Insect Pest Management in Sweet Corn

Peter Deuter *et al*
Queensland Dept. of Primary Industries

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Final Report

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VG 97036
"Insect Pest Management in Sweet Corn"

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See page 27 for complete list of project team members.

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"Insect Pest Management in Sweet Corn" - VG97036 - Final Report.

Contents

Media Summary

➢ Key components of the project

The **major issue** this project has addressed is the effective management of Heliothis (*Helicoverpa armigera*), the most limiting factor in meeting the demands of the sweet corn export market and producing a consistent supply for the domestic market. The project objectives were as follows:

- ➢ Identify and promote integrated pest management systems for sweet corn.
- ➢ Reduce the production risks, particularly for export oriented production systems.
- ➢ Protect and increase the small range of insecticides used for insect pest management including alternatives to broad spectrum insecticides.
- ➢ Test and promote improved application techniques.
- ➢ Identify technology which can separate damaged and undamaged cobs during the grading and packing process.

➢ Industry significance of the project

In 1995, the Australian Sweet Corn industry produced 73 000 t for an on-farm value of $30.5M (ABS, 1995). Queensland produced 19% of the Australian tonnage and 36% of the $ value (14 000 t and $11M annually); NSW produced 53% of the Australian tonnage from 2200 ha, mostly for the processed market. Victoria produced 10% of the Australian tonnage for fresh domestic and export markets.

Attempts were made by growers in Queensland, NSW and Victoria to supply a fresh product to the export market in South East Asia with both bicolour and yellow super sweet varieties. These growers had significant difficulties due to the inability to produce cobs free from heliothis larvae and larval damage. This was due to the high levels of insecticide resistance which occurs in *Helicoverpa armigera* (heliothis). Product free from insects and insect damage is critical from a quarantine point of view and is essential in relation to meeting the export and domestic market specification.
Export opportunities were restricted due to the inability to produce cobs free from heliothis larva and larval damage. In addition, growers had a restricted range of cultivars available, particularly of bicolour sweet corn, due to phytosanitary restrictions relating to boil smut freedom. These limitations impact on quality, production, and productivity and has restricted the development of export opportunities.

➢ Key outcomes

- The major benefit of the project comes from more than just the technically and scientifically excellent work – it is the fact that industry has changed its practices as a result of the project.
- The Australian sweet corn industry has increased from 70,000t (1997) to 120,000t (2001).
- Crop losses have been reduced from an occasional 100% loss (1992 - 1994), to 20% currently.
- Research conducted during this project were used to support the successful application by Dow AgroSciences and Aventis Crop Sciences Pty Ltd to the National Registration Authority (NRA) for the registration of two narrow spectrum, IPM friendly insecticides (Success® and Gemstar®), in sweet corn in Australia.
- The export industry was re-established in 1998, after cessation due to uncontrollable insect damage and contamination.

- Farmers, farm workers and the environment are no longer exposed to the negative effects of organo-phosphate and organo-chlorine insecticides.
- A number of growers in all districts are modifying boom sprayers to take advantage of the 4 fold improvement droppers can make on spray deposition. Work with aircraft in all districts has shown that optimisation of aircraft application can be achieved through modification of spray patterns, increased water volume and use of aids such as GPS.
- There has been an increase in the stability of established populations of *T. pretiosum* in South Queensland due to the major reduction in the amount of broad-spectrum insecticides being used in the crop.
- All sweet corn grown in the Dry Tropics is monitored professionally, and the area monitored in South Queensland has doubled. In NSW there has been a 20 percent increase in the area of sweet corn regularly monitored, and in Victoria, 85 percent of the industry now checks crops for large and small larvae and eggs. All states report the use of improved monitoring protocols and increased grower understanding of monitoring procedures and results.
- Discrimination between physical defects in cobs (poor grain tip fill, insect damage and presence of the heliothis larvae) and undamaged cobs can be achieved non-invasively by near infra-red spectroscopy. The NIR Systems 6500 scanning spectrometer and the Zeiss MMSI miniature spectrometer (coupled with a high intensity quartz halogen lamp - 100 watt) can achieve this discrimination. However, in a practical packing shed operation, the relatively rapid and inexpensive Zeiss MMSI spectrometer offers the most promise.

The project has exceeded expectations set down by the initial Project Objectives, especially in the areas of risk reduction by IPM, more (softer) insecticide choices available to sweet corn producers throughout Australia and application technology. The sometimes controversial trial approach taken to develop **Best Management Options (BMO's)** paid off substantially and the assessments of technology with potential to improve sweet corn grading and packing operations was also a success. By the end of this 5 year project, scientists consistently demonstrated that IPM components used collectively in a system can significantly reduce the level of Heliothis damage in fresh market sweet corn from 100% down to 15%.

The R& D outcomes of this project have assisted the Australian Sweet Corn industry move a long way in pest management – from calendar spraying synthetic broad-spectrum insecticides (often onto resistant pests and with inefficient application technology) **to managing IPM systems** which integrate monitoring, selective insecticides and beneficial insects with improved application equipment targeting appropriate plant parts at the right time.

Information

Annual sweet corn industry workshops brought the project team, growers, consultants and field officers together to share information and co-ordinate further research and development.
The funding invested in hosting annual National Workshops and developing and widely distributing the "Sweet Corn Ear" newsletter, technical and Milestone Reports and Workshop Proceedings was worthwhile for **the major contribution it made to information transfer**, feedback and discussion as well as developing an industry identity.
It was this demonstration of cohesion and a visibly proactive industry seeking responsible solutions to its pest management problems that was the main contributing factor for two chemical companies (Dow and Aventis) to register their new selective insecticides for sweet corn in Australia.

Biological Insecticides

Results from research conducted during this project were used to support the successful application by Dow AgroSciences and Aventis Crop Sciences Pty Ltd to the National Registration Authority (NRA) for the registration of Success® and Gemstar® in sweet corn in Australia.

Sweet corn growers have adopted research showing that the insecticide Gemstar®, containing the nuclear polyhedrosis virus (NPV), can be used effectively in sweet corn to reduce the level of heliothis (*Helicoverpa armigera*) cob damage by 85%. The research, concentrated on improving the efficacy and application of Gemstar® in sweet corn crops.

Gemstar® has a narrow spectrum of activity, thereby preserving beneficial insects within the crop, and it does not adversely effect the environment. However, reduced cob damage can only be achieved if NPV is used correctly and effectively, and factors that cause in-field spray failures are eliminated. As NPV is very specific to Heliothis, it does not affect naturally occurring beneficial insects and spiders which can make a significant contribution to Heliothis management in commercial crops. NPV also has no adverse effects on other animals, including humans, making it extremely environmentally friendly.

Beneficial Insects

Beneficial insects, in combination with NPV can reduce the damage caused by heliothis and improve pack-outs. *Trichogramma preteosum* wasps have shown encouraging control levels of heliothis in the Lockyer Valley (Queensland). They also have shown the ability to survive the northern winters, and are a potential additional control agent for heliothis in sweet corn in NSW and Victoria. However over wintering capacity of *T.pretiosum* is not clear yet under southern Australian conditions.
In fresh market sweet corn in South Queensland, inoculative releases are made by some growers into the spring plantings. This has speeded up the process of Trichogramma establishment considerably and enabled a shift to a minimum insecticide program much earlier in the season. There has been an increase in the stability of established populations of *T. pretiosum* in South Queensland due to the major reduction in the amount of broad-spectrum insecticides being used in the cropping system.

Pesticide Application

Standard hydraulic boom sprayers fitted with droppers and aircraft were compared for efficiency in applying insecticides. Ground rigs with dropper attachments can achieve better coverage in the cob region of the plant.
A number of growers in all districts are modifying boom sprayers to take advantage of the 4 fold improvement droppers can make on spray deposition. Work with aircraft in all districts has shown that optimisation of aircraft application can be achieved through modification of spray patterns (narrow swaths), increased water volume and use of aids such as GPS.

Insecticide Resistance

Helicoverpa armigera larvae collected in East Gippsland from several sweet corn crops in 1996/97 have developed resistance against major pesticide groups registered for control of this pest in sweet corn. Results revealed adult moths and large larvae are resistant to synthetic pyrethroids but larvae less that 5 mm in length are still susceptible. Subsequent monitoring has indicated that this resistance has further increased by 2000 with a doubling of the resistance factor for synthetic pyrethroids and

carbamate resistance also becoming more severe. The above indicates that insecticide resistance in synthetic pyrethroids and carbamates has not improved.
Pyrethroid resistance was 57% and 41% respectively in two samples submitted from the Lockyer Valley (Queensland) in Dec/Jan 1995/96, and carbamate resistance was 15% in Jan 1996. Unmanageable levels of resistance were recorded in North Queensland in the winter of 1996.

Development of Pest Monitoring (scouting) Protocols

Growers and consultants actively worked with project researchers to develop insect scouting (monitoring) protocols for all production regions in Eastern Australia, that incorporated all variations in monitoring methods occurring during the crop's growth. The development of a standardized insect scouting protocol has enabled growers and consultants to identify insect problems before they become significant.

All sweet corn grown in the Dry Tropics is monitored professionally, and the area monitored in South Queensland has doubled. In NSW there has been a 20 percent increase in the area of sweet corn regularly monitored and in Victoria, 85 percent of the industry now check crops for large and small larvae and eggs. All states report the use of improved monitoring protocols and increased grower understanding of monitoring procedures and results, due in the main to the project's trials and information sharing processes.

Moth monitoring and scouting crops for eggs and larvae has been used to identify appropriate methods for evaluating pest pressure in southern Victoria. This is used to identify times of peak pest pressure and to better target the application of pesticides for improved control of heliothis. Data collected during sweet corn seasons from 1995-2000 in East Gippsland identified the peak moth activity periods. Peak pest pressure occurs around mid February and moth counts correlate well with crop damage and the incidence of pest numbers within the crop.

Other Pests

While integrated pest management (IPM) of the caterpillar pest, heliothis is a reality in sweet corn crops, a reduction in the use of broad spectrum pesticides for heliothis management has lead to this increase in the number of other pests. Pests such as thrips, aphids and dried fruit beetles are pests as contaminants in produce bound for export markets. Other caterpillar species, plant hoppers, mites and green vegetable bug are causing physical damage to the crop.

➢ Clear conclusions

The sweet corn industry has **benefited** by changing from a high dependency on broad spectrum insecticides, to a very widespread use of biological methods. Pest management is becoming more complex, a key component being the conservation of naturally occurring parasitoids and predators (Beneficials). Parasitoids, predators, pathogens and some insecticides are being used to manage heliothis by Australian sweet corn growers. This has occurred as a result of a more thorough understanding of pest-beneficial interactions, the use of biological and narrow spectrum insecticides, spray decisions based on scouting information, and pesticide application using improved equipment and techniques, all leading to an integrated package of practices which will be more sustainable and long lasting than those based on broad spectrum insecticides alone.

➢ Recommendations for future R&D

➢ Information Interchange

The funding invested in hosting annual National Workshops and developing and widely distributing the "Sweet Corn Ear" newsletter, technical and Milestone Reports and Workshop Proceedings was worthwhile for the major contribution it made to information transfer, feedback and discussion as well as developing an industry identity. It was this demonstration of cohesion and a visibly proactive industry seeking responsible solutions to its pest management problems that was the main contributing factor for two chemical companies (Dow and Aventis) to register their new selective chemicals for sweet corn in Australia.

This approach is also largely responsible for the speed and desire growers have shown in adopting and adapting research on-farm. The project has seen the industry move a long way in pest management – from calendar spraying synthetic broad-spectrum insecticides (often onto resistant pests and with inefficient application technology) to managing IPM systems which integrate monitoring, selective narrow spectrum insecticides and beneficial insects with improved application equipment targeting appropriate plant parts at the right time.

➢ Other Pests

While IPM is a reality in sweet corn crops, a reduction in the use of broad spectrum insecticides for heliothis management has lead to an increase in the number of other pests. Pests such as thrips, aphids and dried fruit beetles are pests as contaminants in produce bound for export markets. Other caterpillar species, plant hoppers, mites and green vegetable bug are causing physical damage to the crop. R&D will be required to find IPM friendly components to manage these pests without upsetting the balance achieved in managing heliothis.

Technical Summary

➢ Nature of the problem

The **major issue** this project has addressed is the effective management of Heliothis (*Helicoverpa armigera*), the most limiting factor in meeting the demands of the sweet corn export market and producing a consistent supply for the domestic market. The project objectives were as follows:

- ➢ Identify and promote integrated pest management systems for sweet corn.
- ➢ Reduce the production risks, particularly for export oriented production systems.
- ➢ Protect and increase the small range of insecticides used for insect pest management including alternatives to broad spectrum insecticides.
- ➢ Test and promote improved application techniques.
- ➢ Identify technology which can separate damaged and undamaged cobs during the grading and packing process.

➢ Describe the science undertaken

The project work program was conducted through:

a) Focussed Research & Development;
b) Evaluating Best Management Options; and
c) Information Interchange.

1. Baseline data

To clearly define the starting point of this project, baseline data was collected on agronomic practices and pest management strategies used in the sweet corn industry in Eastern Australia. This baseline data of pest management practices in sweet corn has been used in project evaluation, against which gains and improvements have been judged **(See Project Activity 1. – Project Evaluation)**.

2. Best Management Options (BMO's)

BMO's are practical strategies, and include a broad range of appropriate pest management options, including the strategic application of synthetic and biological insecticides, improved pesticide application techniques, insect scouting and crop monitoring procedures, introduction, protection and fostering of naturally occurring and inundatively released beneficials, and work place health and safety aspects of pest management. These BMO's have been the basis of on-farm trials in each of the major sweet corn production districts in Eastern Australia, comparing the pest management outcomes of BMO's with grower practice **(See Project Activity 10. – Evaluation of BMO's)**.

3. Field Trials

a) Focussed Research and Development

1] Field trials have evaluated promising **narrow spectrum and biological insecticides** such as *Bacillus thuringiensis* (Bt), heliothis virus formulations (NPV) and Spinosad; and inundative releases of the parasitoid Trichogramma for management of heliothis populations. **(See Project Activity 3. – Biological Insecticides)**.

Results from research conducted during this project were used to support the successful application by Dow AgroSciences and Aventis Crop Sciences Pty Ltd to the National Registration Authority (NRA) for the registration of Success® and Gemstar® in sweet corn in Australia.

2] Field evaluation of **naturally occurring *Trichogramma spp.*** and their population dynamics by sampling heliothis eggs from commercial sweet corn fields over the entire season and determine:

a) the degree of parasitism over time.
b) the species of trichogramma occurring naturally.
c) the population dynamics of the different species over time.

(See Project Activity 4. – Naturally Occurring Beneficials).

3] Ground rig sprayers with nozzles targeting cobs, and other combinations of **modified application equipment** have been compared with the industry practice of aerial application. Pesticide targeting assessment has aimed at understanding how the arrangements of upper leaves affect the amount of pesticide reaching the cobs, especially the silks.
(See Project Activity 5. – Pesticide Application).

4] Heliothis populations have been **monitored weekly** (twice weekly during periods of pest build up) to improve the timing and application of biological and synthetic pesticides and develop and improve scouting protocols.
(See Project Activities 4 – Crop and Pest Monitoring; and 9 – Naturally Occurring Beneficials.).

5] **Sweet corn cultivars have been evaluated** at Bowen in Queensland and East Gippsland in Victoria. The major varieties have been screened for their tolerance to heliothis in the absence of insecticides. Cultivars were evaluated for performance, yield, quality, uniformity and resistance or tolerance to pests and diseases and in particular to heliothis attack.
(See Project Activity 7. – Cultivar Assessment).

6] Research was carried out using **non-destructive assessment of cob damage** with the use of near infra-red (NIR) spectroscopy, as a potential tool in separating damaged and undamaged cobs in a pack-house.
(See Project Activity 8. – Near Infra-red Technology).

7] The development of **improved pest scouting (monitoring) techniques** was a part of the testing of BMO's as well as focussed research and development associated with improved timing and targeting of pesticides and the testing of alternative biopesticides.
(See Project Activity 9. – Crop and Pest Monitoring).

4. Information Interchange

a) A **database of stakeholders** has been developed for the interchange of information. Information interchange with the Australian Sweet Corn Industry has occurred by the use of mail, fax, Email, **farm walks and field-days and four yearly workshops** for the reporting and review of progress and the planning of future work. All stakeholders were encouraged, and opportunities provided to participate in this information interchange.
b) Technology transfer was an integral part of this project, with stakeholders involved in the planning and review of the project as it progressed. **On-farm trials** provided an opportunity for grower input into the direction of research and development and in the adoption of the outcomes.
c) Four workshops for the reporting and review of progress and planning of future work was held in a major production district in Eastern Australia. **(See Project Activity 2. – Information Interchange).**

d) A number of additional methods have been used to communicate with sweet corn growers in Australia, including Conferences, Symposia, Workshops, Fieldays, Personal Interviews, TV, Radio, Newspapers and 'local' Newsletters.

5. Project Management

The project was managed by the project leader through a coordinator in each of the four teams of research and extension scientists in the major production regions (North Qld, Sth Qld, Central West NSW and Gippsland Vic.).
(See Project Activity 1. – Project Evaluation).

➤ Highlight major research findings and industry outcomes

The sweet corn industry has **benefited** by changing from a high dependency on broad spectrum insecticides, to a very widespread use of biological methods. Pest management is becoming more complex, a key component being the conservation of naturally occurring parasitoids and predators. Parasitoids, predators, pathogens and some insecticides are being used to manage heliothis in sweet corn. This has occurred as a result of a more thorough understanding of pest-beneficial interactions, the use of biological and narrow spectrum insecticides, spray decisions based on scouting information, and pesticide application using improved equipment and techniques, all leading to an integrated package of practices which will be more sustainable and long lasting than those based on broad spectrum insecticides alone.

Information Interchange - (Milestone 3.)

- Four planning and feedback **workshops** have been conducted at Gatton, Queensland (May 1998), Bathurst, NSW (May 1999), Bowen, North Queensland (June 2000); and Lakes Entrance, Victoria (May 2001). These, together with regular regional project team meetings have provided excellent opportunities for stakeholder input and planning project activities according to project plans and the needs identified by stakeholders and team members.
- A **stakeholder database** has been compiled, and proceedings of each of these workshops have been published and posted to all growers and other stakeholders in Australia. Project related news releases and media articles, Milestone Reports, Workshop Proceedings and the Sweet Corn Ear Newsletters have been published, and distributed to all stakeholders.
- A **Web site** > www.nre.vic.gov.au/agvic/ihd/projects/sc.htm < has being constructed, which features research results, and other information relating to the project. Team members in the four growing regions conducted wide publicity campaigns prior to running project field days (e.g. spray application farm walks and BMO field days).
- A number of additional methods have been used to communicate with sweet corn growers in Australia, including Conferences, Symposia, Workshops, Fieldays, Personal Interviews, TV, Radio, Newspapers and 'local' Newsletters.

Biological and Narrow Spectrum Insecticides - This research was used to support the successful application by Dow AgroSciences and Aventis Crop Sciences Pty Ltd to the National Registration Authority (NRA) for the registration of Success® and Gemstar® respectively in sweet corn in Australia.

- The registration of NPV (Gemstar®) and Spinosad (Success®) for use in sweet corn in Australia has occurred as a result of the R&D activities of project team members in all sweet corn growing regions of Eastern Australia. Gemstar® is a biological insecticide, specific to Helicoverpa, and having no adverse effect on beneficials, other pests, humans or the environment. Success® is a narrow spectrum insecticide producing only minor disruption of parasites and predators.

- A permit for the use of *Bacillus thuringiensis*, has been approved using data generated by project work programs.
- Selective heliothis pathogens (*B.t.* and NPV) and other narrow spectrum insecticides (Spinosad), will continue to play a critical role in pest management programs that protect and utilise parasitoids and predators. The action of these natural enemies supplements the mortality by narrow spectrum and biological insecticides, and often effectively control heliothis without any other insecticide intervention.
- Two biological insecticides, Gemstar® (*Nuclear Polyhedrosis Virus*-NPV) and Delfin® (*Bacillus thuringiensis*-Bt) were tested against *Heliothis armigera* in sweet corn as a pre silking spray in East Gippsland, Victoria. Biological pesticides are pest specific, soft on beneficial insects and fit into an IPM program. As pre-silking sprays these will help protect beneficials in a crop and yet provide some control of *H armigera*. Three consecutive field trials showed that Gemstar® is effective on *H. armigera* as a pre-silking spray reducing damage at harvest. Growers have also reported a positive response to Gemstar as a pre-silking spray.
- A field trial was conducted in East Gippsland, Victoria, during the 2000/01 season to evaluate three new narrow spectrum insecticides, Proclaim®, Secure® and Avatar® for control of *H armigera* in sweet corn. Studies conducted in East Gippsland to evaluate softer pesticides introduced for *Helicoverpa* control, produced sufficient evidence that Avatar® and Proclaim® were effective in control of corn earworm in sweet corn with similar control achieved to Success®. These pesticides are new chemical groups and would be effective alternatives and rotational chemicals for Success®. This would give the industry three options instead of the one currently available.
- Trials in SE Qld. indicated that DiPel Forté®(Bta) and XenTari®(Btk), can give control of *H. armigera* in sweet corn at the 1kg rate, with timing a critical issue if Heliothis are to be prevented from damaging the cobs.
- The use of biologically based insecticides such as Bt, are ideal for incorporation into an integrated pest management system. These products are effective at controlling Heliothis, when applied at the appropriate time, preserving beneficial insects and are safe to the environment and the end user. Bt sprays can therefore be valuable additions to those products already registered for use against Heliothis in sweet corn.

