to cover most crops
- It’s hard to produce a strategy for protecting Group 28 chemistry in cucurbits (pumpkins), as we have a prolonged sowing window and very few, (if any) alternative options other than Success Neo, which is prohibitively expensive
- The Ord region has a varied crop mix with variable planting dates. As a result, I am unsure if specified windows would work
    - In corn, use of Group 28 could be restricted to targeting the period around tasselling
    - Cucurbits are harder. Higher levels of scouting in cucurbits would help reduce/avoid calendar spraying which a few growers still do. A problem is that cucurbits are grown on flood irrigation and as a result, windows for ground application are also limited by field access issues.

A different agronomist, heavily focused on sweet corn saw Group 28 as the main concern as there are crops of all growth stages growing adjacent to each other, so while you may not apply more than two applications to one crop, the paddock next door may be treated again the following week, so use can be almost continual.

A regional entomologist also shared views with regard to Group 28 management and the potential for an IRMS. There was some concern that a ‘window’ approach may not be practical, “as we lack the information of how to manage blowouts” should these occur in crops in the reproductive / fruiting stages when the Group 28 window is closed. “We will need a practical option.” “If we get another new product, or products, which are affordable and effective, then we may have the option to look at a defined spray window. For example if the price of Success Neo were to come down it could become an economically viable option.”

The most likely solution in the opinion of this entomologist was to attempt to restrict the number of sprays per crop. “Potentially one application of Vantacor at most in the vegetative stage (or preferably Steward). And then one further Vantacor at tasselling.” There is also the option to rotate Fawligen and Steward with Vantacor.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

Outside of 'new' insecticides, are there options for FAW management that you would like to see pursued?

- Interested in learning more about:
    - Fungal diseases that attack FAW
    - *Cotesia* (x2)
    - Pheromone/mating disruption techniques (x2)
- Is there an option to evaluate / test potential changes in insect genetics (resistance development) under different insecticide selection pressures in the laboratory? This may give data to predict what level of use can be supported in the field
- Better strategies for the attract and kill concept. Magnet isn't effective
- Natural enemies and their effectiveness
- Need an additional soft insecticide. Another NPV to rotate with Fawligen, or to provide better efficacy in certain climatic conditions or on different strains of FAW. Having two products would also address supply chain risk.

14.4.2. Northern WA grains region

The grain belt of WA specifically and national winter broadacre cropping more generally, were not considered by ICAN to be a high target for FAW, compared to other 'tropical' and 'summer crop' regions. This assumption is based on the understanding that colder 'winter' conditions will likely see major reductions in FAW populations each year in regions where winter cropping is the predominate farming practice.

It may be possible that there is some southerly migration, adaptation and subsequent build-up of FAW populations during 'spring' in winter crops grown in these regions, however it is unlikely that these populations will build to large numbers before winter crop harvest (October to December). After winter harvest, there is typically no extensive areas of crop in the ground over summer in most of the southern wheat belt, with FAW survival being constrained to possibly weeds and pockets of irrigated horticulture (i.e. sweet corn north of Perth as covered above).

For these reasons, winter crops were generally not a major focus of this research.

It is noted that DPIRD in Western Australia has a web page dedicated to fall armyworm management in winter grains, canola and pulses https://www.agric.wa.gov.au/fall-armyworm-western-australia?page=0%2C7#smartpaging_toc_p7_s0_h3 , indicating that, a 'watching brief' is being maintained for this farming system.

Understanding the key market drivers that will underpin the development of an insecticide resistance management strategy for fall armyworm (*Spodoptera frugiperda*).

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Appendix A Permits issued by the APVMA for FAW control

Permits issued by the APVMA for FAW control in crops of focus for this research project (as extracted from PUBCRIS as at 29/04/2022). Those in yellow are held by Plant Health Australia.

Authors note, this is not a complete list of all crops (and the individual detail) covered by some of these permits. Entries listed here are deemed by the authors of the report to be the most significant in terms of use and therefore impact on resistance. For example, several minor crop, ornamental, nursery and tree crop use patterns are not included in this table. Formulation details have also been removed, with use rates converted to gai for ease of comparison across different formulations.