Naturally occurring beneficials - a large range of naturally occurring beneficials have been identified as being important in managing Heliothis in sweet corn. These are now more effective in commercial fields because of the reduced use of broad spectrum insecticides, and increased use of NPV, and Spinosad.

- The processing sweet corn industry in southern Queensland does not use broad spectrum insecticides during mid-summer, because of the combination of large populations of naturally occurring beneficials (mainly *Trichogramma spp.*), improved scouting techniques and the availability of NPV and Spinosad. *Trichogramma preteosum* is most abundant in summer (January-April) in SE Queensland.
- Field eggs and laboratory produced *Helicoverpa* eggs were used to investigate parasitism levels of *Trichogramma* species in sweet corn in East Gippsland in the 1998/99 season. Survival and over-wintering ability of *Trichogramma* species were also tested by releasing laboratory reared *T.pretiosum* in the same season but monitoring was carried out in the following two seasons as well. Results of these studies show that over-wintering ability of released *T.pretiosum* is poor under southern winter conditions.
- *T.pretiosum* is a potential additional control agent for helicoverpa pests in sweet corn. Also the monitoring results of these seasons show that another parasite wasp species, *Telenomus* occurs naturally under field conditions and overwinters effectively. Their rate of parasitism in lower than *Trichogramma* species with only one wasp per egg produced.

Pesticide application - (Milestone 4.) Targeting of pesticides (both synthetic and biological) to the cob and silk area has made significant contributions to reducing pest damage. Unless insecticides are targeted at the silks there will always be a significant proportion either not reaching the target or producing a large variance in the deposit levels.

- A four-fold difference in the average deposit on silks between a conventional boom spray and one modified with droppers has been demonstrated. A number of growers in all districts are modifying boom sprayers to take advantage of this improvement. Work with aircraft in all districts has shown that optimisation of aircraft application can be achieved through modification of spray patterns (eg reduced swath width), increased water volume, and the use of aids such as GPS.
- Boom sprays modified with droppers can deposit 4 times more insecticide to sweet corn silks than non-modified booms. Additionally, Gemstar® applications which are timed to coincide with a peak period of *H. armigera* larval activity during silking decrease the level of cob damage.
- In 2000, five evaluations were conducted using ground spray rigs currently used in East Gippsland. A fluorescent tracer was used to detect deposited spray volumes on silks and the volume of spray per unit area was based on the volumes used by growers as current industry practice. After spraying, silks were sampled and laboratory analyses were carried out to measure the deposit volumes of the tracer on the target area. Results clearly show that machines with droppers have a better coverage of silks than over-the-top boom sprays.

Secondary pests - until recently, pest management in sweet corn has focussed on Heliothis control. However as 'softer', host specific management options are being employed in order to cope with the problem of insecticide resistance, other pests have become more evident, viz. sucking insects (leaf hoppers, green vegetable bugs, thrips and aphids), Yellow Peach Moth and Sorghum Head Caterpillar have been recorded in commercial fields and in trials, where no broad spectrum insecticides have been used. These pests have traditionally been controlled by the use of broad spectrum insecticides used in Heliothis control.

- While integrated pest management (IPM) of the caterpillar pest, heliothis (*Helicoverpa armigera*) is a reality in sweet corn crops in Australia, other pests are becoming more prevalent. The reduction in the use of broad spectrum pesticides for heliothis management has lead to this increase in the number of other pests.
- The range of other pests that have been found in sweet corn crops include caterpillars such as armyworms, Noctuidae; sorghum head caterpillar (*Cryptoblabes adoceta*)and yellow peach moth (*Conogethes punctiferalis*), all of which damage the cobs. Pests such as thrips (*Frankliniella williamsi*) aphids, most commonly (*Rhopalosiphum maidis*) and dried fruit beetles (*Carcophilus* sp.) are pests as contaminants in produce bound for export markets. Plant hoppers (*Cicadulina bimaculata*), mites (*Tetranychus urticae*)and green vegetable bug (*Nezara viridula*) are causing physical damage to the crop, contributing to the loss in marketable yield.
- Management of these pests potentially threatens the IPM system that keeps heliothis populations below damaging levels.
- Trials quantified the level of pests in the crop, their location on the plant, whether damage to the crop renders the cobs unmarketable and some potential management options for summer crops in the Lockyer Valley Queensland.

Cultivar assessment - (Milestone 7.) There is anecdotal evidence of differences among Australian cultivars in their susceptibility to Heliothis attack and the incidence of damage. The main differences observed between cultivars appear to be mechanical.

- There is a very strong correlation between husk tightness and the degree of damage to the cob, with a tighter husk reducing the amount of damage when larvae did get to the cob. This is presumably a function of slowing down the progress of the larvae through the silk channel and into the cob. With the currently available commercial temperate cultivars however, a tighter husk has not resulted in a significant reduction in the number of damaged cobs, as is the case with the tighter husk of the H5 tropical cultivar.

- Thirteen sweet corn cultivars were planted in East Gippsland in December 1998 and this planting time was selected to coincide silking with peak insect activity, which generally occurs from the middle of February onwards. Mature cobs sampled from middle rows in the plots were evaluated for husk tightness, length of the husk channel and other husk parameters.
- Though there were demonstrated differences between cultivar characters, in this study, it was not possible to establish a clear relationship between cultivars and susceptibility to attack from heliothis. Results did indicate a relationship between the tightness of the husk, the penetration of the larvae into the cob and the amount of damage caused by the larvae.

Near infrared technology (NIR) - (Milestone 8.) Discrimination between physical defects in cobs (poor grain tip fill, insect damage and presence of the heliothis larvae) and undamaged cobs can be achieved non-invasively by near infra-red spectroscopy.

- The NIR Systems 6500 scanning spectrometer and the Zeiss MMSI miniature spectrometer (coupled with a high intensity quartz halogen lamp -100 watt) can achieve this discrimination. However, in a practical packing shed operation, the relatively rapid and inexpensive Zeiss MMSI spectrometer offers the most promise.

Scouting (Monitoring) techniques - (Milestone 5.) Regular scouting, using the protocol developed by project team members in conjunction with industry Consultants and Field Officers, is able to determine when and where Heliothis infestations (and other pests and beneficials) occur, and the best time to make spray treatments, and if they are necessary.

- Routine pest monitoring is a tool that provides this information for farm managers that will enable them to make improved pest management decisions.
- Insect scouting (monitoring) is a critical component in all Integrated Pest Management (IPM) systems. IPM uses field specific information and improved decision making to protect crop yield and quality while minimising the risks associated with pesticide use. If knowledge about insect activity and density is not known then informative and appropriate IPM decisions can't be implemented. Researchers worked with consultants and growers to develop a standardized insect scouting (monitoring) protocol.
- The scouting (monitoring) protocol describes the step by step process needed to collect field data in sweet corn. Additional information, such as biological, agronomic and environmental factors, are also included in the protocol.
- The development of a standardized insect scouting protocol has enabled growers to identify problems before they become significant, thereby reducing the level of insect damage occurring. The use of the insect scouting protocol has become standard industry practice in Queensland.
- Moth monitoring and scouting crops for eggs and larvae has been used to identify appropriate methods for evaluating pest pressure in southern Victoria. This is used to identify times of peak pressure and better target the application of pesticides for improved control of corn earworm.
- Scentry® pheromone traps were set up in East Gippsland area from October to May of the following year during 1995-2001. Data has been collected since 1992 and these traps have proven more effective than pot traps in assessing moth numbers. Peak pest pressure occurs around mid February and moth counts correlate well with crop damage and the incidence of pest numbers within the crop. The moth numbers were counted twice a week and when higher moth activity was detected, crops were scouted for eggs and larvae. At harvest 80% of crops (1998/99) were assessed for larval infestation and cob damage. Moth counts correlate well with crop damage and the incidence of pest numbers within the crop.
- Feedback from workshop participants in NSW was that the workshops helped clarify the issues and share information between participants, for some it taught them what to look for in the paddock and encouraged more regular monitoring of crops. However the

original intention of all the participants filling in the crop monitoring notebooks and sending in the carbon copy results for the season was not achieved. A small number of growers or processing field officers returned monitoring data. On follow up many did not record their results or necessarily follow the protocol each check. In processing sweet corn only 2-3 sprays are economical and tend to be timed to the crop growth rather than to egg levels in the paddock. Thresholds perhaps have limited value if the total number of sprays to be applied is limited and that in general the most vulnerable stage is during silking. So perhaps prior to tasselling quick checks are made and at tasselling a full monitor be made and a decision about whether a pre-silk spray is needed and keep the remaining 2 sprays for 25% and 75% silking if monitoring indicates eggs are present.

- Crop monitoring is an integral part of an IPM system and the training of growers, processor field officers and local agronomists was important. The sharing of information benefited all participants and raised questions for further research. A systematic and routine monitoring of all plantings was not achieved and the benefit of keeping detailed records was not considered by the participants to be worth the time given other pressures in the height of the sweet corn season. Employment of a full-time professional crop monitor/s to cover as many of the crops in the one region is the best option.

Evaluating Best Management Options (BMO) - (Milestones 2.& 6.) BMO demonstration plantings have been conducted in all the major sweet corn growing regions.

- These BMO's have been practical strategies including the use of scouting procedures, the strategic application of insecticides (particularly biological insecticides), improved application equipment and inundatively released *Trichogramma* wasps.
- In most demonstrations, the BMO planting has provided improved insect pest management when compared with broad spectrum insecticide treatments. Well attended farm walks have been conducted at each of the locations where BMO demonstrations have been planted.
- The changes in grower practice can be attributed to a combination of factors. The Project has generated information about new insecticides and how they can be used, along with improved application techniques. Through the BMO concept, any relevant information could be formulated into a strategy, tested and incorporated very rapidly into commercial practice because of the close relationship between the consultants/researchers and sweet corn growers in the region. In addition, because the growers (as stakeholders) have been exposed to the extensive information the Project has produced and have been involved in the trials, this had enabled new products or techniques to be rapidly implemented in commercial operations.

Insecticide resistance management strategies – Regional strategies have been constructed in consultation with growers, chemical company representatives and other stakeholders.

- *H. armigera* larvae were collected from several sweet corn crops in East Gippsland in 1996/97 season and tested for resistance. Results indicated that moths have developed 96% and 50 % resistance levels against synthetic pyrethroids (tested pesticide was fenvalerate) and carbamate (tested chemical was methomyl). They also have developed 35 % resistance against organochlorines and 6% resistance against profenofos). Results revealed that adult moths and large larvae are resistant to synthetic pyrethroids but larvae less that 5 mm in length are still susceptible to these pesticides. Subsequent monitoring has indicated that this resistance has further increased by 2000 with a doubling of the resistance factor for synthetic pyrethroids and carbamate resistance also becoming more severe. The resistance factor has increased in the range of 10 – 39 from 1997 to 2000 for samples from Dalmore and Lindenow and in addition there is a percentage of individuals identified as homozygotes for carbamate resistance which provides stronger resistance to this pesticide group

➢ Recommendations to industry, peers, and HAL

This project provides an excellent example of how much a well-coordinated National project can impact on an industry at all levels – from the farm through to consultants, retailers and multi-national agribusiness companies. The participatory approach that was applied to project management, research and extension created a team atmosphere which has facilitated truly synergistic work. The method by which team members participated in work planning, gave them the ownership to conduct excellent, self-directed research.

The funding invested in hosting annual National Industry Workshops and developing and widely distributing the "Sweet Corn Ear" newsletter, technical and Milestone Reports and Workshop Proceedings was worthwhile for the major contribution it made to information transfer, feedback and discussion as well as developing an industry identity. It was this demonstration of cohesion and a visibly proactive industry seeking responsible solutions to its pest management problems that was the main contributing factor for two chemical companies (Dow and Aventis) to register their new selective chemicals for sweet corn in Australia.

The involvement of stakeholders in discussing and reviewing results and developing research plans contributed significantly to building the relationship with chemical company representatives which lead to the project not only trialing the new insecticides, but contributing required data for registration.

The above approach is also largely responsible for the speed and desire growers have shown to adopting and adapting research on farm. The project has contributed to, and has seen the industry move a long way in pest management – from calendar spraying synthetic broad-spectrum insecticides (often onto resistant pests and with inefficient application technology) to managing IPM systems which integrate monitoring, selective pesticides and beneficial insects with improved application equipment targeting appropriate plant parts at the correct time.

➢ Contribution to new technology

Registration of Two Narrow Spectrum Insecticides.

- The registration of NPV (Gemstar®) and Spinosad (Success®) for use in sweet corn in Australia has occurred as a result of the R&D activities of project team members in all sweet corn growing regions of Eastern Australia. Gemstar® is a biological insecticide, specific to Helicoverpa, and having no adverse effect on beneficials, other pests, humans or the environment. Success® is a narrow spectrum insecticide producing only minor disruption of parasites and predators.
- A permit for the use of *Bacillus thuringiensis*, has been approved using data generated by project work programs.

Modification of Pesticide Application Equipment.

- A four-fold difference in the average deposit on silks between a conventional boom spray and one modified with droppers has been demonstrated. A number of growers in all districts are modifying boom sprayers to take advantage of this improvement. Work with aircraft in all districts has shown that optimisation of aircraft application can be achieved through modification of spray patterns (eg reduced swath width), increased water volume, and the use of aids such as GPS.

Near infrared technology (NIR).

- Discrimination between physical defects in cobs (poor grain tip fill, insect damage and presence of the heliothis larvae) and undamaged cobs can be achieved non-invasively by near infra-red spectroscopy.

- The NIR Systems 6500 scanning spectrometer and the Zeiss MMSI miniature spectrometer (coupled with a high intensity quartz halogen lamp -100 watt) can achieve this discrimination. However, in a practical packing shed operation, the relatively rapid and inexpensive Zeiss MMSI spectrometer offers the most promise.

➢ Suggested future work

Further progress for the industry will rely on developing systems to manage diseases and the secondary pests which are now occurring under IPM, the introduction of pest tolerant plant varieties with high market acceptability and improved in-line damage detection for whole cobs in packing houses, and make significant contributions towards the management of insecticide resistance.

This project has identified areas of future work which address some of the **KEY ISSUES for R&D** that were developed at a HAL organized Sweet Corn Industry Priorities Workshop in May 2001, (in conjunction with the 4th and Final Sweet Corn Project Industry Workshop at Lakes Entrance, Victoria).

The Key Issues identified by participants from the sweet corn industry are, in order of priority :

No. 1. – Pest Management - IPM
No. 2. - Insecticide Resistance Management Strategies
No. 3. - Development of Export Protocols to Japan
No. 4. - New Chemical Registrations
No. 5. – Find out what the consumers wants – can we deliver?

Areas of further work to address Priorities 1, 2 and 4 include:-

- Trialing of other new chemical or biological options for Heliothis and other secondary or minor pests
- Improving the use of NPVs, including defining conditions it is likely to work well and further evaluation of its' use with centre pivots or overhead sprinkler irrigation.
- Refine 'Best Management Options' to include management of other pests
- Define the potential risks and control methods for disease management in sweet corn
- Investigating what conditions or strategies may enhance beneficial insect levels in the Riverina.

Introduction

➢ Historical background to the project

In 1995, the Australian Sweet Corn industry produced 73 000 t for an on-farm value of $30.5M (ABS, 1995). Queensland produced 19% of the Australian tonnage and 36% of the $ value (14 000 t and $11M annually); NSW produced 53% of the Australian tonnage from 2200 ha, mostly for the processed market. Victoria produced 10% of the Australian tonnage for fresh domestic and export markets.

Attempts were made by growers in Queensland, NSW and Victoria to supply a fresh product to the export market in South East Asia with both bicolour and yellow super sweet varieties. These growers had significant difficulties due to the inability to produce cobs free from heliothis larvae and larval damage. This was due to the high levels of insecticide resistance which occurs in *Helicoverpa armigera* (heliothis). Product free from insects and insect damage is critical from a quarantine point of view and is essential in relation to meeting the export and domestic market specification. Export opportunities were restricted due to the inability to produce cobs free from heliothis larva and larval damage. In addition, growers have a restricted range of cultivars available, particularly of bicolour sweet corn, due to phytosanitary restrictions relating to boil smut freedom. These limitations impact on quality, production, and productivity and has restricted the development of export opportunities.

These export and domestic (fresh and processing) markets were difficult to access, as insecticide resistance levels increased and losses and costs increased as a consequence. Pyrethroid insecticide resistance was 57% and 41% respectively in two samples submitted from the Lockyer Valley (Queensland) in Dec/Jan 1995/96, and carbamate resistance was 15% in Jan 1996. Unmanageable levels of resistance were recorded in North Queensland in the winter of 1996. These levels represent the magnitude of the problem in all production districts in Australia, and were continuing to rise towards unmanageable levels. Growers in some districts were assessing their options for production in the 1997 and subsequent seasons because of the difficulties they had encountered in the 1996 season.

Most pesticides were applied by air due to the size of fields and the need to cover these areas regularly during the silking growth stage. A few growers were using ground rigs and in the majority of cases these growers were not experiencing the same level of damage and loss as those using aerial application.
The range of synthetic insecticides registered on sweet corn was small, and increasing resistance levels were making them less effective. In the case of the registered carbamate insecticides, resistance levels were assessed at or near 100% in North Queensland in the winter of 1996. Complete crop failure occurred in these situations.

➢ Why was the project undertaken

The damage caused by heliothis in sweet corn cobs is not readily detectable in the field, nor in the pack-house. Therefore a large percentage of infected cobs can make their way onto the market, with consequential negative effects on demand and price. For the export market, the effect is that consignments are rejected at the point of AQIS inspection, or worse are rejected at the port of entry.

There are a range of issues which affect quality and export opportunities such as productivity, the development of best management practices, and improved harvesting, post harvest handling and storage techniques. In sweet corn production, apart from cultivar availability, the control of heliothis was the most limiting factor in meeting the demands of a developing export market, and to a consistent supply for the domestic market.

➢ Significance to the industry

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➢ Literature review

Research in Progress (from ARRIP search Jan 1997):-
1. Sweet corn breeding. Mr IF Martin, QDPI, Kairi, Qld
2. Improved profitability in bean, beetroot and sweet corn production. Mr CWL Henderson, QDPI, Gatton Research Station.
3. Developing an integrated pest management package for heliothis in vegetables. Mr BC Scholz, QDPI, Toowoomba.
4. Development of the fresh sweet corn industry. Mr RM Wright, QDPI, Bowen.
5. Evaluation of temperate vegetable cultivars for fresh export. Mr R Hart, DPIF, Devonport, Tas.

Heliothis is considered to be one of Australia's most economically damaging pests in a range of crops. McGahan et. al.(1991) estimated the losses to horticultural crops in Queensland as $188M per year. This includes control costs and crop losses. Heliothis is the most damaging pest with which the sweet corn industry has to contend (Deuter, 1995). Insecticide resistance in *Helicoverpa armigera* is a major factor contributing to management difficulties with this pest in all crops including sweet corn. Resistance to methomyl was detected in 1984 in tobacco in north Qld, and the first significant spray failures in sweet corn, due to high resistance levels were detected on the Darling Downs in 1992. Since then resistance levels ranging from 10 to 100% have been detected in all major sweet corn production districts in Australia (D. Murray, pers. comm.) and (R. Gunning, pers. comm.).
Synthetic insecticide alternatives such as trichogramma (Scholz, 1994) and (Scholz - ARRIP), *Bacillus thuringiensis* and nuclear polyhedrosis virus (NPV) (Monsour, 1995 and 1996), have potential in managing heliothis as part of an integrated approach.
Breeding programs, primarily aimed at developing super sweet cultivars resistant to maize dwarf mosaic virus (MDMV), are also assessing material for susceptibility to heliothis attack (Martin - ARRIP) and (Wright - ARRIP).

Very few new synthetic insecticides or alternatives are likely to be available in the short or medium term, so the presently useful chemicals need to be nurtured through the next 5 years, whilst the alternatives are developed as part of a crop management system. Bt and parasitoids (naturally occurring and inundative release) and NPV appear to be the 'best bet' alternatives for the near future. The present evidence is that they are unlikely to replace synthetic insecticides. The combination of a number of alternatives with targeted synthetics is the most likely scenario, with absolute dependence on synthetics a thing of the past (Deuter, 1995).

References cited:-

Deuter, P.L. (1995). Heliothis Control - Queensland Experiences. In - "Sweet Corn - Integrated Pest Management". Proceedings of an industry workshop, Cowra, NSW, Oct., 1996. C. Beckingham. (ed.) NSW Agriculture, Bathurst.

McGahan, P., Lloyd, R.J. and Rynne, K.P. (1991). The cost of Heliothis in Queensland crops. In - 'A review of Heliothis Research in Australia', Twine, P.H. and Zalucki, M.P. (eds.). Queensland Department of Primary Industries, Brisbane.

Monsour, C.J. (1995). Report on a Preliminary Assessment of Bacillus thuringiensis and a Nuclear Polyhedrosis Virus for the Control of Helicoverpa armigera in Sweet Corn. Co-operative Research Centre For Tropical Pest Management, Univ. of Queensland, St. Lucia.

Monsour, C.J. (1996). Report on the efficacy of Bacillus thuringiensis and a Nuclear Polyhedrosis Virus in Pre-Tasselling Sweet Corn. Co-operative Research Centre For Tropical Pest Management, Univ. of Queensland, St. Lucia.

Scholz, B. (1994). An evaluation of egg parasitoids for the management of heliothis. A final report prepared for the Horticultural Research and Development Corporation and the Queensland Fruit and Vegetable Growers. (HRDC Report Ref No. V106).

➢ Aims of the project

Aim :- To reduce the risks of crop loss from insect damage, mainly *Helicoverpa armigera* (heliothis), and improve production and quality in sweet corn aimed at domestic (fresh and processing) and export markets.

Objectives :-

- Identify and apply "best management options" (BMO's) to the production of sweet corn
- Identify and promote integrated pest management systems for sweet corn
- Reduce the production risks, particularly for export oriented production systems
- Protect and increase the small range of insecticides used for insect pest management
- Test and promote the use of alternatives to broad spectrum pesticides
- Test and promote improved application techniques
- Identify varieties for improved product and production characteristics for export and domestic markets
- Identify technology which can separate damaged and undamaged cobs during the grading and packaging process

➢ Impact of results

The sweet corn industry has **benefited** by changing from a high dependency on broad spectrum insecticides, to a very widespread use of biological methods. Pest management is becoming more complex, a key component being the conservation of naturally occurring parasitoids and predators. Parasitoids, predators, pathogens and some insecticides are being used to manage heliothis in sweet corn. This has occurred as a result of a more thorough understanding of pest-beneficial interactions, the use of biological and narrow spectrum insecticides, spray decisions based on scouting information, and pesticide application using improved equipment and techniques, all leading to an integrated package of practices which will be more sustainable and long lasting than those based on broad spectrum insecticides alone.

- The major benefit of the project comes from more than just the technically and scientifically excellent work – it is the fact that industry has changed its practices as a result of the project.
- The Australian sweet corn industry has increased from 70,000t (1997) to 120,000t (2001).
- Crop losses have been reduced from an occasional 100% loss (1992 - 1994), to 20% currently.
- Research conducted during this project were used to support the successful application by Dow AgroSciences and Aventis Crop Sciences Pty Ltd to the National Registration Authority (NRA) for the registration of two narrow spectrum, IPM friendly insecticides (Success® and Gemstar®), in sweet corn in Australia.
- The export industry was re-established in 1998, after cessation due to uncontrollable insect damage and contamination.
- Farmers, farm workers and the environment are no longer exposed to the negative effects of organo-phosphate and organo-chlorine insecticides.
- A number of growers in all districts are modifying boom sprayers to take advantage of the 4 fold improvement droppers can make on spray deposition. Work with aircraft in all districts has shown that optimisation of aircraft application can be achieved through modification of spray patterns, increased water volume and use of aids such as GPS.
- There has been an increase in the stability of established populations of *T. pretiosum* in South Queensland due to the major reduction in the amount of broad-spectrum insecticides being used in the crop.
- All sweet corn grown in the Dry Tropics is monitored professionally, and the area monitored in South Queensland has doubled. In NSW there has been a 20 percent increase in the area of sweet corn regularly monitored, and in Victoria, 85 percent of the industry now checks crops for large and small larvae and eggs. All states report the use of improved monitoring protocols and increased grower understanding of monitoring procedures and results.
- Discrimination between physical defects in cobs (poor grain tip fill, insect damage and presence of the heliothis larvae) and undamaged cobs can be achieved non-invasively by near infra-red spectroscopy. The NIR Systems 6500 scanning spectrometer and the Zeiss MMSI miniature spectrometer (coupled with a high intensity quartz halogen lamp -100 watt) can achieve this discrimination. However, in a practical packing shed operation, the relatively rapid and inexpensive Zeiss MMSI spectrometer offers the most promise.

Technology Transfer

Peter Deuter, DPI Gatton Research Station and Larissa Bilston, R,D&E Services.

Further details of **Technology Transfer** activities in this project have been reported in :-

- Milestone No. 3. – "All major stakeholders in the sweet corn industry have been identified, and a mechanism for information exchange has been developed."
- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 29-36.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 128, 160-163.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 113-115.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 135-136.

The Research, Development and Extension work program was conducted through:

1. Information Interchange.
2. Evaluating Best Management Options
3. Focussed Research & Development

➢ Information Interchange

• A **database of stakeholders** has been developed for the distribution of a newsletter ("The Sweet Corn Ear"), the Yearly Sweet Corn Industry Workshop Proceedings, Project Milestones and other Reports published by the Project Team.
The Microsoft Access database contains the names, postal and email addresses, phone and fax numbers of over 450 sweet corn stakeholders in eastern Australia. The database is regularly up-dated and has grown from over 250 contacts in the first year of the project. It includes growers, researchers, chemical company representatives and distributors, seed company representatives and processors.

Yearly **Industry Workshops** involving project team members and stakeholders have been a venue for reporting outcomes, sharing ideas and planning future work together. Workshop No 1, May 1998, (Gatton, Qld); Workshop No 2, May 1999, (Bathurst, NSW); Workshop No 3, June 2000, (Bowen , Qld) and Workshop No 4, April/May 2001, (East Gippsland, Vic).

All stakeholders were encouraged, and opportunities provided to participate in this information interchange. Proceedings of all four Sweet Corn Industry workshops were published and have been distributed to all stakeholders on the database.

The mechanism for the exchange of information among stakeholders between annual workshops involved mailing **"The Sweet Corn Ear" newsletter** to all stakeholders on the database. Sixteen (16) Sweet Corn Ear Newsletters were published and distributed :-

April 1998; July 1998; December 1998; January 1999; March/April 1999; September 1999; March/April 2000; May 2000; August 2000; Sept/Oct 2000; December 2000; Feb 2001; April 2001; May 2001; June 2001 and March 2002.

• A Web site has been established and is updated and maintained by project tem members in Victoria.
Web Address :- www.nre.vic.gov.au/agvic/ihd/projects/sc.htm

• The **print media** have also been used as a communication mechanism for the project. All Newsletters have resulted in articles in rural magazines and newspapers. Good Fruit and Vegetables have published several articles on sweet corn pest management and the results and outcomes of the project work program.

A number of methods were used to communicate with sweet corn growers in NSW, they included:

- Sessions at the annual NSW Farmers Vegetable Conference (August 1997, 1998,1999,2000).
- Presentations at the day-long Simplot Sweet Corn Symposium (September 1997).
- Crop monitoring workshops were held in Narromine (December 1997, August 1998, December 1998)
- Scouting and pest identification field days was held in the Sydney basin (January 1999 and 2000).
- A general sweet corn field day was held in Sydney (February 2000)
- Personal interviews with a number of growers gave a snap-shot of current practices (1997).
- Many growers were visited by team members throughout the project which included discussions about their pest management concerns and project outcomes.
- A TV story on sweet corn IPM was aired in May 2000 on regional stations in NSW.
- Biological control in sweet corn interview (ABC Radio) May 2000
- an article with some of the sweet corn work was published in the *Farmers' Newsletter*: S McDougall "IPM of Heliothis in Vegetables" IREC 184 June 2000 pp 28-33.

To clearly define the starting point of this project, baseline data was collected on agronomic practices and pest management strategies used in the sweet corn industry in Eastern Australia. This baseline data of **pest management practices in sweet corn** has been used in project evaluation, against which gains and improvements have been judged. A Report **"Evaluation: *Industry Changes from 1998 to 2001*"** has been published and distributed through the stakeholder database. **(See Project Activity 1. – Project Evaluation)**.

➢ Best Management Options (BMO's)

BMO comparisons have been the basis of on-farm trials in each of the major sweet corn production districts in Eastern Australia, comparing the pest management outcomes of BMO's with grower practice. These sites have been the focus of farm walks and fieldays in each of the regions. These **farm walks** have been designed to achieve feedback from growers and consultants on the practicalities and effectiveness of components of IPM incorporated in each of these BMO comparisons. **(See Project Activity 10. – Evaluation of BMO's)**.

➢ Focussed Research and Development

The following issues were reported to stakeholders at fieldays, farm walks, yearly Industry Workshops, newsletters, newspaper articles, and Milestone and other Reports.

1] Field trials evaluating promising **narrow spectrum and biological insecticides** such as *Bacillus thuringiensis* (Bt), heliothis virus formulations (NPV) and Spinosad; and inundative releases of the parasitoid Trichogramma for management of heliothis populations. **(See Project Activity 3. – Biological Insecticides)**.

2] Field evaluation of **naturally occurring *Trichogramma spp.*** and their population dynamics in commercial sweet corn fields. **(See Project Activity 4. – Naturally Occurring Beneficials)**.

3] Ground rig sprayers with nozzles targeting cobs, and other combinations of **modified application equipment** have been compared with the industry practice of aerial application. Pesticide targeting assessment has aimed at understanding how the arrangements of upper leaves affect the amount of pesticide reaching the cobs, especially the silks.
(See Project Activity 5. – Pesticide Application).

4] Heliothis populations have been **monitored weekly** (twice weekly during periods of pest build up) to improve the timing and application of biological and synthetic pesticides and develop and improve scouting protocols.
(See Project Activities 4 – Naturally Occurring Beneficials and 9. – Crop and Pest Monitoring).

5] **Sweet corn cultivars have been evaluated** at Bowen in Queensland and East Gippsland in Victoria. The major varieties have been screened for their tolerance to heliothis in the absence of insecticides. Cultivars were evaluated for performance, yield, quality, uniformity and resistance or tolerance to pests and diseases and in particular to heliothis attack.
(See Project Activity 7. – Cultivar Assessment).

6] Research was carried out using **non-destructive assessment of cob damage** with the use of near infra-red (NIR) spectroscopy, as a potential tool in separating damaged and undamaged cobs in a pack-house.
(See Project Activity 8. – Near Infra-red Technology).

7] The development of **improved pest scouting (monitoring) techniques** was a part of the testing of BMO's as well as focussed research and development associated with improved timing and targeting of pesticides and the testing of alternative biopesticides.
(See Project Activity 9. – Crop and Pest Monitoring).

Recommendations - Scientific and Industry

➢ Make recommendations on the need for further research

Further progress for the industry will rely on developing systems to manage diseases and the secondary pests which are now occurring under IPM, the introduction of pest tolerant plant varieties with high market acceptability and improved in-line damage detection for whole cobs in packing houses, and make significant contributions towards the management of insecticide resistance.

This project has identified areas of future work which address some of the **KEY ISSUES for R&D** that were developed at a HAL organized Sweet Corn Industry Priorities Workshop in May 2001, (in conjunction with the 4th and Final Sweet Corn Project Industry Workshop at Lakes Entrance, Victoria).

The Key Issues identified by participants from the sweet corn industry are, in order of priority :

No. 1. – Pest Management - IPM
No. 2. - Insecticide Resistance Management Strategies
No. 3. - Development of Export Protocols to Japan
No. 4. - New Chemical Registrations
No. 5. – Find out what the consumers wants – can we deliver?

Areas of further work to address Priorities 1, 2 and 4 include:-

- ➢ Trialing of other new chemical or biological options for Heliothis and other secondary or minor pests
- ➢ Improving the use of NPVs, including defining conditions it is likely to work well and further evaluation of its' use with centre pivots or overhead sprinkler irrigation.
- ➢ Refine 'Best Management Options' to include management of other pests
- ➢ Define the potential risks and control methods for disease management in sweet corn
- ➢ Investigating what conditions or strategies may enhance beneficial insect levels in the Riverina.

➢ Recommendations on the enhanced adoption of outcomes

There has been significant implementation of the project outcomes by a majority of the industry (See Project Activity 1. – Project Evaluation) :-

Project Evaluation Conclusions

- The project far exceeded expectations set down by the initial Project Objectives, especially in the areas of application technology, risk reduction by IPM and more narrow spectrum insecticide choices available to sweet corn producers throughout Australia. The sometimes controversial trial approach taken to develop Best Management Options (BMO's) paid off substantially, and preliminary work to assess technology with potential to improve sweet corn grading and packing operations was also a success.
- A major benefit of the project comes from more than just the technically and scientifically excellent work – it is the fact that industry has changed its practices as a result of the project. The following explanation for industry change written by the North Queensland team also holds true for other growing regions:

  "The changes in grower practice can be attributed to a combination of factors. The Project has generated a lot of information about new insecticides and how they can be used, along with improved application techniques.

Through the BMO concept, any relevant information could be formulated into a strategy, tested and incorporated very rapidly into commercial practice because of the close relationship between the consultants/researchers and sweet corn growers in the region. In addition, because the growers (as stakeholders) have been exposed to the extensive information the Project has produced and have been involved in the trials conducted in NQ, this had enabled new products or techniques to be rapidly implemented in commercial operations." [Industry Changes Report]

- The funding invested in hosting annual National Workshops and developing and widely distributing the "Sweet Corn Ear" newsletter, Technical and Milestone Reports was worthwhile for the major contribution it made to information transfer, feedback and discussion as well as developing an industry identity. It was this demonstration of cohesion and a visibly proactive industry seeking responsible solutions to its pest management problems that was the main contributing factor for two chemical companies (Dow and Aventis) to register their new narrow spectrum insecticides for sweet corn in Australia.
- The involvement of stakeholders in discussing and reviewing results and developing research plans helped to build the relationship with chemical company representatives which lead to the project not only trialing the new insecticides, but contributing required data for registration.
- This approach is also largely responsible for the speed and desire growers have shown in adopting and adapting research on farm. The project has seen the industry move a long way in pest management – from calendar spraying synthetic broad-spectrum insecticides (often onto resistant pests and with inefficient application technology) to managing IPM systems which integrate monitoring, narrow spectrum insecticides and beneficial insects with improved application equipment targeting appropriate plant parts at the right time.
- Further progress for the industry will rely on developing systems to manage diseases and the secondary pests which have started occurring under IPM, the introduction of pest tolerant plant varieties with high market acceptability and improved in-line damage detection for whole cobs in packing houses. This technology also has the promise to increase access to export markets.

Acknowledgments and Project Team

➢ Acknowledgments

The project team would like to thank the following for their assistance and participation in the project activities :-
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➢ Project Team

Four groups of research and extension scientists have contributed to the work program and the outcomes of this project in the major production regions of eastern Australia (North Qld, Sth Qld, Central West NSW and Gippsland Vic./Nthn Tasmania). A number of Project Team changes (*) have occurred over the five years of this project :-

North Queensland

- Mr. Ross Wright, Senior Horticulturist, QDPI, Bowen, Qld..
- Mr. John Brown, Principal Experimentalist, QDPI, Ayr, Qld..
- **Mr. Johnny Andersen, Extension Horticulturist, QDPI, Ayr, Qld.
- **Mr Kynan Gooding, Extension Horticulturist, QDPI, Ayr, Qld.
- Mr Chris Monsour, Bowen Crop Monitoring Services, Bowen, Qld.
- Mr John Guthrie, Principal Food Technologist, QDPI, Rockhampton, Qld.

South Queensland

- Mr Peter Deuter, Principal Extension Horticulturist, QDPI, Gatton Research Station, Gatton, Qld.
- Mr. John Duff, Entomologist, QDPI, Gatton Research Station, Gatton, Qld.
- Ms Bronwyn Walsh, Entomologist, QDPI, Gatton Research Station, Gatton, Qld..
- Mr. Brendan Nolan, Experimentalist, QDPI, Gatton Research Station, Gatton, Qld.
- **Mr. Brad Scholz, Senior Entomologist, QDPI, Toowoomba, Qld.
- **Mr Robert Battaglia, Horticulturist (Pesticide Application Technology), QDPI, Gatton Research Station, Gatton, Qld.
- **Mr Glenn Geitz, Experimentalist (Pesticide Application), QDPI, Gatton Research Station, Gatton, Qld.
- **Mr Peter Hughes, Senior Extension Officer, QDPI, Dalby, Qld.
- Mr Iain Kay, Senior Entomologist, QDPI, Bundaberg, Qld.
- **Mr Tom Franklin, Executive Engineer, QDPI, Redlands Research Station, Cleveland, Qld.
- Ms. Larissa Bilston, Research Scientist, RD&E Services, R&D Extension Service, Waterford, Qld.
- Dr. Peter Room, Chief Research Scientist, CSIRO, Long Pocket, Qld.
- **Jim Hanan, UQ Centre for Plant Architecture Informatics & CSIRO Entomology, Brisbane, Qld.

New South Wales

- Mr. Clarrie Beckingham, District Horticulturist, NSW Agric., Bathurst, NSW.
- Dr Sandra McDougall, Entomologist (Vegetables), Yanco Agricultural Institute, Yanco, NSW.
- Tony Napier, Extension Horticulturist, Yanco Agricultural Institute, Yanco, NSW.
- Adrian Nicholas, Entomologist (Horticulture), Yanco Agricultural Institute, NSW.
- **Leigh James, District Horticulturist, NSW Agric, Windsor, NSW.
- **Dr Jianhua Mo, Entomologist, Yanco Agricultural Institute, Yanco, NSW.

Victoria/Tasmania

- Dr Peter Ridland, Entomologist, IPM Vegetables, IHD, Agriculture Victoria, Knoxfield, Vic..
- Mr. Rob Dimsey, Horticulturist, Department of Natural Resources and Environment, Bairnsdale, Vic.
- **Dr Siva Subramaniam, Scientist, DNRE, Bairnsdale, Vic.
- **Neville Ferdinand, Scientist, DNRE, Bairnsdale, Vic.
- Mr Lionel Hill, Entomologist, DPIWE, Devonport, Tas.
- **Julia French, IPM Extension Officer, DPIWE, Devonport, Tas.

Project Activities

1. Project Evaluation

[Copies of this evaluation will be distributed to all stakeholders.]

Larissa Bilston
R&D Extension Service

Executive Summary

Background

In 1995, the Australian sweet corn industry produced 73,000t (ABS, 1995), on-farm value of $30.5M (ABS, 1995). This is estimated to have increased to 120,000t in 2001.
Prior to the project beginning, attempts had been made by growers in Queensland, NSW and Victoria to supply a fresh product to the export market in South East Asia with both bicolour and yellow super sweet varieties. Export opportunities were restricted due to the inability to produce cobs free from heliothis larvae and larval damage. In addition, growers had a restricted range of cultivars available, particularly of bicolour sweet corn.

These export and domestic (fresh and processing) markets were becoming more difficult to access as insecticide resistance levels increased and losses and costs increased as a consequence. Resistance levels were continuing to rise towards unmanageable levels. Growers in some districts were assessing their options for production in the 1997 and subsequent seasons because of the difficulties they had encountered in the 1996 season.

Most pesticides were applied by air due to the size of fields and the need to cover these areas regularly during the silking growth stage. The range of synthetic insecticides registered on sweet corn was small, and increasing resistance levels were making them less effective.

The damage caused by heliothis in sweet corn cobs is not readily detectable in the field, nor in the pack-house. Therefore a large percentage of infected cobs can make their way onto the market, with consequential negative effects on demand and price.

Evaluation Method

Monitoring activities were planned to collect the minimum amount of evidence required to demonstrate achievement of each of the 7 project objectives. Bennett's Hierarchy was used in the planning process to spell out what all the activities were within each objective, and how they were contributing to reaching the overall aim of the project. The evaluation team formulated key evaluation questions for each objective, then identified indicators which could be measured to help answer those questions. Whilst realising that indicators higher up in Bennett's hierarchy provide better evidence (Bennett, C.F., 1997 *Analysing impacts of extension programs,* USDA, Washington), the indicators chosen for the study had to be bounded by the resources available. In addition, the indicators were chosen from several levels of the hierarchy to strengthen the evaluation.

Did the project meet its objectives?

The project far exceeded expectations set down by the initial Project Objectives, especially in the areas of application technology, risk reduction through adoption of IPM and more narrow spectrum insecticide choices available to sweet corn producers throughout Australia. The sometimes controversial trial approach taken to develop BMOs paid off substantially and preliminary work to assess technology with potential to improve sweet corn grading and packing operations was also a success.

The major benefit of the project comes from more than just the technically and scientifically excellent work – it is the fact that industry has made significant changes to its practices as a result of the project.