Active ingredient	MOA	Permit No	Expires	Crop	Rate
carbaryl	1A	89425	31/5/23	Rice	1.1 kgai/ha
methomyl	1A	89293	30/4/23	Brassica vegetables Capsicums Sweet corn Beans Peas Potatoes	337.5-450 gai/ha
				Fruiting vegetables Legume vegetables	225-450 gai/ha
		89279	31/3/23	Maize Sorghum Sweet corm Soybean Peanut	450 gai/ha
alpha cypermethrin	3A	89425	31/5/23	Rice	23-27 gai/ha
		89279	31/3/23	Maize Sorghum Sweet corn	40 gai/ha
				Pulse crops	30 gai/ha
				Winter cereals	24 gai/ha
				Millet	22-28 gai/ha
		85447	30/4/26	Maize Sweet corn Chickpeas Faba beans Field peas Mung beans Navy beans Soybeans Sorghum Millet	22-28 gai/ha
				Winter cereals	22-24 gai/ha
		89403	31/5/23	Millet	22-28 gai/ha
zeta cypermethrin	3A	89279	31/3/23	Maize Sorghum Sweet corn Sunflower	50 gai/ha
spinetoram	5	89390	30/4/23	Maize Popcorn Sorghum Millet	30-36 gai/ha

		89241	31/3/23	Sweet corn Brassica vegetables Leafy vegetables Cotton Cucurbits Fruiting vegetables Legume vegetables Stalk and stem vegetables Root and tuber vegetables	48 gai/ha
				Soybean Pulses (excluding chickpeas)	36 gai/ha
				Chickpeas	24 gai/ha
		90737	20/9/23	Ginger	48 gai/ha
		89331	31/3/23	Onions	24-48 gai/ha
		89284	31/3/23	Leek, spring onion, shallot, galangal	48 gai/ha
spinosad	5	89870	31/7/23	Brassica vegetables Brassica leafy vegetables Cucurbits Culinary herbs Fruiting vegetables Leafy vegetables Legume vegetables Root and tuber vegetables Stalk and stem vegetables	96 gai/ha
				Sweet corn	96 gai/ha or 9.6 gai/100L
emamectin	6	89371	31/8/23	Wheat Maize	10.2-15.3 gai/ha
		89300	30/4/23	Pulses	7.7-11.9 gai/ha
		89344	31/3/23	Cotton	9.4-11.9 gai/ha
		89285	31/3/23	Brassica leafy vegetables	11-13.2 gai/ha
		89263	31/3/23	Brassica vegetables Root and tuber vegetables (except potato) Leafy vegetables, Brassica leafy vegetables	11-13.2 gai/ha
				Sweet Corn, Cucurbits, Legume vegetables Fruiting vegetables	11 gai/ha
		92220	31/3/23	Brassica vegetables Root and tuber vegetables (except potato) Leafy vegetables, Brassica leafy vegetables	10-13.2 gai/ha
				Sweetcorn Sweet Corn, Cucurbits, Legume vegetables Fruiting vegetables	11 gai/ha
indoxacarb	22A	89530	31/5/23	Maize	60-75 gai/ha
		90374	30/11/23	Sweet corn	75 gai/ha
		90577	31/1/24	Peanuts	45-75 gai/ha

		89306	31/3/23	Cotton	75-127.5 gai/ha
		89279	31/3/23	Soybean	60 gai/ha
		89311	30/4/23	Pigeon pea	60 gai/ha
		89278	31/3/23	Broccoli Brussels sprouts Cabbage Cauliflower Capsicum Eggplant Peppers Tomato	75 gai/ha
chlorantraniliprole	28	89259	31/3/23	Brassica vegetables Brassica leafy vegetables Stalk and stem vegetables Leafy vegetables Fruiting vegetables Legume vegetables Potatoes Sweet corn	20 gai/ha
				Lettuce	30 gai/ha
				Cotton	52.5 gai/ha
				Pulse crops	24.5 gai/ha
		89384	31/5/23	Sugarcane	157 gai/ha in-furrow + 28 gai/ha foliar
		89457	30/11/22	Sunflower Safflower	24-33 gai/ha
		90621	28/2/23	Rice	24-33 gai/ha
		91386	31/5/23	Maize	24-33 gai/ha
		86014	31/8/23	Peanut	24 gai/ha
		91616	31/10/24	Millet Sorghum	33-54 gai/ha
		90758	30/9/23	Ginger	20 gai/ha
chlorantraniliprole + thiamethoxam	28 +	89280	31/3/23	Brassicas Leavy vegetables Fruiting vegetables	Seedling drench See permit for rates
methoxyfenozide	18	84531	31/8/25	Sweet corn (for lepidopteran pests)	30-40.8 gai/100L
amorphous silica 450g/L	N/A	90841	31/3/24	Sweet corn	2.5-5 L/ha

Additional non-insecticide permits include

Active ingredient	Permit No	Expires	Situation
Pheromone lures + dichlorvos	89169	28/2/23	Not crop specific
Magnet insect attractant + methomyl	89398	30/6/22	Cotton Cereal Grains (includes Maize and Sorghum) Sweet corn Pastures Oilseeds (includes Canola and Sunflower)
	91306	31/10/24	Ginger

In addition to the above, there are two ‘Emergency Use’ permits in place, which allow for the use of products that are not currently registered in Australia.