The funding invested in hosting annual National Workshops and developing and widely distributing the "Sweet Corn Ear" newsletter, technical and Milestone Reports and Proceedings of Workshops was worthwhile for the major contribution it made to information transfer, feedback and discussion as well as developing an industry identity. It was this demonstration of cohesion and a visibly proactive industry seeking responsible solutions to its pest management problems that was the main contributing factor for two chemical companies (Dow and Aventis) to register their new narrow spectrum insecticides for sweet corn in Australia.

This approach is also largely responsible for the speed and desire growers have showed to adopt and adapt research on farm. The project has seen the industry move a long way in pest management – from calendar spraying synthetic broad-spectrum insecticides (often onto resistant pests and with inefficient application technology) to managing IPM systems which integrate monitoring, selective insecticides and beneficial insects with improved application equipment targeting appropriate plant parts at the right time.

Recommendations
Further progress for the industry will rely on developing systems to manage diseases and the secondary pests which have started occurring under IPM, the introduction of pest tolerant plant varieties with high market acceptability and improved in-line damage detection for whole cobs in packing houses. This technology also has the promise to increase access to export markets.

This project provides an outstanding example of how much a well-coordinated National project can impact on an industry at all levels – from the farm through to consultants, retailers and multi-national agribusiness companies. The participatory approach that was applied to project management, research and extension created a team atmosphere which facilitated truly synergistic work. The method by which team members participated in work planning and were provided with a supportive project management environment gave them the ownership to conduct excellent, self-directed research.

The participative theme was continued at a research level, with scientists actively collaborating with growers, chemical companies and consultants to plan and conduct trials. Results and their interpretation were openly discussed with all stakeholders at field days and National Workshops so that all participants in the conversation could learn from the experience of others. This kind of interaction helped increase implementation of practice changes on farms. The development of a stakeholder database and publication of newsletters, milestone reports and workshop proceedings were a key to keeping the whole industry informed of progress although in future more use of electronic publication could reduce some costs provided it does not exclude stakeholders from accessing information.

The team management and communication processes implemented by this project could illustrate how large national, multi-disciplinary projects can maximise their impact.

Acknowledgements

I would like to thank the many sweet corn growers, processors and crop and chemical consultants who participated in the project and its evaluation for their cooperation, time and ideas contributed throughout the evaluation process. Many thanks to the project team for their assistance in the data collection and interpretation of results. I am greatly indebted to Peter Deuter for his faith and support in the process, and for his practical, people-oriented approach to project management.

Table of Contents

1. Introduction

1.1 Project Overview

In 1995, the Australian Sweet Corn industry produced 73 000 t for an on-farm value of $30.5M (ABS, 1995). Queensland produces 19% of the Australian tonnage and 36% of the $ value (14 000 t and $11M annually). NSW produces 53% of the Australian tonnage from 2200 ha, mostly for the processed market. Victoria produces 10% of the Australian tonnage for fresh domestic and export markets. It is estimated that this has increased to 120,000 t in 2001.

Prior to the project beginning, attempts had been made by growers in Queensland, NSW and Victoria to supply a fresh product to the export market in South East Asia with both bicolour and yellow super sweet varieties. These growers had significant difficulties due to the inability to produce cobs free from heliothis larvae and larval damage. This was due to the high levels of insecticide resistance which occurs in *Helicoverpa armigera* (heliothis). Product free from insects and insect damage is critical from a quarantine point of view and is essential in relation to meeting the export and domestic market specification.

Export opportunities were restricted due to the inability to produce cobs free from heliothis larvae and larval damage. In addition, growers had a restricted range of cultivars available, particularly of bicolour sweet corn, due to phytosanitary restrictions relating to boil smut freedom. These limitations impact on quality, production, and productivity and had restricted the development of export opportunities.

These export and domestic (fresh and processing) markets were becoming more difficult to access as insecticide resistance levels increased and losses and costs increased as a consequence. Pyrethroid insecticide resistance was 57% and 41% respectively in two samples submitted from the Lockyer Valley (Queensland) in Dec/Jan 1995/96, and carbamate resistance was 15% in Jan 1996. Unmanageable levels of resistance were recorded in North Queensland in the winter of 1996. These levels represent the magnitude of the problem in all production districts in Australia, and were continuing to rise towards unmanageable levels. Growers in some districts were assessing their options for production in the 1997 and subsequent seasons because of the difficulties they had encountered in the 1996 season.

Most pesticides were applied by air due to the size of fields and the need to cover these areas regularly during the silking growth stage. A few growers were using ground rigs and in the majority of cases these growers were not experiencing the same level of damage and loss as those using aerial application. The range of synthetic insecticides registered on sweet corn was small, and increasing resistance levels were making them less effective. In the case of the registered carbamate insecticides, resistance levels had been assessed at or near 100% in North Queensland in the winter of 1996. Complete crop failure occurred in these situations.

The damage caused by heliothis in sweet corn cobs is not readily detectable in the field, nor in the pack-house. Therefore a large percentage of infected cobs can make their way onto the market, with consequential negative effects on demand and price. For the export market, the effect is that consignments are rejected at the point of AQIS inspection, or worse are rejected at the port of entry.

There are a range of issues which affect quality and export opportunities such as productivity, the development of best management practices, and improved harvesting, post harvest handling and storage techniques. In sweet corn production, apart from cultivar availability, the control of heliothis is the most limiting factor in meeting the demands of a developing export market, and to a consistent supply for the domestic market.

1.2 Project Objectives

Project Aim:
This project aimed to reduce the risks of crop loss from insect damage, mainly *H. armigera* (heliothis), and improve production and quality in sweet corm aimed at domestic (fresh and processing) and export markets.

The specific objectives were:

1. To identify and apply "best management options" (BMO's) to the production of sweet corn;
2. To identify and promote integrated pest management systems for sweet corn;
3. To reduce the production risks, particularly for export oriented production systems;
4. To protect and increase the small range of insecticides used for insect pest management;
5. To test and promote the use of alternatives to broad spectrum pesticides;
6. To test and promote improved application techniques;
7. To identify varieties for improved product and production characteristics for export and domestic markets; and
8. To identify technology which can separate damaged and undamaged cobs during the grading and packaging process.

1.3 Evaluation Objectives

Aim of the Evaluation:
This project evaluation has met the dual aims of accountability to clients/funding providers and assist with project management through the provision of timely information for decision-making thereby allowing managers to be responsive to stakeholder needs.

1.4 Key Definitions

This project evaluation was based on the project planning hierarchy illustrated below.

RESOURCES
are consumed by
ACTIVITIES
which produce
EFFECTS
as they try to achieve
OBJECTIVES
while pursuing more distant
GOALS.

Key definitions used in this document are:

Monitoring: Monitoring is an internal activity which is part of day-to-day project management. It involves continuous assessment of the functioning of project activities relative to project plans and the extent to which the project is meeting expectations in terms of client coverage/involvement of stakeholders (REC, 1995, *Programming and Evaluating Extension Projects*, Dairy Horizons Conference, Melbourne).

Evaluation: The systematic collection of information to appraise or judge value, usually to assist in making strategic decisions or to guide future action (REC, 1995, *Programming and Evaluating Extension Projects*, Dairy Horizons Conference, Melbourne).

Indicators: Performance indicators are statements which help management and staff measure the appropriateness, effectiveness and efficiency of a program. They are generally program specific and are a direct reflection of the objectives of a program (Fishpool, K.I., Frybort, P. and Graham, J. 1989, *Performance Indicators for Advisory Services*, NSW Agriculture).

Triangulation: The use of multiple sources of information from different methods, or different informants in order to increase the rigour of the evaluation (Dick, B. 1992,Qualitative evaluation for program improvement, IIR Conference on Evaluation, Brisbane).

Secondary data: Data useful for the evaluation, but not collected specifically for it (e.g. data collected by someone else for another purpose).

1.5 Evaluation Stakeholders

People with a major stake in the evaluation of this project include the project team members, HAL, sweet corn growers, processors, the marketing industry (markets, exporters, supermarkets) and businesses which supply pest management products or services to the sweet corn industry. Other stakeholders include consumers and businesses supplying other products or services to the sweet corn industry.

2. Evaluation Method

2.1 Development of the Plan:

The concept of evaluation was raised at the first National workshop when all team members were present. Information from work plans and discussions at the workshop were used to develop a draft evaluation framework using Bennett's Hierarchy. Project team members were then consulted with particular reference to their work area about which indicators could be measured to provide the most efficient evaluation of impacts.

2.2 Evaluation Plan

Monitoring activities were planned to collect the minimum amount of evidence required to demonstrate achievement (or otherwise) of each of the 7 project objectives. Bennett's hierarchy was used in the planning process to spell out what all the activities were within each objective, and how they were contributing to reaching the overall aim of the project. The evaluation team formulated key evaluation questions for each objective, then identified indicators which could be measured to help answer those questions. Whilst realising that indicators higher up in Bennett's hierarchy provide better evidence (Bennett, C.F., 1997 *Analysing impacts of extension programs,* USDA, Washington), the indicators chosen for the study had to be bounded by the resources available. In addition, the indicators were chosen from several levels of the hierarchy to strengthen the evaluation.

Details of the evaluation plan are presented in full in Appendix A. [See also Proceedings of Workshop No. 4 - pp. 137-143, for more information on the Project Evaluation work program].

2.3 Data Collection

A strategic array of data was collected during the life of the project, to provide 'triangulation,' a means of cross-checking the integrity of the data.

2.3.1 Grower Surveys

Team members in each major growing region interviewed key, representative stakeholders (mainly growers, agronomists and consultants) to collect the data for input into "Current Management Practices" documents in 1998 and again in 2001.

2.3.2 Stakeholder Workshops

Evaluation sheets were collected from workshop participants for each of the four National Workshops conducted under the project. Information collected related to improving future workshops, and to the likely impact new knowledge from the workshop would have on farming practices.

2.3.3 Milestone Attainment

The evaluation was designed to integrate with normal project management activities. In many cases the indicators were measured by attainment of project milestones. This was particularly true of milestones relating to improved scientific knowledge and understanding which was documented in reports.

3. Results by Objective

3.1 Objective 1.

To identify and apply "best management options" (BMO) to systems for sweet corn

Key Question	Indicator	Result
Were BMOs identified?	Documentation of BMOs	Details of BMO trials were published in "The Sweet corn Ear" throughout the life of the trials. BMOs were also reported on at each of the National Workshops.
Were BMOs applied to systems?	Field trials and demo crops to compare BMOs and standard practice regionally	Trials comparing BMOs with standard grower practice have been conducted in each of the major sweet corn production areas in Eastern Australia. BMOs have been tested in both small-plot and commercial scale trials. [MS6 Report]
	BMOs in trials modified and improved each year	Through newsletters, grower meetings, project workshops and field days, sweet corn growers and industry representatives have been provided an opportunity to assess BMO research first hand. This has allowed team members to receive feedback from industry on how to improve BMOs and secondly it has allowed growers to rapidly adopt any insect management improvements developed by project team members. [MS6 Report] BMO practices were changed as a result of grower feedback. For example in Victoria the first recommended time to spray had been at 50% silking but this varies in a paddock and as an average over the paddock would be too late. Therefore recommendation changed to spraying when earliest part of the crop was at 50% silking. [Rob Dimsey, Pers Comm]
Has industry changed practices to use tested and modified BMOs?	Growers implementing and adapting relevant components of BMOs for commercial use.	Results from BMO trials have been implemented, and are now the standard industry practice in many areas. [MS6 Report] A major change in the amount and quality of pest and crop monitoring has occurred in the sweet corn industry since 1998. All sweet corn grown in the Dry Tropics is monitored professionally, and the area monitored in South Queensland has doubled. In NSW there has been a 20 percent increase in the area of corn regularly monitored and in Victoria, 85 percent of the industry now check crops for large and small grubs and eggs. All States report the use of improved monitoring protocols and increased grower understanding of monitoring procedures and results, due in part to the Project's trials and information sharing processes. [Industry Changes Report]

	Less pest damage and crop loss	Although the damage assessments indicate that the BMO, in most instances, is better than standard practice, some results would still be considered commercially unacceptable. [MS6 Report] Most areas have reported significant reductions in pest damage and crop losses due to improved management practices attributed to the increased knowledge facilitated by the Project. In particular, information about the use of new chemicals, improved spray application techniques and better monitoring techniques have had the most impact. Increased market acceptance of pre-pack sweet corn also allows growers to accept a slightly higher risk from pest damage. [Industry Changes Report]
	Reduced and more efficient use of synthetic pesticides	Results of BMO trials conducted in all regions have successfully demonstrated that alternatives to the use of broad-spectrum insecticides can be combined into practical strategies that provide improved IPM in sweet corn [MS6 Report]

Objective 2.
To identify and promote IPM systems

Key Question	Indicator	Result
Was an IPM system identified?	Documentation of trials	An array of trials were conducted during the life of the project to test and combine various elements of IPM. Most of the BMOs were IPM-based, and additional work was conducted on biological pesticides, beneficial insects, pest behaviour, spray targeting, improved scouting protocols and new pesticides in sweet corn. [Workshop Reports]
	Develop an IPM Manual	Sweet Corn Agrilink (incorporating chapters on IPM) publication due late 2002. Richard Llewellyn published a field guide " Sweet corn insect pests and their natural enemies" published in 2000 and available through QDPI bookshop. The book was funded within a complementary project VG97040.

Were promotional activities held?	Promote scouting through scouting workshop, National Workshops, field days, "The Sweet Corn Ear"	Project team members in Queensland, NSW and Victoria have documented detailed scouting protocols for monitoring the abundance of *H. armigera* and other insects in sweet corn from planting until harvest. In New South Wales, Sandra McDougall and Clarrie Beckingham planned and conducted three scouting workshops in 1997 and 1998. The Narromine Workshop (1997) brought together growers, company field officers and scientists to develop a consensus sampling protocol for evaluation during the project. Scouting record books were designed and distributed to interested growers to trial. [MS5 Report] In 1998/99 four scouting workshops and field day, together with a pest identification field day were held to promote the scouting protocol [Progress Report, Jan 2000] Scouting work and workshops were reported in the "Sweet Corn Ear" when relevant, and were discussed at field days and National Workshops. The project developed and published a laminated pocket guide to sweet corn silk length and condition as a scouting tool. This was distributed at field days and extension activities including the National Workshops.
	Trial results promoted at field days etc.	The "Sweet Corn Ear" featured regional updates on a regular basis, providing a means of sharing results for trials underway and completed. Feature articles relating to particular trials or IPM related issues were also included when relevant.
Has industry changed practices to use IPM?	Growers implementing and adapting relevant components of IPM on own farms	The use of broad-spectrum and synthetic insecticides has decreased markedly in all States (with the exception of Tasmania during periods of high pest pressure). This is due mainly to the availability of two new products which, whilst more expensive and difficult to use correctly, are producing much better results. [Industry Changes Report] The processing sweet corn industry in southern Queensland has not used any broad spectrum insecticides for the past 2 seasons during mid-summer because of the combination of large populations of naturally occurring beneficials, improved scouting techniques and the availability of Bt, Success® and Gemstar® [Progress Report, Jan 2000] Growers attending National Workshops responded to short questionnaires about the value of the project and workshops and have reported changing to IPM although they felt there had been a huge change in thinking about pest management in the industry. [National Workshop Reports 2001, 2000, 1999, 1998]

	Increased use of scouting in sweet corn industry	A major change in the amount and quality of pest and crop monitoring has occurred in the sweet corn industry since 1998. All sweet corn grown in the Dry Tropics is monitored professionally, and the area monitored in South Queensland has doubled. In NSW there has been a 20 percent increase in the area of sweet corn regularly monitored and in Victoria, 85 percent of the industry now check crops for large and small grubs and eggs. All States report the use of improved monitoring protocols and increased grower understanding of monitoring procedures and results, due in part to the Project's trials and information sharing processes. [Industry Changes Report]
	Improved spray decision making skills	The increased use of monitoring and employment of professional scouts mentioned above has contributed to improved decision-making regarding the use of pesticides.
	Less pest damage and crop loss	Most areas have reported significant reductions in pest damage and crop losses due to improved management practices attributed to the increased knowledge facilitated by the Project. In particular, information about the use of new chemicals, improved spray application techniques and better monitoring techniques have had the most impact. Increased market acceptance of pre-pack sweet corn also allows growers to accept a slightly higher risk from pest damage. [Industry Changes Report]
	Reduced and more efficient use of synthetic pesticides	The use of broad-spectrum and synthetic insecticides has decreased markedly in all States (with the exception of Tasmania during periods of high pest pressure). This is due mainly to the availability of two new products which, whilst more expensive and difficult to use correctly, are producing much better results. [Industry Changes Report] The processing sweet corn industry in southern Queensland has not used any broad spectrum insecticides for the past 2 seasons during mid-summer because of the combination of large populations of naturally occurring beneficials, improved scouting techniques and the availability of Bt, Success® and Gemstar® [Progress Report, Jan 2000] In Victoria, the reduction in broad spectrum insecticides is approx. 80%. Growers have changed from around 5 sprays of a broad spectrum insecticide to one as a clean up spray using a narrow spectrum insecticide such as Success®, with the other insecticides use being targeted at a range to pests including Helicoverpa. [Rob Dimsey, Pers. Comm.]

Objective 3.
To reduce the production risks, particularly for export oriented production systems

Key Question	Indicator	Result
Were production risks identified?	Research and publication of current management practices document (1997 and 2001)	The information collected by team members in preparation of the 1997 Current Management Practices Report provided the team with a detailed understanding of the production risks experienced by sweet corn producers in the major growing regions of Eastern Australia. This knowledge formed the basis of the BMO and IPM component trials which were conducted within the project. Repeating the information gathering process in 2001 and compiling it in the Industry Changes Report allowed a comparison of production risks in each region over time.
Were the risks for export-oriented production systems reduced?	Increased knowledge of how to reduce risks	The industry reports that it has increased knowledge of how to reduce production risks since 1998, despite the many practice changes that have occurred and have been fine-tuned during those years. Most areas have reported significant reductions in pest damage and crop losses due to improved management practices attributed to the increased knowledge facilitated by the Project. In particular, information about the use of new chemicals, improved spray application techniques and better monitoring techniques have had the most impact. [Industry Changes Report]
	Increase in sweet corn exports and improved reliability/continuity of supply	North Queensland reported a slight increase in exports and an improvement in reliability of supply due to agronomic practices and improved pest management but there are still issues to be addressed. Exports of processed sweet corn have risen from nil to 15% in South Queensland mainly due to market acceptance of the varieties grown and the value of the A$. Fresh exports for the region remain static when compared to 1998 and there is still an opportunity to improve the reliability/continuity of supply. In Victoria there has been an overall trend for increase in sweet corn exports but no change in reliability and continuity of supply since 1998. [Industry Changes Report]

	Less pest damage and crop loss.	Most areas have reported significant reductions in pest damage and crop losses due to improved management practices attributed to the increased knowledge facilitated by the Project. In particular, information about the use of new chemicals, improved spray application techniques and better monitoring techniques have had the most impact. Increased market acceptance of pre-pack sweet corn also allows growers to accept a slightly higher risk from pest damage. [Industry Changes Report]

Objective 4.
To protect and increase the small range of insecticides used for IPM

Key Question	Indicator	Result
Has the number of IPM-friendly insecticides available for sweet corn increased?	Larger range of insecticides commercially available	The registration of Gemstar® by Aventis Crop Science in early 2002 is the culmination of 4 years work conducted by scientists and sweet corn growers funded by this project. The project team and growers have worked with Aventis researchers to integrate Gemstar® into IPM system which has been able to significantly reduce sweet corn losses from Heliothis damage. [QDPI News Release] Success® has also been registered for Sweet Corn in 1999 using data generated by work in this project. [Industry Changes Report]
Has action been taken to prevent insecticide resistance towards IPM-friendly insecticides?	Strategies to protect new pesticides implemented	The use of Success® and Gemstar® in sweet corn has created a major change in pest management. The chemical companies have stated that they probably would not have applied for registration in sweet corn if not for the work contributed by the Project towards data collection and presentation of the industry as being responsible and structured. The availability of these products has been the key to improving monitoring practices and improved spray application for better targeting. Without these narrow spectrum insecticides, these techniques would not be so important. [Industry Changes Report] The industry made an agreement at the May 2001 Pest Management in Sweet Corn workshop (under the Project) to reduce the number of sprays of Success® used per crop to assist with resistance management. A formal resistance management strategy is under development for the whole industry. In addition, the Project's contribution to improved monitoring has also helped growers to target application to the right time, and minimise pesticide use from calendar spraying to using only when necessary.[Industry Changes Report] Growers are increasingly using Gemstar® as a pre-silking spray to protect new chemistry such as

		Success. They are also limiting the number of applications. In Victoria, growers can legally use chemicals off-label if they meet certain criteria and a number have used Avatar® off-label as a rotational chemical to protect Success®. [Rob Dimsey, Pers. Comm]
Were new insecticides tested for IPM friendliness?	Field trial results published	BMO and IPM trials included testing new insecticides as part of the development of better pest management strategies. Results were presented at National Workshop and in the "Sweet Corn Ear" throughout the life of the project.
Has grower dependence on broad-spectrum synthetic insecticides been reduced?	Reduced reliance on broad-spectrum insecticides	The registration of new, narrow spectrum insecticides has reduced reliance on broad-spectrum insecticides. Many growers are now integrating the use of narrow spectrum insecticides with naturally occurring or inundatively released insects to manage pests. [Industry Changes Report] The processing sweet corn industry in southern Queensland has not used any broad spectrum insecticides for the past 2 seasons during mid-summer because of the combination of large populations of naturally occurring beneficials, improved scouting techniques and the availability of Success®, Bt and Gemstar® [Progress Report, Jan 2000] In Victoria the reduction in broad spectrum insecticides is approx. 80%. Growers have changed from around 5 sprays of a broad spectrum insecticide to one as a clean up spray such as Success®, with the other insecticides use being targeted at a range to pests including Helicoverpa. [Rob Dimsey, Pers. Comm.]
	Industry using more IPM-friendly (specific) insecticides	The reduction in use of broad-spectrum insecticides is due mainly to the availability of two new products which, whilst more expensive and difficult to use correctly, are producing much better results. [Industry Changes Report] The processing sweet corn industry in southern Queensland has not used any broad spectrum insecticides for the past 2 seasons during mid-summer because of the combination of large populations of naturally occurring beneficials, improved scouting techniques and the availability of Success®, Bt and Gemstar® [Progress Report, Jan 2000]

	Industry using less broad-spectrum insecticides	The use of broad-spectrum and synthetic insecticides has decreased markedly in all States (with the exception of Tasmania during periods of high pest pressure). [Industry Changes Report] The processing sweet corn industry in southern Queensland has not used any broad spectrum insecticides for the past 2 seasons during mid-summer because of the combination of large populations of naturally occurring beneficials, improved scouting techniques and the availability of Success®, Bt and Gemstar® [Progress Report, Jan 2000]

3.2 Objective 5.
To test and promote the use of alternatives to broad-spectrum insecticides

Key Question	Indicator	Result
Were alternatives tested for efficacy?	BMO trials and small plot trials Incorporation of the better alternatives into IPM trials for further research	BMO and IPM trials included testing new insecticides and measuring the impact of beneficial insects as part of the development of better pest management strategies. Results were presented at National Workshops and in the "Sweet Corn Ear" throughout the life of the project. A specific example is the trials with Trichogramma conducted in the Lockyer Valley where it was found that local populations of *Trichogramma pretiosum* build up to very high levels as the season progresses. This situation has facilitated the successful use of products like Bt, Gemstar® and Success®.
Were alternatives tested for 'fitness' for IPM (beneficial friendly, target specific, environmentally friendly)?		As NPV (Gemstar®) is very specific to heliothis, it does not affect naturally occurring beneficial insects and spiders which can make a significant contribution to heliothis management in commercial crops. NPV also has no adverse effects on other animals, including humans, making it extremely environmentally friendly. [QDPI News Release]
Were alternatives promoted?	Field days and demonstrations	BMO demonstration plantings have been conducted in all major sweet corn growing regions. Well attended farm walks have been conducted at each BMO location [Progress Report, Jan 2000]
	Publication of improved application techniques in the "Sweet Corn Ear" etc.	Relevant articles were published in the "Sweet Corn Ear" and mailed to all stakeholders in Jul 98, Dec 98, Mar 99, Sep 99, Dec 00, Feb 01, Jun 01. The majority of presentations and discussions at each of the 4 National Workshops were centered around BMOs, beneficial insects and biological insecticides. News Releases were also distributed for publication in regional and agricultural publications as well as radio. Information was published on the Project's web site and on Richard Llewellyn's web site (an associated project). Web Site :-

Are more alternatives being used for sweet corn production?	Growers making rational decisions about which pesticide to use	The Project's contribution to improved monitoring has also helped growers to target application to the right time, and minimise pesticide use from calendar spraying to using only when necessary. A greater awareness of the benefits of beneficial insects (especially in Queensland) has influenced pesticide choice towards softer products where possible. [Industry Changes Report] A sweet corn diagnostic tool developed by the project (Nolan 2001) will assist growers in correct identification of insects, diseases and weeds which should contribute to more rational pesticide choices to target identified pests.

	More use of inoculative release of beneficial insects	In the course of the project it was found that local parasitoids (including *T. pretiosum*) typically make a significant contribution in many areas including the Lockyer Valley, Sydney Basin and Central West NSW and occasionally in the other areas. Use of narrow spectrum insecticides instead of broad spectrum insecticides has enabled growers in these areas to take advantage of these egg parasitoids. *T. pretiosum* is well established in the LV and appears to be established in the Sydney Basin and some areas of Central West NSW. [Richard Llewellyn, Pers. Comm] In North Queensland and NSW the use of inoculative release of beneficials has not increased since 1998, and the local population of *T. pretiosum* has remained static in North Queensland but populations are now more stable in NSW. In fresh market sweet corn in South Queensland, inoculative releases are made by some growers into the spring plantings. This has speeded up the process of Trichogramma establishment considerably and enabled a shift to a minimum chemical program much earlier than otherwise. There appears to have been an increase in the stability of established populations of T. pretiosum in South Queensland due to the major reduction in the amount of broad-spectrum insecticides being used in the crop. Use of inundative releases of beneficials has not been carried out commercially in Victoria although a number of releases have been made as part of the Project which has increased awareness of the potential benefits. Uptake has not occurred to date due to uncertainty of the commercial viability in southern Victoria and lack of knowledge about the ability to overwinter. Despite of several releases of beneficial insects, *T. pretiosum* in 1998/99 and 99/00, observations showed that there were very low levels of Trichogramma at present in East Gippsland in 2000/01. Inundative releases of beneficial insects are not used in Tasmania because of the biology of the pest. *T. pretiosum* populations have not been recorded in Tasmania. [Industry Changes Report]

	More use of biological insecticides	The registration of new, selective pesticides has reduced reliance on broad-spectrum insecticides. Many growers are now integrating the use of narrow spectrum and biological insecticides, with naturally occurring or inundatively released insects to manage pests. [Industry Changes Report] The processing sweet corn industry in southern Queensland has not used any broad spectrum insecticides for the past 2 seasons during mid-summer because of the combination of large populations of naturally occurring beneficials, improved scouting techniques and the availability of Success®, Bt and Gemstar® [Progress Report, Jan 2000]

Objective 6.
To test and promote improved pesticide application techniques

Key Question	Indicator	Result
Were pesticide application techniques tested?	Field trials completed	Field trials were undertaken in all major growing regions in Eastern Australia to evaluate spray systems in common commercial use including ground rigs and aerial equipment. [MS4 Report]
Were improved application techniques developed?	Publication of details and demonstration of new techniques	Through newsletters, grower meetings, National workshops and field days, sweet corn growers and industry representatives in all major growing regions in Eastern Australia have been provided an opportunity to view and discuss research first hand. This has allowed team members to receive feedback from industry for improvements, and it has allowed growers to rapidly adopt and adapt the improvements developed by project team members. [MS4 Report] In addition, in April 1999, 500 copies of a 22 page booklet detailing the design and construction of spray droppers to fit to existing boom sprays to improve pesticide targeting to the areas of the plant where it is needed, were printed and distributed.
Were effective application techniques promoted?	Project team trialing improved methods in IPM and BMO trials	Sprayer maintenance, timing and targeting of sprays were an important part of the BMOs assessed in all growing regions. [MS6 Report] In many cases, the droppers built for use in trials on research stations would have been the first time growers could examine their design and see their effectiveness.

	Field days and demonstrations comparing application methods	Farm walks were held in all major sweet corn production areas during 1998 and 1999. These events comprised a presentation of trial results and general spray application, a demonstration of spray application methods and viewing coverage from different application methods using fluorescent dye and UV lights after dark. These night farm walks were popular and generated much discussion and interest. [MS4 Report]
	Publication of improved application techniques in the "Sweet Corn Ear" etc.	Relevant articles were published in the "Sweet Corn Ear" in Dec 98, Jan 99, Mar 99, Dec 00, Jun 01. Many newspaper articles were also published in regional and agricultural publications over the 4 years of the project. In addition, in April 1999, 500 copies of a 22 page booklet detailing the design and construction of spray droppers to fit to existing boom sprays to improve pesticide targeting to the areas of the plant where it is needed, were printed and distributed.
Has industry changed practice to using more effective application techniques?	Growers using more effective spray application techniques	Many areas have changed their pesticide application practices in response to trial results and demonstrations conducted through the Project. Where possible, growers have moved to the use of ground rigs with droppers, but many unable to change for financial reasons or due to timing/scale of operations have improved spray application by changing nozzles or speed of application. [Industry Changes Report]
	Growers modifying equipment to improve spray application	Many areas have changed their pesticide application practices in response to trial results and demonstrations conducted through the Project. Where possible, growers have moved to the use of ground rigs with droppers, but many unable to change for financial reasons or due to timing/scale of operations have improved spray application by changing nozzles or speed of application. [Industry Changes Report] A number of growers in all districts are modifying boom sprayers to take advantage of the 4 fold improvement droppers can make on spray deposition. Work with aircraft in all districts has shown that optimisation of aircraft application can be achieved through modification of spray patterns, increased water volume and use of aids such as GPS. [Progress Report Jan 2000]
	Growers purchasing new, more appropriate equipment if available	All growing regions have experienced an increase in the use of improved ground rigs, with some areas undergoing a major shift to 100% use of ground rigs unless the ground is so wet that aerial applications are required. The advantages and improved targeting demonstrated by the Project has confirmed theories and has been a major factor influencing fresh market growers to purchase and use ground rigs wherever possible. [Industry Changes Report]

3.3 Objective 7.
To identify cultivars for improved product and production characteristics

Key Question	Indicator	Result
Were a range of cultivars assessed in field trials for their capacity to improve insect pest management?	New knowledge about the pest/disease resistance/tolerance of new cultivars	Emphasis has been on cultivar tolerance to insect damage since anecdotal evidence has suggested that there are differences between Australian sweet corn cultivars in their susceptibility to heliothis damage. Field trials to compare the susceptibility of a range of cultivars in Australia to heliothis damage were carried out at Bowen in North Queensland in the 1998 and 1999 seasons and at Lindenow in East Gippsland in Victoria over the 1998 -1999 season. [MS7 Report]
Has the project communicated field trial results to the industry?	Growers aware of properties of new cultivars	The latest available cultivars were on show to growers at farm walks at Bowen in Nov 98 and Sep 99. Trial results were published in all National Workshop Proceedings and as a Milestone Report which was sent to all stakeholders.
	Growers selecting cultivars using susceptibility/ tolerance information as well as other factors	The cultivars chosen by growers in the various regions are those which perform best in their respective environment and meet the market specification. Pest management considerations are taken into account after these conditions are satisfied. [Industry Changes Report]
	Industry uses cultivars which minimize pest management problems but still meet other requirements	Cultivar choice depends on a range of quality characteristics and market acceptability. Good husk cover protection is a desirable attribute to protect cobs from weather and harvesting damage as well as providing some protection from insect attack. The development of good quality temperate and tropical cultivars with this attribute is a desirable plant breeding objective and remains a challenge for breeding programs [MS7 Report]

Objective 8.
To identify technology which can separate damaged and undamaged cobs during the grading and packaging process

Key Question	Indicator	Result
Was the work done to determine whether NIR technology can identify heliothis larvae in whole sweet corn cobs?	Identification of technology suitable for packing lines.	Discrimination of the defects of sweet corn cobs (poor grain tip fill, insect damage and presence of the heliothis grub) from clean cobs can be achieved non–invasively by near infra-red spectroscopy. The NIRSystems 6500 scanning spectrometer and the Zeiss MMSI miniature spectrometer (coupled with a high intensity quartz halogen lamp -100 watts) can achieve this discrimination. However, in a practical packing shed operation the relatively rapid and inexpensive Zeiss MMSI spectrometer offers the most promise. [MS8 Report]
	Communication of results in "Sweet Corn Ear" and at National Workshops	The presentation of NIR technology information at National Workshops was received with great stakeholder interest and usually raised many questions. The Milestone Report detailing all the research conducted by the project was distributed to the 400 stakeholders on the database. A highlights summary was published in the "Sweet Corn Ear" in June 2001.
Are components of an in-line NIR system available?	Milestone Report	The following commercial suppliers of NIR equipment have been identified [MS8 Report]: Colour Vision Systems Pty. Ltd. 11 Park Street, Bacchus Marsh, Victoria Australia 3340 Fantec Research Institute Hamamatsu City Shizuoka Prefecture Japan Horticultural Automation Limited 11 Spring Street Onehunga PO Box 13516, Auckland 1132 New Zealand Mitsui Mining & Smelting Co. Saitama, Japan
Was the technology practical for use during the grading and packaging process?	Industry interest in the use of NIR in packing lines	Stakeholders reported an interest in developing the near-infra red technology to a commercial level to facilitate growth in accessing export markets for high quality, Australian whole sweet corn cobs. [Industry Changes Report]
	Scientific knowledge about NIR technology which could be used in packing sheds.	The NIRSystems 6500 scanning spectrometer and the Zeiss MMSI miniature spectrometer (coupled with a high intensity quartz halogen lamp -100 watts) can achieve this discrimination. However, in a practical packing shed operation the relatively rapid and inexpensive Zeiss MMSI spectrometer offers the most promise. [MS8 Report]

4. Conclusions

The project far exceeded expectations set down by the initial Project Objectives, especially in the areas of application technology, risk reduction by IPM and more narrow spectrum insecticide choices available to sweet corn producers throughout Australia. The sometimes controversial trial approach taken to develop Best Management Options (BMO's) paid off substantially, and preliminary work to assess technology with potential to improve sweet corn grading and packing operations was also a success.

A major benefit of the project comes from more than just the technically and scientifically excellent work – it is the fact that industry has changed its practices as a result of the project. The following explanation for industry change written by the North Queensland team also holds true for other growing regions:

> "The changes in grower practice can be attributed to a combination of factors. The Project has generated a lot of information about new insecticides and how they can be used, along with improved application techniques. Through the BMO concept, any relevant information could be formulated into a strategy, tested and incorporated very rapidly into commercial practice because of the close relationship between the consultants/researchers and sweet corn growers in the region. In addition, because the growers (as stakeholders) have been exposed to the extensive information the Project has produced and have been involved in the trials conducted in NQ, this had enabled new products or techniques to be rapidly implemented in commercial operations." [Industry Changes Report]

The funding invested in hosting annual National Workshops and developing and widely distributing the "Sweet Corn Ear" newsletter, Technical and Milestone Reports was worthwhile for the major contribution it made to information transfer, feedback and discussion as well as developing an industry identity. It was this demonstration of cohesion and a visibly proactive industry seeking responsible solutions to its pest management problems that was the main contributing factor for two chemical companies (Dow and Aventis) to register their new narrow spectrum insecticides for sweet corn in Australia.

The involvement of stakeholders in discussing and reviewing results and developing research plans helped to build the relationship with chemical company representatives which lead to the project not only trialing the new insecticides, but contributing required data for registration.

This approach is also largely responsible for the speed and desire growers have shown in adopting and adapting research on farm. The project has seen the industry move a long way in pest management – from calendar spraying synthetic broad-spectrum insecticides (often onto resistant pests and with inefficient application technology) to managing IPM systems which integrate monitoring, narrow spectrum insecticides and beneficial insects with improved application equipment targeting appropriate plant parts at the right time.

Further progress for the industry will rely on developing systems to manage diseases and the secondary pests which have started occurring under IPM, the introduction of pest tolerant plant varieties with high market acceptability and improved in-line damage detection for whole cobs in packing houses. This technology also has the promise to increase access to export markets.

Appendix A – Evaluation Plan, 1998.

2.2.1 Evaluation of Best Management Options work

Objective:

To identify and apply "best management options" to systems for sweet corn.

Key questions:

i) Were BMOs identified?
ii) Were BMOs applied to systems?
iii) Has industry changed practices to use tested and modified BMOs?

Bennett's Hierarchy

Inputs	Activities	People Involvement	Reactions	KASA Change	Practice Change	End Results
• project team members • time • money • library access • phone hook-up systems • Research farm space • Farm machinery and farm hands	• Surveys to determine present pest management systems • **Documentation of BMOs** • **Field trials & demo crops to compare BMOs and standard practice regionally** • **Field days/farm walks** • **Report results in "Sweet Corn Ear"** • Keep up to date with literature on BMOs • **Inter-regional BMO transfer - annual review & 6 monthly phone hook up** • Identification of spray strategies and modifications • Other forms of publicity	• Sweet corn producers • research scientists • extension scientists • research support staff • industry (chemical companies, seed companies, resellers) • consultants • processor field officers	• Stakeholder input into BMO evaluation and improvement • Stakeholders interested to see current status of pest management • Realisation that good ideas can come from other regions • Stakeholder awareness of local BMOs raised through seeing trial results	• Improved scientific knowledge about how BMOs fit into production system • Increased grower interest in using BMOs • recognition of the complexity of the system (no magic bullets) • **Improved scouting skills** • **Scouting workshops** • **Improved decision making skills based on knowledge thresholds & scouting** • **Improved decision making regarding spray application**	• **BMOs in trials modified and improved each year** • **Growers implementing and adapting relevant components of BMOs for commercial use**	• Lower risk of major pest damage due to use of BMOs • Pest management integrated with production system in complementary way • **Less pest damage and crop loss** • More profitable production system • **Reduced and more efficient use of synthetic pesticides**

Indicators are marked in bold in table above. Measurement will be via:

- Team member email survey
- Project management reports/milestones
- Final survey
- Stakeholder telephone interviews
- Current management practices document

2.2.2 **Evaluation of IPM systems activities**

Objective:

To identify and promote IPM systems.

i) **Key questions:** Was an IPM system identified?

ii) Were promotional activities held?

iii) Has industry changed practices to use IPM?

Bennett's Hierarchy.

Inputs	Activities	People Involvement	Reactions	KASA Change	Practice Change	End Results
• Project team members • Time • Money • Research farm space for trials • Research farm machinery and labour • Grower co-operators • Space for commercial size trials	• Comparison of standard practice vs IPM through: • replicated small plot trials • commercial size trials of most promising components • demonstration plantings of most promising components • **Trial results published in "Sweet Corn Ear"** • **promoting scouting through scout workshop, symposia, field days, newsletter** • **Develop an IPM manual** • **Trial results promoted at field days etc.**	• Sweet corn producers • scientific staff • extension staff • industry (chemical companies, seed companies, resellers) • consultants • scouts • processor field officers	• Stakeholder input into IPM evaluation and improvement • Stakeholders interested to see results of comparison trials • Realisation of importance of monitoring • Stakeholder awareness of IPM raised through seeing trial results and IPM manual	• Improved scientific knowledge about IPM systems • Increased grower interest in IPM • Recognition of the complexity of the system (no magic bullets) • **Improved scouting skills** • **Improved decision making skills based on knowledge thresholds and scouting** • **Improved spray decision making skills**	• **IPM trials modified and improved each year** • **Growers implementing and adapting relevant components of IPM on own farms** • **Increased use of scouting in sweet corn industry**	• Lower risk of major pest damage due to use of IPM • Pest management integrated with production system in complementary way • **Less pest damage and crop loss** • More profitable production system • **Reduced and more efficient use of synthetic pesticides.**

Indicators are marked in bold in table above. Measurement will be via:

- Team member email survey
- Project management reports/milestones
- Final survey
- Stakeholder telephone interviews
- Chemical sales statistics
- Current management practices document

2.2. 3 Evaluation of the activities conducted to reduce production risks

Objective:
Reduce the production risks, particularly for export oriented production systems.

Key Questions: Were production risks identified?
i) Were the risks for export oriented production systems reduced?

Bennett's Hierarchy

Inputs	Activities	People Involvement	Reactions	KASA Change	Practice Change	End Results
• project team members • time • money	• Identification of production risks through baseline management practices survey (1997) and follow-up survey (2001) and Peter Deuter's 1996 paper • Assess change in risks over time • Communicate findings with stakeholders	• growers • research scientists • extension scientists	• BMO and IPM trials to include strategies to reduce risks	• Increased awareness of what the risks are • Increased knowledge of how to reduce risks • Growers skilled to make risk reductions	• BMO trials and IPM components to further reduce risks each year • Growers implementing and adapting relevant components of a reduced risk strategy	• **increase in sweet corn exports** • improvement in quality of exports • **less pest damage and crop loss** • more economically sustainable production systems • decreased grower risk of major pest damage

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Indicators are marked in bold in table above. Measurement will be via:

- Team member email survey
- AQIS records
- Final survey
- Stakeholder telephone interviews
- Current management practices document

2.2. 4 Evaluation of insecticide related activities

Objective:

To protect and increase the small range of insecticides used for IPM

Key Questions:

i) Has the number of IPM-friendly insecticides available for sweet corn increased?
ii) Has action been taken to prevent insecticide resistance towards IPM-friendly insecticides?
iii) Were new insecticides tested for IPM-friendliness?
iv) Has grower dependence on broad-spectrum synthetic insecticides been reduced?