SfMNPV[1]	31	91477	31/3/24	Cereal grains Oilseeds Pulses Fodder and forage crops	50-200 mL/ha
				Cotton	150-300 mL/ha
				Sweetcorn, corn Root & tuber vegetables Legume vegetables	100-200 mL/ha
SfMNPV[2]	31	90820	31/3/24	Cereal grains Oilseeds Pulses Fodder and forage crops	50-200 mL/ha
				Cotton	150-300 mL/ha
				Sweetcorn, corn	200 mL/ha
				Root & tuber vegetables Legume vegetables	100-200 mL/ha

SfMNPV[1] – Spodovir Plus 5 x 10^8 occlusion bodies of *Spodoptera frugiperda* multiple nucleopolyhedrovirus isolate 19 per millilitre

SfMNPV[2] – Fawligen 7.5 x 10^9 occlusion bodies of *Spodoptera frugiperda* multiple nucleopolyhedrovirus strain 3AP2 per millilitre

Appendix B Impact of insecticides on beneficial insects

Beneficial toxicity ratings for insecticides in grain crops (Cesar Australia, 2022)

As a comparison, ratings from this new ‘grains’ information has been compared below to long published insecticide ratings from cotton (Cotton Research and Development Corporation, 2021) [Note: For brevity, only the overall rating have been included in this table. More detailed information is available in each original study].

	Grains per Cesar Australia		Cotton per CottonInfo	
	gai/ha		gai/ha	
BT	1700	L		VL
NPV	400	L		VL
Chlorantraniliprole	24.5	L	52.5	L
Flonicamid	50	L	70	M
Afidopyropen	5	L	10	L
Paraffinic oil	1584	L		VL
Pirimicarb (low)	75	M	250	VL
Abamectin	5.4	M	5.4	M
Indoxacarb	60	M	60-127.5	L
Pirimicarb (high)	500	M		
Diafenthiuron	300	M	350	L
Gamma-cyhalothrin	4.5	M		
Spinetoram	36	M	48	L
Thiodicarb	281.25	M	750	H
Sulfoxaflor	50	M	48-96	M
Other SPs		H		VH
OPs		H		H
Methomyl	450	H		H

Beneficial toxicity ratings for horticultural pesticides – sweet corn (Hort Innovation, 2020)

Beneficial toxicity ratings for horticultural pesticides – cucurbits and fruiting vegetables (Hort Innovation, 2020)

Appendix C Approximate costs of insecticides for FAW control

Approximate costs of insecticides for FAW control, for which permits have been issued by the APVMA (Kearns, et al., 2020)

INSECTICIDE	MOA†	CROP	COST (AUD$/L OR KG)[1*]	PRODUCT VOLUME (L/HA)	COST (AUD$) PER HECTARE AT MAXIMUM FIELD RATE
Methomyl	1A	Maize, sorghum, sweetcorn, soybean, peanut and millet	10	2	20
Alpha-cypermethrin	3A	Winter cereals	7	0.24	1.68
Alpha-cypermethrin	3A	Millet	7	0.28	1.96
Alpha-cypermethrin	3A	Pulse crops	7	0.3	2.10
Alpha-cypermethrin	3A	Maize, sorghum and sweetcorn	7	0.4	2.80
Gamma-cyhalothrin	3A	Lupins	108[1]	0.02	2.16
Gamma-cyhalothrin	3A	Canola, field peas, chickpeas, faba beans, lentils, vetch	108[1]	0.03	3.24
Gamma-cyhalothrin	3A	Barley, wheat	108[1]	0.035	3.78
Gamma-cyhalothrin	3A	Navy beans, mung beans, sorghum, soybeans	108[1]	0.06	6.48
Gamma-cyhalothrin	3A	Sunflower	108[1]	0.07	7.56
Spinetoram	5	Canola	409.30[1]	0.15	61.40
Spinetoram	5	Chickpeas	409.30[1]	0.2	81.86
Spinetoram	5	Soybeans, maize cereals, sorghum grain and millet	409.30[1]	0.3	122.79
Emamectin benzoate	6	Wheat, maize	80	0.9	72
Emamectin benzoate	6	Canola, pulse	80	0.7	56
Indoxacarb	22A	Soybean	60	0.4	3.20
Indoxacarb	22A	Maize cereals	60	0.5	4.00
Chlorantraniliprole	28	Winter and summer pulse crops	440	0.07	30.80
Chlorantraniliprole	28	Maize cereals	440	0.09	39.60

†MoA: Mode of action

[1]J. Khurana, pers. comm. August 2020

*Prices provided are approximate at the time of publication and may change or differ between areas.

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