Bennett's Hierarchy

Inputs	Activities	People Involvement	Reactions	KASA Change	Practice Change	End Results
project team members time money resistance monitoring lab & staff chemicals beneficial insects trial space machinery & farm staff chemical company representatives	▪ test new synthetic chemistry in replicated field trials ▪ standardise scouting protocols ▪ develop & support resistance management strategies for existing control agents ▪ continue insecticide resistance monitoring ▪ **evaluate beneficial insects alone & in combination with synthetics** ▪ keep abridge of development of minor use registration protocols ▪ monitor NRA-ECR program for MRL information	▪ scientific staff ▪ chemical company reps ▪ growers ▪ resistance monitoring lab staff ▪ resistance management strategy group representative ▪ NRA	▪	▪ Awareness of a wider range of insecticide possibilities ▪ Knowledge of the effect of insecticides on beneficials ▪ **Reduced reliance on broad-spectrum insecticides** ▪ Knowledge of strategies for using new pesticides	▪ **Industry using more IPM-friendly (specific) insecticides** ▪ **Industry using less broad-spectrum insecticides** ▪ **Strategies to protect new pesticides implemented**	▪ Insecticide resistance levels not increasing ▪ Heliothis management no longer a significant production problem ▪ **Larger range of insecticides commercially available.**

Indicators are marked in bold in table above. Measurement will be via:

- Team member email survey
- Project management reports/milestones
- Final survey
- Stakeholder telephone interviews
- Reseller data
- Current management practices document

2.2. 5 Evaluation of insecticide alternatives work

Objective:
To test and promote use of alternatives to broad-spectrum insecticides.

Key Questions:

i) Were alternatives tested for efficacy?
ii) Were alternatives tested for 'fitness' for IPM (beneficial friendly, target specific, environmentally friendly)?
iii) Were alternatives promoted?
iv) Are more alternatives being used for sweet corn production?

Bennett's Hierarchy

Inputs	Activities	People Involvement	Reactions	KASA Change	Practice Change	End Results
roject team members ime noney new chemicals beneficial insects equipment for other lternatives rial space nachinery & farm staff chemical company epresentatives	**•BMO trials** **•small plot trials** **•extension activities** **•communication of results**	•Cooperative growers •Growers & other stakeholders attending extension activities	•Interest in trying alternative methods in own crops	•Improved understanding of effects of alternatives on IPM systems •Industry aware of alternatives and many trying them •Growers learning new IPM skills or hiring consultants to manage alternatives in IPM system •Growers and chemical industry aiming to use IPM friendly pest management methods wherever possible	**•Growers making rational decisions about which pesticide to use** **•Incorporation of the better alternatives into IPM trials for further research** **•More use of inundative release of beneficials** **•More use of biological insecticides**	•Industry has reduced dependence on broad spectrum synthetic pesticides •Wide industry use of IPM **•Established population of Trichogramma pretiosum in Victoria and NSW production areas**

Indicators are marked in bold in table above. Measurement will be via:

- Team member email survey
- Project management reports/milestones
- Final survey
- Stakeholder telephone interviews
- Reseller data
- Trichogramma sales data
- Current management practices document

2.2.6 Evaluation of pesticide application activities

Objective:
To test and promote improved pesticide application techniques.

Key Questions:

i) Were pesticide application techniques tested?
ii) Were improved application techniques developed?
iii) Were effective application techniques promoted?
iv) Has industry changed practice to using more effective application techniques?

Bennett's Hierarchy

Inputs	Activities	People Involvement	Reactions	KASA Change	Practice Change	End Results
·oject team members me ·oney ıemicals ˌuipment for testing & :asuring ial space achinery & farm staff ıemical and spray :hnology company ɔresentatives	•surveying current spray application methods •trials for testing effectiveness of methods •extension activities •communication of results	•grower collaborators in trials •growers participating in extension activities •project team trialing improved methods in IPM and BMO trials	•Growers realising their spray application techniques may be causing problems •Growers realising that improvements are possible, even on existing equipment	•Knowledge of current spray practices •Knowledge of which methods are most effective •Realisation that application techniques are an important component of pest management •Growers learn new skills to improve spray application techniques •Industry desire to use most effective spray application technology possible in their situation	**•Growers using more effective spray application techniques** **•Growers modifying equipment to improve spray application** **•Growers purchasing new, more appropriate equipment if available**	•More effective pest management •To eliminate spray application as a contributor to pest management problems

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Indicators are marked in bold in table above. Measurement will be via:

- Team member email survey
- Project management reports/milestones
- Final survey
- Stakeholder telephone interviews
- Current management practices document

2.2.7 Evaluation of cultivar improvement activities

Objective:
To identify cultivars for improved product and production characteristics.

Key Questions:
i) Were a range of cultivars assessed in field trials for their capacity to improve insect pest management?
ii) Has the project communicated field trial results to the industry?

Bennett's Hierarchy

Inputs	Activities	People Involvement	Reactions	KASA Change	Practice Change	End Results
·oject team members me oney ial space achinery & farm staff :w cultivars	•cultivar trials •extension activities •communication of results	•researchers involved in trial •growers involved in assessment •growers, researchers and extension officers involved in extension activities •	•growers interested to see how new cultivars perform •processors, researchers & other stakeholders also interested **in results**	**•new knowledge about the pest/disease resistance/tolerance of new cultivars** **•growers aware of properties of new cultivars** •growers have skills to assess which cultivar is right for them **•new knowledge about how different cultivars should be sprayed**	**•cultivars selected using pest susceptibility/tolerance information as well as other factors** •processors assessing heliothis incidence in their trials •researchers using improved cultivars in BMO and IPM trials	**•industry uses cultivars which minimize pest management problems but still meet other requirements**

Indicators are marked in bold in table above. Measurement will be via:
- Team member email survey
- Project management reports/milestones
- Final survey
- Stakeholder telephone interviews

2.2.8 Evaluation of activities to identify technology for grading and packing

Objective:
Identify technology which can separate damaged and undamaged cobs during the grading and packaging process.

Key Questions:
1. Was the work done to determine whether NIR technology can identify heliothis larvae in whole sweet corn cobs?
2. Are components of an in-line NIR system available?
3. Was technology practical for use during the grading and packaging process?

Bennett's Hierarchy

Inputs	*Activities*	People Involvement	Reactions	KASA Change	Practice Change	End Re
•project team members •time •money •NIR equipment •corn samples from regional trials	•research to detect cob damage **•identification of technology suitable for packing lines** **•communication of results in Sweet Corn Ear and other publications**	•researcher •project team members supplying samples •growers involved in discussions on technology for packing lines	**•industry interest in the use of NIR in packing lines**	**•Knowledge about NIR technology which could be used in packing sheds** •industry aware of NIR equipment which can be used to ID and reject damaged cobs in a packing line	•beyond the scope of this project •growers using NIR technology in packing sheds	•beyond the sco project •reduced costs a improved retur •more consisten marketplace

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Indicators are marked in bold in table above. Measurement will be via:
- Team member email survey
- Project management reports/milestones
- Stakeholder telephone interview

2. Information Interchange
(Technology Transfer)

Peter Deuter, QDPI Gatton Research Station and Larissa Bilston, R,D&E Services.

Further details of **Information Interchange** activities over 4 years of this project have been reported in :-

- Milestone No. 3. – "All major stakeholders in the sweet corn industry have been identified, and a mechanism for information exchange has been developed."
- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 29-36.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 128, 160-163.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 113-115.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 135-136.

➢ Activities to ensure adoption

The Research, Development and Extension work program was conducted through:

1. Information Interchange.
2. Evaluating Best Management Options
3. Focussed Research & Development

➢ Information Interchange

• A **database of stakeholders** has been developed for the distribution of a newsletter ("The Sweet Corn Ear"), the Yearly Sweet Corn Industry Workshop Proceedings, Project Milestones and other Reports published by the Project Team.
The Microsoft Access database contains the names, postal and email addresses, phone and fax numbers of over 450 sweet corn stakeholders in eastern Australia. The database is regularly up-dated and has grown from over 250 contacts in the first year of the project. It includes growers, researchers, chemical company representatives and distributors, seed company representatives and processors.

Yearly **Industry Workshops** involving project team members and stakeholders have been a venue for reporting outcomes, sharing ideas and planning future work together. Workshop No 1, May 1998, (Gatton, Qld); Workshop No 2, May 1999, (Bathurst, NSW); Workshop No 3, June 2000, (Bowen , Qld) and Workshop No 4, April/May 2001, (East Gippsland, Vic).

All stakeholders were encouraged, and opportunities provided to participate in this information interchange. Proceedings of all four Sweet Corn Industry workshops were published and have been distributed to all stakeholders on the database.

The mechanism for the exchange of information among stakeholders between annual workshops involved mailing **"The Sweet Corn Ear" newsletter** to all stakeholders on the database. Sixteen (16) Sweet Corn Ear Newsletters were published and distributed :-

April 1998; July 1998; December 1998; January 1999; March/April 1999; September 1999; March/April 2000; May 2000; August 2000; Sept/Oct 2000; December 2000; Feb 2001; April 2001; May 2001; June 2001 and March 2002.

• A Web site has been established and is updated and maintained by project tem members in Victoria. **Web Address :- www.nre.vic.gov.au/agvic/ihd/projects/sc.htm**

• The **print media** have also been used as a communication mechanism for the project. All Newsletters have resulted in articles in rural magazines and newspapers. Good Fruit and Vegetables have published several articles on sweet corn pest management and the results and outcomes of the project work program.

A number of methods were used to communicate with sweet corn growers in NSW, they included:

- Sessions at the annual NSW Farmers Vegetable Conference (August 1997, 1998,1999,2000).
- Presentations at the day-long Simplot Sweet Corn Symposium (September 1997).
- Crop monitoring workshops were held in Narromine (December 1997, August 1998, December 1998)
- Scouting and pest identification field days was held in the Sydney basin (January 1999 and 2000).
- A general sweet corn field day was held in Sydney (February 2000)
- Personal interviews with a number of growers gave a snap-shot of current practices (1997).
- Many growers were visited by team members throughout the project which included discussions about their pest management concerns and project outcomes.
- A TV story on sweet corn IPM was aired in May 2000 on regional stations in NSW.
- Biological control in sweet corn interview (ABC Radio) May 2000
- an article with some of the sweet corn work was published in the *Farmers' Newsletter*: S McDougall "IPM of Heliothis in Vegetables" IREC 184 June 2000 pp 28-33.

To clearly define the starting point of this project, baseline data was collected on agronomic practices and pest management strategies used in the sweet corn industry in Eastern Australia. This baseline data of **pest management practices in sweet corn** has been used in project evaluation, against which gains and improvements have been judged. A Report **"Evaluation: *Industry Changes from 1998 to 2001*"** has been published and distributed through the stakeholder database. **(See Project Activity 1. – Project Evaluation)**.

➤ Best Management Options (BMO's)

BMO comparisons have been the basis of on-farm trials in each of the major sweet corn production districts in Eastern Australia, comparing the pest management outcomes of BMO's with grower practice. These sites have been the focus of farm walks and fieldays in each of the regions. These **farm walks** have been designed to achieve feedback from growers and consultants on the practicalities and effectiveness of components of IPM incorporated in each of these BMO comparisons. **(See Project Activity 10. – Evaluation of BMO's)**.

➤ Focussed Research and Development

The following issues were reported to stakeholders at fieldays, farm walks, yearly Industry Workshops, newsletters, newspaper articles, and Milestone and other Reports.

1] Field trials evaluating promising **narrow spectrum and biological insecticides** such as *Bacillus thuringiensis* (Bt), heliothis virus formulations (NPV) and Spinosad; and inundative releases of the parasitoid Trichogramma for management of heliothis populations. (**See Project Activity 3. – Biological Insecticides**).

2] Field evaluation of **naturally occurring *Trichogramma spp.*** and their population dynamics in commercial sweet corn fields. (**See Project Activity 4. – Naturally Occurring Beneficials**).

3] Ground rig sprayers with nozzles targeting cobs, and other combinations of **modified application equipment** have been compared with the industry practice of aerial application. Pesticide targeting assessment has aimed at understanding how the arrangements of upper leaves affect the amount of pesticide reaching the cobs, especially the silks.
(**See Project Activity 5. – Pesticide Application**).

4] Heliothis populations have been **monitored weekly** (twice weekly during periods of pest build up) to improve the timing and application of biological and synthetic pesticides and develop and improve scouting protocols.
(**See Project Activities 4 – Naturally Occurring Beneficials and 9. – Crop and Pest Monitoring**).

5] **Sweet corn cultivars have been evaluated** at Bowen in Queensland and East Gippsland in Victoria. The major varieties have been screened for their tolerance to heliothis in the absence of insecticides. Cultivars were evaluated for performance, yield, quality, uniformity and resistance or tolerance to pests and diseases and in particular to heliothis attack.
(**See Project Activity 7. – Cultivar Assessment**).

6] Research was carried out using **non-destructive assessment of cob damage** with the use of near infra-red (NIR) spectroscopy, as a potential tool in separating damaged and undamaged cobs in a pack-house.
(**See Project Activity 8. – Near Infra-red Technology**).

7] The development of **improved pest scouting (monitoring) techniques** was a part of the testing of BMO's as well as focussed research and development associated with improved timing and targeting of pesticides and the testing of alternative biopesticides.
(**See Project Activity 9. – Crop and Pest Monitoring**).

3. Biological Insecticides

Further details of work programs and outcomes associated with **Biological Insecticides** have been reported in :-

- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 30-36.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 123 –129 & 151-159.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 29-37.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 93-103.

Summary of research conducted to evaluate NPV for the management of *Helicoverpa armigera* and other insects in Queensland sweet corn.

Brendan Nolan, Senior Experimentalist, QDPI, Gatton Research Station,

Introduction

Synthetic insecticides are commonly used to manage *Helicoverpa armigera* larvae in sweet corn. Their overuse has lead to *H. armigera* larvae developing high levels of resistance to them. Recently, the biological insecticides Gemstar® (nuclear polyhedrosis virus (NPV)) has been developed as alternate method to manage *H. armigera* in sweet corn, as larvae have no or very low levels of resistance to them.

The biological insecticide Gemstar® was investigated by Queensland project team members. The exact outline of each biological insecticide experiment can be found in the 4 workshop proceedings. The experiments main objectives were first, develop efficacy data for support of a registration application. Second, improve the application of Gemstar® in sweet corn crops. Thirdly, show Gemstar® is not toxic to non target pests and environment.

Materials and Methods

The benefits of biological insecticides as a tool to reduce crop loss from Heliothis caterpillars and other insect pests were completed in south east Queensland between 1998 and 2001. The field experiments were conducted on the Queensland Department of Primary Industries Gatton Research Station (GRS) and on grower's properties. Golden Sweet and H5, the main commercial cultivars used by growers, were the only cultivars used during the experiments.

To achieve outcomes for the project objectives the following experiments were conducted.

1. Performance experiments.
   - These experiments were designed to assess performance of Gemstar® to control heliothis larvae during the silking crop growth stage. The performance of Gemstar® was compare with synthetic insecticide applications and a control no insecticide).
   - The performance of each treatment was determined by assessing its ability to reduce insect numbers and sweet corn cob damage

2. Gemstar® spray application improvements
   - Boom sprays were modified with droppers to increase the coverage of Gemstar® applied to silks.

- Petroleum oils designed to protect Gemstar against ultraviolet light degradation were assessed.
- Experiments designed to test if Gemstar® applications timed to coincide with a peak period of *H. armigera* larval activity during silking can increase the efficacy of *H. armigera* larvae, thereby reduce the level of cob damage.

3. Toxicity of Gemstar® on beneficial insects
   - Assessments of the efficacy of Gemstar® towards non-target pests were performed during above experiments by comparing the insect populations in the control treatments.
   - The control treatment has no insecticides applications. Therefore, comparing insect activity in control treatments with insecticide treatments gives a good indication insecticide toxicity.

Results

The following list main outcome from biological insecticide experiments: -

1. Performance experiments
   - Initial experiments between 1998 and 1999 produced results (Cob damage: Gemstar® 30%, synthetic insecticide 53%, and the control 38) showed Gemstar® was significantly better at reducing cob damage compared with synthetic insecticides, but was not significant compared to the control.
   - Experiments conducted between 2000 and 2001 focussed on improving spray applications factors (see below). Results from these experiments (Cob damage: Gemstar® 14%, synthetic insecticide 35%, and control 46%),showed Gemstar® was significantly better than both the synthetic insecticide and control.
2. Gemstar® spray applications improvements
   - Boom sprays modified with droppers applied 4 times more Gemstar® to silks than non modified boom sprays.
   - NPV is sensitive to ultraviolet rays, cause Gemstar® to be come inactive 24 hours after application. Petroleum oils designed to protect Gemstar® against ultraviolet light degradation did not protect the NPV prolong Gemstar®.
   - A few applications (4-5) of Gemstar®, timed to coincide with a *H. armigera* larval activity during silking, will provide significantly less damage cobs, compared with applying insecticides every 2nd day.
3. Toxicity of Gemstar® on beneficial insects
   - Results from all experiments show no significant difference in beneficial insects between the Gemstar® and control treatments.

Discussion

At the beginning of the HAL Project the biological insecticide Gemstar® was not registered, but a permit enabled its use by sweet corn growers. Results from initial experiments (during 1998-1999) and through industry usage showed it did not provide significant control of Heliothis larvae. As a result the sweet corn industry did not using it during silking corn, but instead relied on synthetic insecticides to control heliothis larvae.

Additional research conducted during 2000-2001 focussed on modifying the way Gemstar® was applied to the sweet corn crop. For example, coverage and timing of the insecticide are major factors in improving its efficacy against heliothis larvae. The outcome from these experiments resulted on its nation registration. The improved efficacy has lead to growers selecting it for control of heliothis larvae during silking.

Conclusions

As a result of research produced during the HAL Project, growers have the biological insecticide Gemstar® register nationally for the control of *Helicoverpa armigera* larvae in sweet corn crops.

Vegetable growers using of Gemstar® are able to: -

- apply an insecticide that has a narrow pest spectrum and is very safe to the environment making them it ideal for IPM strategies.
- provide opportunities to develop sustainable production practices by reducing the dependence on synthetic insecticides for pest management.
- limit opportunities for environmental contamination by developing non-chemical IPM strategies.
- contributed to consumer food safety by meeting the HACCAP 9000 standard, which is an international food safety standard. To achieve HACCAP 9000, growers need to reduce critical control points such as synthetic insecticide usage.
- assisted in opening new market opportunities and meeting market requirements through reduced chemical usage.

Recommendations

There are factors that limit the effective use of NPV when controlling heliothis in sweet corn. These factors require an understanding of the following fundamental issues associated with NPV use in sweet corn: -

1. The product Gemstar®, nuclear polyhedrosis virus (NPV), will **ONLY** control the target pest *Helicoverpa armigera* and *Helicoverpa punctigera*. It has no affect on any other insect.
2. NPV is a live organism. Therefore, store in the closed, original container out of direct sunlight. The product can be stored for short periods (less than seven days) at temperatures below 20°C. For long term storage keep refrigerated at or below 4°C.
3. NPV has a specific place in IPM systems. It is a biological insecticide and its efficacy is dependent on environmental conditions, spray application, population and feeding behaviour of the target pest. For example, research has shown that rapid inactivation of insect viruses by sunlight can occur within 12 hours after initial field application, and the efficacy of NPV may be reduced when large target pest populations are experienced during its field application. For these reasons, when environmental and crop microclimatic conditions are unfavourable, control of the target pest using NPV may be below expectations.
4. It is important to target very small larvae, as NPV acts slowly and can take up to 8 days to kill target pest larvae. Older larvae may complete their lifecycle before they are killed. Speed of kill and efficacy is dependent on climatic conditions. Warm conditions will favour the performance of NPV as the larvae will be feeding actively and moving around. Best performance of NPV can be experienced when daytime temperatures are between 25°C to 35°C.
5. NPV needs to be ingested to be effective, so coverage of the target area, where the larvae are feeding, is essential. As NPV is readily degraded in the presence of ultra violet light it should preferably be applied in the late afternoon or early evening. This will ensure that larvae feeding during the night will have a significant opportunity to ingest the product before it is degraded.
6. The pH of water used in the spray mix should be neutral (pH 7.0) for optimum performance. Partially fill the spray tank with clean water and add the required volume of

NPV to the water whilst agitating. Top up the tank with clean water to the required volume. NPV should be applied as soon after mixing as possible. The virus can be rendered inactive if the mixture is left to stand overnight.

7. Thorough coverage of the target area is essential. Apply in sufficient water, and ensure application equipment is well maintained and calibrated (nozzles, pressure, boom height, speed, swath width etc) to ensure thorough coverage of the target area.

    - Up to tasseling: NPV may be applied by ground rig or aerial spray equipment, however, for best results application by ground rig is recommended.
    - Silking: Apply NPV only by ground rig spray equipment, preferably through booms fitted with droppers. Application by aerial equipment is not recommended, as coverage of the lower silks is less effective and control may be reduced.

Biological Insecticides (cont.)

Summary of research conducted to evaluate *Bacillus thuringiensis* for the management of *Helicoverpa armigera* in sweet corn in East Gippsland, Victoria.

R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle, DNRE, Vic.

Introduction

This work evaluated the use of biological insecticides as an effective rotation and their use in a time slot prior to silking and cob development. Control of grubs during cob development is crucial and the use of biological pesticides may be better suited to earlier in the cropping cycle, to reduce pest pressure when complete control is not so critical. They would also have minimal impact on, and prolong the activity of beneficial insects.

Studies were undertaken to compare the effectiveness of *Bacillus thuringiensis* (Delfin WG®) and Nuclear polyhedrosis virus (Gemstar®) when used as a tasselling (pre-silking) spray to evaluate their effectiveness at controlling *Helicoverpa* at this stage and the impact on damage at harvest.

Materials and Methods

Three field trials were conducted in Lindenow during the 1999-2000 season to compare Gemstar® and Delfin WG® (2 treatments of each, a single spray and 2 applications 4 days apart). Both were sprayed on crops at 50% tassel and for the second treatment application was 4 days later control plots were unsprayed. Altogether there were five treatments in each trial. Treatments were replicated 4 times in a 25m row. Gemstar® was sprayed at 750 ml/ha and Delfin® was applied at 1kg/ha

During the first trial (established on 12th December 1999) the moth activity was unseasonably high but dropped to normal levels during silking. The second trial was established during a relatively low moth activity but the third trial had very high pest levels.

Results

Larvae mortality

Following the second spray, larvae were collected and mortality was assessed after incubation. Significant differences between treatments were evident at trial 1 with both Gemstar® treatments (one application and two successive applications) resulting in significantly higher mortality of larvae than the Bt treated (two successive applications) and untreated plots. At trial 2 larvae mortality showed a lot more variability between plots and there were no significant differences between treatments as a consequence. The untreated control was at the higher end of the range although conditions were hot and this may have affected survival of larvae. In Trial 3, mortality of larvae was lower than in the previous trials and also there were no significant differences between treatments. There was also a large amount of variability between plots (Figure1).

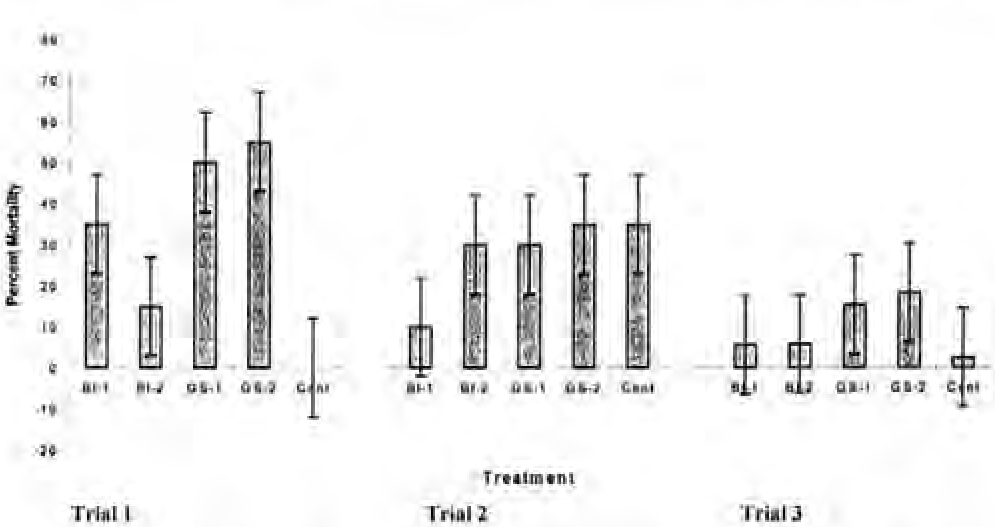

Figure1. Mortality of larvae following pre-silking sprays of Gemstar® or Bt, Trials 1-3

In all 3 trials, there were no significant differences among treatments either on number of per plant larvae or damaged cobs by larvae. However a higher variability was evident among treatments in larvae number and the damage.

Discussion

With the exception of the first trial, it was not possible to demonstrate any differences between treatments and whether or not a tasselling spray was beneficial in reducing larvae pressure on the crop and affected cob damage at harvest. However, growers who applied pre-silking sprays of Gemstar® (at tasselling) reported experiencing a satisfactory control of larvae in their crops.

Conclusion

We are unable to determine conclusively whether two applications are better than one, Gemstar® is better than Bt or whether or not tasselling sprays are beneficial. Anecdotal evidence from growers and observation would imply that tasselling sprays are useful, particularly in high pest pressure periods for reducing numbers of larvae at an early stage within a crop and also in adding an alternative insecticide to the spray rotation that is not harmful to beneficial insects.
For more details see the workshop notes in Proceedings of Workshop No. 3.

Technology Transfer

Findings of this study were discussed at grower meetings 11/2000 and reported in the following publications:

Dimsey, R., Peter R.., Siva S. and Rundle B., (2000) Best Management Options - Victoria, Sweet Corn Season 1999/2000. 94pp Proceedings of workshop No. 3, Bowen, QLD, June 2000.

Report: Milestone 6, Best Management Options, April 2000.

Recommendations

Further studies are needed to evaluate the effectiveness of NPV and Bt organisms in control of Helicoverpa at this growth stage.

Acknowledgments

The project team would like to thank the following for their assistance and participation in the project: Aventis, Dow Agrochemicals, E. E. Muir & Sons, Bon Accord, Growco, N. Cox, Whitbourne Farms.

Biological Insecticides (cont.)

Summary of research conducted to evaluate *Bacillus thuringiensis* for the management of *Helicoverpa armigera* in sweet corn in Southern Queensland.

John Duff, QDPI, Gatton Research Station

Introduction

Helicoverpa armigera (Heliothis) is by far the most serious insect pest found to attack sweet corn. This pest can be found laying its eggs on the leaves, tassels and silks, the latter being of most concern. Once the larva emerges from the egg it will feed on the new silks and tunnel down to the cob causing various amounts of tip damage and side damage, rendering cobs unsaleable for the fresh and export markets.

Traditional methods of control of this pest have been to use repeated applications of synthetic insecticides. This was generally successful up until the early 1990's, when resistance to carbamates was first evident, with synthetic pyrethroid resistance also being a problem by the mid 1990's (Deuter, 1997).

This opened the way for newer generation biological insecticides to come to the fore as alternatives for the control of Heliothis. Although *Bacillus thuringiensis* has been available for over 20 years, its increase in popularity has only been evident since the late 1980's in the vegetable industry. This was against diamondback moth (*Plutella xylostella*) which was found to be resistant to a wide range of traditional synthetic insecticides, and more recently against Heliothis in sweet corn, with promising results (Monsour, 1995 and 1996a; Scholz *et al.*, 1998).

As Bt currently has an NRA permit (and should be registered late 2001), this trial was designed with the purpose of generating additional efficacy data to have these products registered for use against Heliothis in sweet corn.

Materials and Methods

Trial Location and Design

This trial was conducted at QDPI, Gatton Research Station, west of Brisbane, in the Lockyer Valley.

The sweet corn was planted on the 23rd August on a one-acre block and divided into four bays or replications. A 3.5m strip of bare ground separated each replication. Each replication was divided into four treatments 15m long with a 5m buffer zone between each treatment. The trial area was set up as a randomised complete block design.

The treatments were as follows:

Bacillus thuringiensis subsp. *aizawai* (XenTari®) 1kg/ha
Bacillus thuringiensis subsp. *kurstaki* (DiPel Forté®) 1kg/ha
Methomyl 2L/ha
Unsprayed Control

Agral® wetting agent was applied with each insecticide and all treatments were applied using an over the top air assisted boom spray, putting on 400L water per hectare.

Monitoring

Monitoring of the whole block commenced four weeks after planting for a range of pest and beneficial insects and was carried out twice weekly. Initially, 10 locations with 4 plants per location were checked. Individual plots were marked out six weeks after planting. Monitoring of individual plots consisted of 5 locations with 4 plants per location.

Heliothis eggs were recorded as either white, brown or black (parasitised), while the larvae were recorded as either very small (VS<3mm), small (S 3-7mm), medium (M 7-15mm) or large (L>15mm). From tasselling through until the brown silk stage, monitoring continued twice a week. Beneficial insects were also monitored for, ladybirds, pirate bugs, lacewings and spiders.

Spray decisions

Three applications of Bt and methomyl were made to the crop during silking. Bad weather delayed the first treatment application and prevented additional applications of insecticides when Heliothis pest pressure was increasing. This was during peak silking and Figure 2 indicates when spray applications would have been necessary.

Final yield

Marketable cobs (those suitable for the fresh market and able to be sold as pre packs) were assessed by randomly collecting 30 cobs from the middle two rows of each plot (120 cobs per treatment). These cobs were then classified as those that were free from damage, damage to silks only, damage to the tips (which could then be trimmed and sold in pre-packs) or side damage, and whether larvae were present.

Results

Monitoring and spray decisions

During the time of the year that this trial was conducted, Heliothis pressure was expected to be high as in previous years. However, pressure during this season was very low and remained so up until silking (Figure 2.) Once Heliothis egg pressure started to increase it became difficult to apply sprays due to wet weather and strong winds. As seen in Figure 1 only three sprays were applied to the treatments with a 15 day gap between the first and second applications. The first spray application was also delayed by three days due to bad weather.

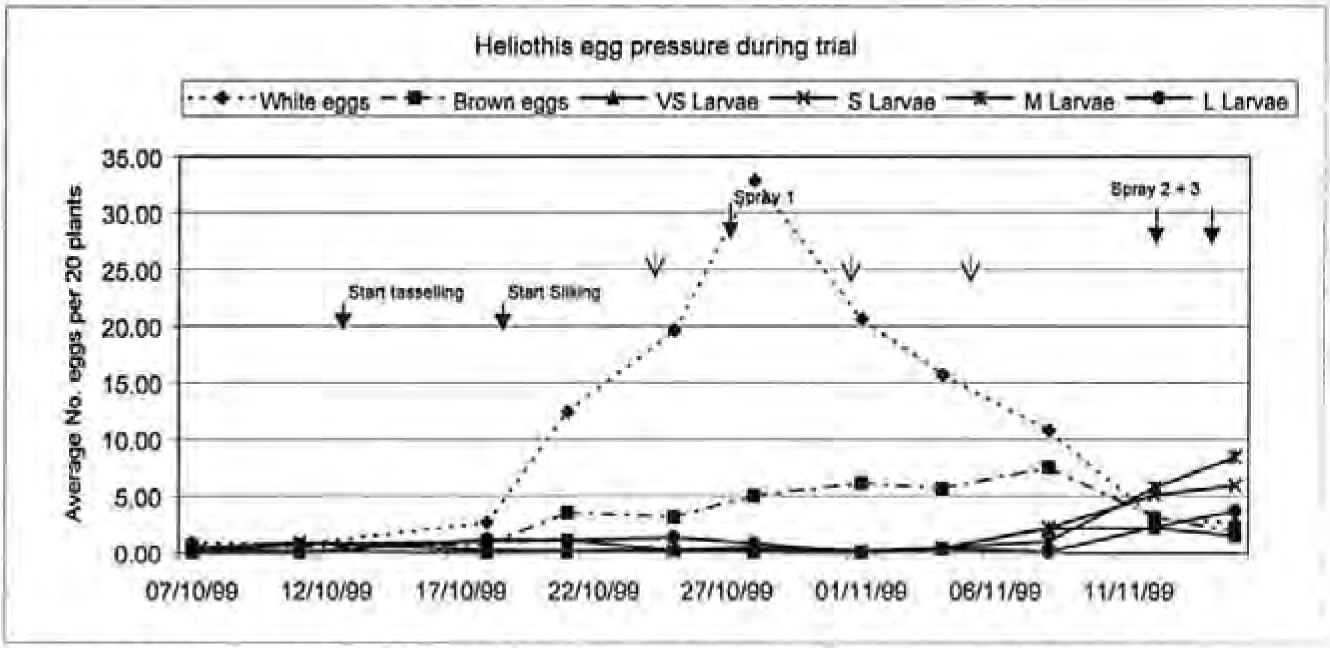

Figure 1. Monitoring data for Heliothis from pre-tasselling until harvest. The black arrows indicate when sprays were applied to the crop and the broken arrows indicate when sprays should have been applied.

Prior to harvest, there was very little difference between treatments with respect to eggs and larvae found in or on the cobs. Methomyl did have the greater number of very small larvae while the unsprayed control had the greater number of large larvae. There were no significant differences between treatments for the small and medium sized larvae or the number of Heliothis eggs found on the cobs. The Bt treatments were more effective at controlling the very small larvae, with Bta giving greater control. The use of methomyl significantly reduced the number of beneficial insects compared to the control and Bt treatments.

Final yield

The harvest data showed that Bta, Btk and the unsprayed control were significantly better than the methomyl treatment for producing clean cobs as seen in Figure 2. The total marketable cobs were greatest for the Bta treatment, and were significantly better than the control but not for the other spray treatments. There were no significant differences between Btk, methomyl and the unsprayed control when assessing the total marketable number of cobs. The methomyl treatment resulted in a greater percentage of tip damage although this was not significantly different from the Bta treatment. Btk and the control produced significantly fewer cobs with tip damage than the methomyl treatment.

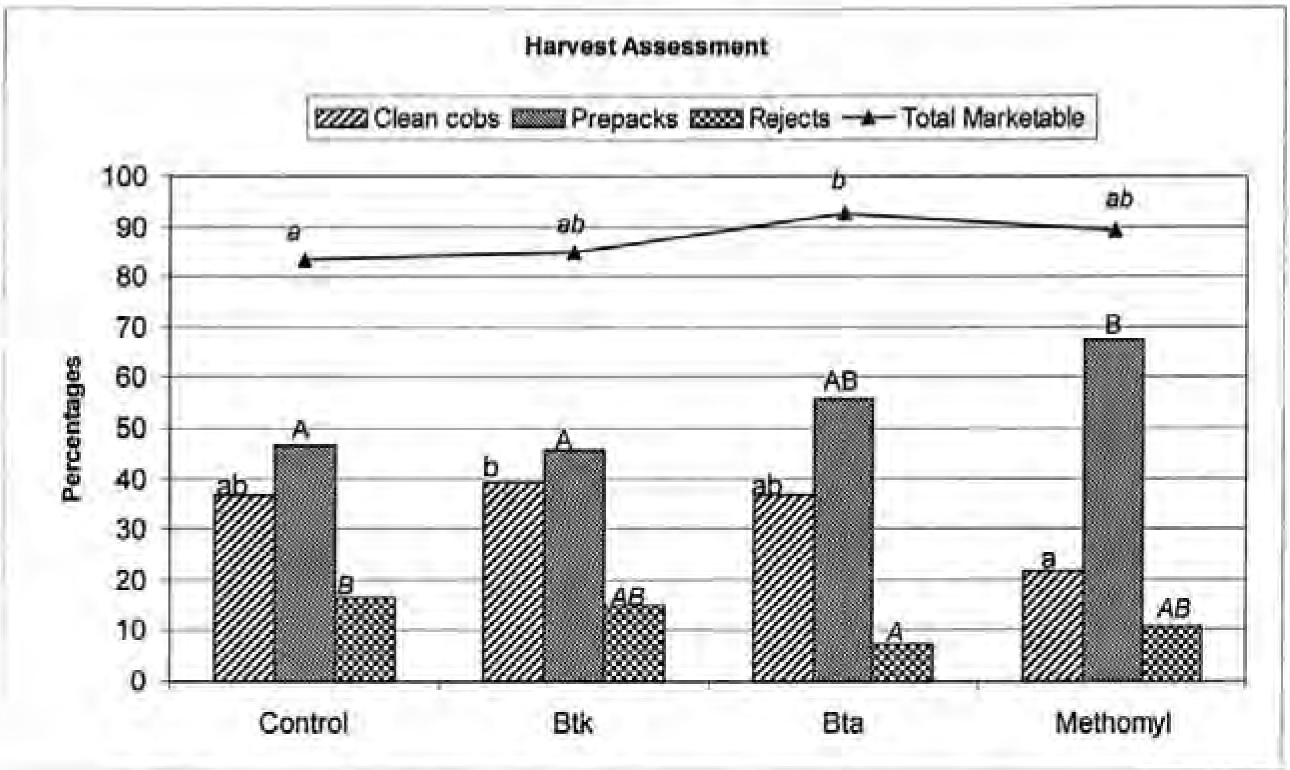

Figure 2. Harvest results for sweet corn var. Golden Sweet, 22 November 1999, GRS. The bars with the same letter are not significantly different from one another.

Discussion

Delayed spray applications as a result of bad weather, allowed eggs laid during early silking to hatch unchallenged. The emerging larvae were allowed to make there way into the throats of the cobs making it difficult to control them with conventional insecticides as well as the Bt insecticides. The broken arrows in Figure 2, indicates when spray applications should have been applied according to the monitoring figures at the time of silking. The three days delay in applying the first application and the resulting second application 15 days latter allowed larvae to become well established in the crop as medium and large larvae, making it very difficult to control them with the treatment insecticides. When interpreting the values shown in Figure 2 it could be said that the last 2 sprays were unnecessary as the number of eggs found on silks were reducing to almost negligible levels and the larval counts being only slightly greater than in previous monitoring. Certainly the pre-harvest counts in Tables 1a and 1b of larvae indicated that there was very little difference between spray treatments. However the predator count was worse in the methomyl treatment than in either of the Bt treatments or the unsprayed control treatment. The low incidence of very small larvae in the control could be attributed to the large number of beneficial insects found in the crop. These predators could have also enhanced the effectiveness of the Bt treatments. This effect should be further investigated in future work with this pest.

The harvest results also indicate that the use of Bt sprays in combination with beneficial insects resulted in improved yield, i.e. reduced tip damage and cleaner cobs. Better timing of sprays could possibly have resulted in much better results in favour of the Bt sprays and should be assessed again in the future research project to encourage growers to have more confidence in these products.

Overall, the Bt treatments were equal to or better than a standard treatment of methomyl for the control of Heliothis in sweet corn with the option of doing nothing being just as effective and in some cases better than a standard methomyl treatment. If the treatments were applied with respect to the monitoring data it is possible that these results could have been even better than those that were achieved using three ill timed applications.

This small plot trial has indicated that both Bta XenTari® and Btk DiPel Forté® can give adequate control of *H. armigera* in sweet corn at the 1kg rate, with timing a critical issue if Heliothis are to be prevented from damaging the cobs. Timing is an important factor with any pest management program as was seen in this trial.

The use of biologically based insecticides such as Bt, are ideal for incorporation into an integrated pest management system. These products are effective at controlling Heliothis, when applied at the appropriate time, preserving beneficial insects and are safe to the environment and the end user. Bt insecticides will therefore be valuable additions to those products already registered for use against Heliothis in sweet corn.

Recommendations
As these Bt products will soon be registered for use in sweet corn, promotion of their effectiveness should be encourage to inform growers of just how effective they can be as viable alternatives to the currently available products. Trials conducted by Monsour 1996a and 1996b and from this trial have shown the benefits of using Bt to control Heliothis in sweet corn. Like all products, timing is a critical factor and with the improved application technology developed as part of this national sweet corn project, growers should be able to get the product to where it is of most use, on the silks. A follow up trial should also be carried out in the new sweet corn project as part of a BMO with particular attention being paid to timing of the products

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Scholz, B.C.G., Monsour, C.J. and Zalucki, M.P. 1998. An evaluation of selective *Helicoverpa armigera* control options in sweet corn. *Australian Journal of Experimental Agriculture*. **38**:601-607.

Biological Insecticides (cont.)

Dr Sandra McDougall, NSW Agriculture, Yanco.

A series of replicated small plot trials were conducted in commercial sweet corn paddocks in the Riverina and Central Western NSW. In the Central West two larger plot unreplicated trials were also conducted. In all cases the treatments were compared against an industry standard (synthetic pyrethroid and carbamate) and an unsprayed control. The range of treatments investigated included the Heliothis nuclear polyhedrosis virus (Gemstar®), releases of the egg parasitoid Trichogramma (*T. brassicae* and *T. pretiosum*); the bacterial insecticides MVP II® and Xentari®(*Bacillus thuringiensis* [Bt]) and new generation chemistry: Success®(spinosad) and Avatar® (indoxacarb). In a couple of trials feeding stimulants milk powder, Pheast® and Envirofeast® and the sticker extender, NuFilm-17® were added to either the Bts or Gemstar to evaluate whether they improved efficacy. Heliothis damage was assessed at harvest. The number of cobs with tip and side damage were counted, the severity of the damage was assessed, the percentage of damage by weight, and the number of cobs with caterpillars present were counted.

In 1997 a trial comparing Heliothis nuclear polyhedrosis virus (Gemstar®), releases of the egg parasitoid Trichogramma (*T. brassicae*); the bacterial insecticide *Bacillus thuringiensis* (MVP); a chemical (esfenvalerate & methomyl) to an unsprayed control. In 1998 two rates of Gemstar (nuclear polyhedrosis virus) were compared to a single rate of Xentari (*Bacillus thuringiensis* aizawai strain), Success (Spinosad), a industry standard control and an unsprayed control. In 1999/2000 a small plot trial on methods of improving Gemstar® efficacy was conducted. Gemstar treatments at 250ml/ha, 500ml/ha were compared to Gemstar 500ml/ha with milk powder (1kg/ha), Pheast® (3kg/ha), and NuFilm-17® (600ml/ha), and unsprayed and industry control treatments.

In the Central West NSW larger unreplicated trials with Gemstar and Trichogramma were conducted.
In 1997 a single application of Gemstar (350ml/ha and 500ml/ha) were applied to plots, a release of *Trichogramma pretiosum* was made into a 1 ha plot within the 350ml/ha rate plot and the three plots were compared to a conventionally treated (methomyl and esfenvalerate mix) control plot.
In 1998 two replicated small plot trials were conducted. The first compared Gemstar, MVP II® (Bt), Avatar® (indoxacarb), Success® (spinosad) with an industry standard (methomyl and alphacypermethrin) and an unsprayed control. The second had similar treatments but only single applications for most treatments. It compared a single and a double application of Gemstar, to Avatar, Success, an industry and unsprayed controls. In 1999/2000 five separate trials were run in the Central West NSW. They were all variations upon combinations of Bt, Gemstar, Success, Trichogramma and the feeding stimulants, milk powder and Envirofeast®.

Results
Trichogramma brassicae releases in the Riverina in 1997 resulted in 66-75% egg parasitism in the Trichogramma plots but we also noted an increase in other treatment plots on subsequent monitoring which probably indicated movement out the release plots. Damage levels ranged from 3.1-6.6% by weight or 59-80% by number. The Gemstar treatment was the most effective treatment and the unsprayed the least effective.

In 1998 in the Riverina Success® had least and the unsprayed plots had most caterpillar damage compared to the other treatments. All the treatments except the industry standard control and Success had Armyworm in the cobs at harvest. Aphid numbers were highest in the industry standard control plots presumably because the chemical killed the aphid predators that were present in the other treatment plots.

In 1998 a replicated large-scale trial in the Riverina of aerially applied Gemstar® and an industry standard control was conducted in a commercial sweet corn planting in the Riverina. Due to unforseen problems with the weed, Johnson grass we were unable to properly evaluate the results.

The 1999/2000 Riverina Gemstar trial found Gemstar 500ml/ha alone gave the best results.

Prior to the *Trichogramma pretiosum* release in the Central West in 1997 43 viable Heliothis eggs were collected of which 32.6% were parasitised by *Telenomus* spp. At harvest 63.3%, 55.5% and 86.0% of cobs were damaged in the 350ml/ha Gemstar, the 500ml/ha Gemstar and the conventional plots respectively. In 1998 Success® was the most effective treatment. Gemstar, Avatar and the industry standard gave similar control and were better than MVP II or the unsprayed control. In the second trial the single applications were not particularly effective, with the double application of Gemstar having the best overall result. From the 1999/2000 trials an aerial application of Success and Gemstar out performed the industry control. In the smaller replicated trials the one site with low Heliothis pressure showed no differences between treatments but in the other higher pressure sites the Gemstar and Success treatments performed best. Feeding stimulants did not make a significant improvement in the performance of Gemstar.

Discussion

One of the rationales for using biologicals is to allow the natural enemies or beneficial insects to co-exist and provide additional control of *Helicoverpa armigera*, in light of its resistance to synthetic pyrethroids and carbamates. Egg parasitoids are the single most important natural enemy of Heliothis and a range of other more generalist predators can combine to be effective controls. In the Riverina we found the beneficial numbers decreased over the years of the study and that Trichogramma releases were hard to establish therefore the additional benefits of using biologicals was relatively small. Some of the reasons for poor establishment may be a response to extreme summer temperatures and low humidity, but also the density of Heliothis eggs. Although damage levels can be 100% of the cobs egg numbers were often very low per plant which does not provide for the building up or perhaps even maintenance of the egg parasitoids and other beneficial insects. In the Central West however, egg parasitoids seem to find more favourable conditions and enhanced the control gained from the use of biologicals.

Conclusion

Success performed well in all the trials it was included as did Avatar in the one trial it was included in. Gemstar did lower Heliothis damage both in the Riverina and the Central West, and performed better than the industry control but the percentage of cobs damaged by Heliothis was still generally above 90%. The proportion of the cob damaged tended to be less with Gemstar than the industry control. Feeding stimulants did not significantly improve the performance of Gemstar. Gemstar is not effective against other caterpillar species. Egg parasitism was consistently higher in the Central West than in the Riverina with the releases of *Trichogramma pretiosum* resulting in some additional benefits to the use of biological sprays.

4. Naturally Occurring Beneficials

Further details of work programs and outcomes associated with **Naturally Occurring Beneficials** have been reported in :-

- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 10-19 &26-28.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 94 –117 & 128-129.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 38-71.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 67-92.

Naturally Occurring Beneficials (cont).

R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle, DNRE, Vic

Introduction

There is no background information on local species of egg parasitoids or on parasitism level in East Gippsland. The success of *T. pretiosum* in the Lockyer Valley, Queensland has given encouragement to evaluate their use and the survival under Victorian conditions. Evaluation of the potential of *T. pretiosum* commenced 1998/99 and their ability to carry over through the winter evaluated by assessing their presence in subsequent seasons.

Materials and methods

Following field releases of *T.pretiosum*, the establishment and presence in subsequent seasons of *T.pretiosum* in the field was evaluated by collecting *Helicoverpa* eggs from various sweet corn crops. Later in the season when field egg numbers were low, *Helicoverpa* egg-cards (prepared from laboratory laid eggs) were used to assess the level of parasitism and predation. The egg cards (average of 20 eggs per cards) were stapled to leaves at silk height. Two days later the egg cards were collected and the remaining eggs (damage and undamaged) on the cards were recorded. Hatched larvae removed daily and after 7 days parasitised eggs were recorded (Table 1).

Results

- **Early season releases** (21 Nov 98): before the release, there were only a few eggs found in the field and non of the eggs produced parasites. A week after the field release of *T. pretiosum* 42 % of the cards were parasitised by *T. pretiosum*.
- **Mid season releases** (25 Feb - 19 Mar, 99): released in BMO trial. Parasitism was very low in the Dominex® treated plots. There was also some reduction in the Success treated plots. However in the control (untreated) and Gemstar plots parasitism was 80% of the eggs on the egg cards.
- **Late season releases** (25 Mar - 9 Apr 99): Following a late season release *Trichogramma* field levels were monitored early in the following season to assess over wintering. Egg parasitism was minimal suggesting little activity of *T. pretiosum*.

Egg parasitism level monitored on field-laid eggs are shown in Table 1. Egg pressure was quite low this year, and egg parasitism was monitored only in few fields. *Telenomus* sp. accounted for up to 50 % of parasitism prior to *Trichogramma* release. The parasitism was very low or nil in intensively sprayed areas.

Table 1. Egg parasitism of field-laid eggs

Field	Date collected	No. of eggs collected	Grubs hatched %	Unhatched eggs %	Parasitised eggs %	Parasitoid spp.		Comments
						T. pretiosum	*Telenomus*	
Exp. plots	18-Feb	13	15.3	23.1	61.4	7.6	53.8	Before T.p release
Exp. plots	3-Mar	16	31.2	6.2	62.5	62.5	0	5 days release
Grower crop (Woodglen)	11-Mar	32	21.8	34.4	43.8	0	43.8	unsprayed crop
Grower crop (Lindenow)	8-Mar	52	67.3	23.1	9.6	5.7	3.9	before spray
	26-Mar	22	81.8	18.2	0	0	0	after 3 sprays

Discussion

The data collected in the 1998/99 & 1999/00 seasons showed that *T. pretiosum* exist poorly in south Victorian conditions but when they are introduced they can successfully parasitise *Helicoverpa* eggs with potentially good levels of parasitism when soft or biological chemicals are used. However it was shown that later in the season parasitism level falls considerably. Observations made in the following seasons without any further releases of *T. pretiosum* have indicated minimal levels of field occurrence.

Conclusions

Results of this study showed *T.pretiosum* is a potential additional control agent for *Helicoverpa* pests in sweet corn. However over wintering capacity of *T.pretiosum* is not clear yet under Victorian conditions. The low levels of parasitoids identified at the beginning of the season (after releasing in the previous season) raise the question of whether or not they are over wintering and their effectiveness in Southern Victoria under low pest pressure. Field releases of *T.pretiosum* may be a useful component of an integrated pest control program but their effectiveness will depend on pest pressure and ultimately cost.

Technology Transfer

Grower Information Night – 11/2000.

Recommendations

Further studies are needed to evaluate the over wintering ability of *T.pretiosum* under E. Gippsland climatic conditions and their potential use in southern sweet corn production systems.

Naturally Occurring Beneficials (cont).

Dr Sandra McDougall, NSW Agriculture, Yanco.

In 1997/98 season all crop monitoring involved identifying all insects observed. In subsequent seasons all insects were monitored periodically. In 1997/98 and 1999/2000 unsprayed plantings of sweet corn were monitored regularly for insect pressure. In 2000-1 season 4 plantings of field peas were established as a 'nursery crop' adjacent to sweet corn plantings and *Trichogramma pretiosum* released into the field. It was anticipated that the Trichogramma would establish in the nursery crop and then subsequently move into the latter planted sweet corn. Parasitism was monitored from field collected and sentinel eggs. Latter in the season Trichogramma were released into pre-tasselling sweet corn crop and egg parasitism monitored in it and a neighbouring non-release crop.

Trichogramma pretiosum was released in small quantities in the Western Sydney area in November 1998 and at a site in Bathurst and a site in Cowra in Feb 1999. In Feb 2000, Heliothis eggs were sampled at these sites before releasing any more T *pretiosum* to determine if the parasitoid was able to overwinter. Releases of T *pretiosum* were then made at three sites at Bathurst and two sites at Cowra. Eggs were collected after the release to observe the natural increase in parasitism as well as the impact of the mass release. Egg samples were also taken at three sites in the Dubbo district, an area not previously sampled. T *pretiosum* was then released at the three Dubbo sites.

Results

At least 19 species of 'Beneficial' arthropods and 20 species of 'Pest' arthropods were regularly observed in sweet corn in the Riverina. Species and populations varied considerably from year to year. In 1999/2000 the beneficial numbers were close to zero at the commercial field site which may be related to aerial applications of Azodrin® (monocrotophos) in the area. In the organic demonstration site on the Yanco Agricultural Institute the sweet corn plantings had higher populations of beneficials than the unsprayed plots in the commercial sites in 1998/99 and 1999/2000 field seasons but Heliothis pressure was sufficiently high to warrant control and over 80% of the cobs were infested.

In 2000-1 season the Heliothis egg densities were low in the field peas and the Trichogramma failed to establish. In December a release of *T. pretiosum* into a maize crop with high levels of beneficial activity and some Heliothis eggs but a sudden period of 40+ temperatures and no subsequent Heliothis egg lays prevented the Trichogramma for establishing. Releases of Trichogramma were made in mid-January into a sweet corn planting, however the results seemed to be confounded by a general increase in egg parasitism by Trichogramma in all nearby sweet corn crops. The increase was either a very rapid dispersal from the release site or *T. pretiosum* had established previously but the only known releases were the seemingly failed releases in October and December 2000 approximately 15km away.

In Central Western NSW natural levels of egg parasitism, particularly from *Telenomus spp.* were observed in sweet corn. *Telenomus spp.* were observed to parasitise 32% (1997, site 1), 89% (1998, site 1) and 49% (1998, site 2) of eggs prior to releases of *Trichogramma pretiosum*.

Discussion

Results from the releases did not clarify what situations encourage and maintain egg parasitoids from season to season. The findings from the Central West and Sydney did show that egg parasitoids were active at moderate to high levels at all the sites sampled. Natural enemies are clearly having an overall greater impact on heliothis than the insecticide. One or two sprays with broad spectrum insecticides is not enough to reduce larvae numbers over the necessary period while the natural enemies are significantly reduced. Although other natural enemies are resent, with between 40% and 95% of eggs parasitised this suggests that egg parasitoids are the main contributing natural enemy.

The data collected in the Central West and Sydney also showed that the number of parasitised eggs per hectare can increase many times in a week. This means that by tasseling a high proportion of the eggs present are likely to be parasitised but there may also be high numbers of grubs present that have hatched from eggs laid two weeks previous before parasitism had reached high levels. Commercial use of NPV is likely to become more common in processing crops and this will provide opportunities to further understand these interactions and to refine practices on a commercial scale.

In the Riverina the end of 2001 season build up of egg parasitism whether from a natural or released population was highly encouraging. However the dramatic reduction of all beneficials observed after a period of extreme temperatures suggests it may be difficult to maintain high levels of beneficial activity throughout a typical season in the Riverina. Perhaps counter intuitively the low to moderate pressure years for Heliothis are also likely to be difficult for maintenance of beneficial numbers due to low densities of Heliothis eggs.

5. Pesticide Application

Further details of work programs and outcomes associated with **Pesticide Application** have been reported in :-

- Milestone 4 – "Commonly used pesticide application techniques have been tested for efficiency in targeting of insecticides to silks of sweet corn. Improved application techniques have been identified and promoted at farm walks and fieldays" (1999).
- A Report – "Design Details of Spray Droppers" (1999).
- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 37-39.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 12 -34.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 1-28.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 49-66.

Pesticide Application (cont.)

Glenn Geitz and Robert Battaglia, DPI, Gatton Research Station.

Commonly used pesticide application techniques have been tested for efficiency in targeting of pesticides to sweet corn. Application equipment and/or techniques have been identified and promoted. These techniques and equipment will enable improved targeting of pesticides in sweet corn.

Introduction
Insect pests and diseases can cause major crop losses and create unacceptable contamination for the semi-processed sweet corn and the export markets.
All major sweet corn production regions in Australia have some requirement to apply insecticides to manage *Helicoverpa armigera* (Heliothis) and other insect pests in fresh market or processed sweet corn production. Heliothis larvae have the potential to cause damage at all stages of sweet corn growth however the cupping stage is critical, as once larvae enter the cob of the sweet corn they can not be controlled. Best management options are being evaluated in a number of regions and compared with conventional practices to help reduce Heliothis damage. Best management options consider a range of strategies that can be employed in combination such as improved targeting of insecticides, improved timing of application through monitoring and using more selective insecticides that preserve beneficial insects. This report presents some of the work undertaken to test commonly used application techniques for sweet corn production in Australia.

Aircraft and a range of ground based spraying equipment are used throughout most production areas in Australia. Some of the equipment evaluated to date include aircraft, ground sprayers with over the top booms and droppers, ground based air assisted sprayers and air-shear ground based sprayers with side delivery heads. Equipment performance was assessed using a fluorescent tracer. Quantitative data was collected by extracting the fluorescent tracer from various parts of the sweet corn canopy that is leaves, tassels and silks. Spray recoveries were expressed either as microlitres (μL) of spray volume or nanograms (ng) of dye recovered per unit target area.

Even though equipment plays a significant role in the effectiveness of coverage, particularly on the silks, the interaction between the plant canopy and application equipment is also important. Unfortunately if the silks are critical targets, only small proportions of spray released from over the top will actually find it way to the silk (approximately 0.5%). Leaves filter out a large proportion of spray applied from overhead. Equipment that directs spray closer to the silks has a much better chance of getting greater and more even deposits.

There is tremendous scope for improvement in application techniques with both aerial and ground based spray equipment. Although aircraft are heavily scrutinised they will continue to be an important tool for sweet corn growers. The volumes applied by aircraft (40 to 60 L/ha) are much higher than application volumes in broad acre cropping systems such as cotton. In some areas the swath width flown by aircraft are up to 30% less than what they would be in other crops.

Many sweet corn growers and contract spray operators use high clearance sprayers fitted with droppers. A comprehensive trial was conducted using droppers set up to specifically target the silks and this was compared with a conventional boom spraying over the top. The sprayer equipped with droppers gave up to 4 times the spray recovery on the silks. Droppers have problems if the crop is lodging or rows are not particularly straight and leaves brush past nozzles preventing spray droplets from reaching the silks. Of those operators using droppers there is a large variance in the water volumes applied per hectare. Contractors generally tend to apply much lower volumes (200 to 500L/ha) than growers using their own spray equipment (200 to 1300 L/ha). Further work needs is required to determine if this variation in water volumes is important in pest management and to determine optimum nozzle configuration for droppers.

Air-assisted sprayers are used for spraying sweet corn as they have considerable benefits including spray drift management and spray penetration. Testing has been conducted with air-assisted sprayers using silks as targets to determine if there were significant differences in the spray deposit for the different settings (air velocity and angle) that can be used on this equipment.

Background to spray application equipment

Aircraft

Aircraft are extensively used in many sweet corn production areas in Eastern Australia. There is considerable debate as to the effectiveness of aircraft compared with ground based sprayers. The discussion should revolve around "over the top spraying" (ground and aircraft) versus "directed spraying" (boom + droppers). Table I lists several important factors that should be considered when comparing various equipment types. Using this comparison, aircraft application scores well because it receives the greatest number of ticks in most categories. When interpreting Table I, a grower or operator who ranks achieving good spray penetration as very important, would be seeking equipment capable of directing spray onto the target zone to improve pest control.

Table I. Advantages of different types of equipment.

	Standard Boom	Air-assisted Boom	Boom + Droppers	Aircraft
Penetration		✓✓✓	✓✓✓✓	
Timing (work rate)				✓✓✓✓
All weather access				✓✓✓✓
Crop Lodging	✓✓✓✓	✓✓✓✓		✓✓✓✓
Crop Height	✓	✓		✓✓✓✓
Labour Input				✓✓✓

The application volumes used by aircraft when spraying sweet corn may range from 40 to 60L/ha. These volumes are very high compared to conventional volumes applied by aircraft when low volume spraying (20 to 30 L/ha) or ultra low volume (ULV) spraying, (2 to 5 L/ha) in cropping systems such as cotton.

The types of nozzles used to deliver this volume are either CP nozzles or the Micronair AU5000. The CP nozzle is a hydraulic nozzle that gives the operator a great deal of flexibility. This nozzle has multiple orifice sizes (that can be used to alter flow rate) and a selection of three angles on a deflector plate (that are used to alter droplet size).

The Micronair AU5000 falls into the category of controlled droplet application (CDA) equipment. It consists of a cage that can be made to spin at a range of speeds by altering the pitch on three blades. Faster rotational speeds produce smaller droplets and slower speeds larger droplets.

There have been many recent advances in the technology associated with precision application of pesticides with aircraft. Differential global position systems (DGPS) have enabled aircraft to apply pesticides to fields with a pre-selected swath with an accuracy of less than 1m. With DGPS technology aerial operators can also store flight paths allowing them to produce print outs of a spray job showing every swath flown.

Ground Based Sprayers

The sprayers used to apply pesticides to sweet corn by ground rigs are:-

i) over the top booms with hydraulic nozzles or air-shear outlets,
ii) over the top booms with hydraulic nozzles and air-assistance,
iii) over the top booms with hydraulic nozzles plus droppers or
iv) over the top booms with CDA nozzles and air assistance.
v) spray directed from the side across multiple rows using an air-shear cannon.

The three main principles used for droplet formation on these booms are hydraulic pressure, air-shear, and spinning disc/cages (CDA). Hydraulic pressure is used to produce droplets from nozzles such as flat fans and hollow cones. Sprayers using the air-shear principle produce droplets by using high velocity air (> 200 km/hr) to shatter the spray liquid into droplets. Sprayers using CDA (spinning disc) principle used the kinetic energy velocity of the spinning disc to produce droplets of a narrow droplet spectrum.

The Basics of Application

Know your product

Insecticides used to control insect pests in sweet corn have different modes of action. A sound knowledge of the mode of action for a particular product may help in understanding the application requirements. Contact insecticides kill insects by direct contact at the time of application or by contact with the insect, after application, with the spray residue layer on the plant surface. Other products that have a stomach poison action need to be eaten by the larvae and the pest must consume a lethal dose of the pesticide for it to work and the dosage required relates to the size of the larvae. Larger larvae require higher doses than smaller larvae. After application, pesticides will persist for varying periods of time on the plant before breaking down.

Another consideration is the impact of insecticides on beneficial insects. Products that have a broad action can decimate a range of beneficial insects. The contribution that beneficial insects play in controlling Heliothis larvae should not be underestimated. Data is being collected in various growing regions on the significance of beneficial insects in controlling Heliothis larvae and other insect pests in sweet corn.

What is Your Target?

The target can vary depending on the growth stage of the plant and the pest attacking the plant. This can change from leaves, to the tassel, to the silk and even the actual pest. Ultimately the aim of growing fresh market sweet corn is to produce cobs with minimal larval or pest damage and cobs free from live larvae. Once larvae entrench themselves in the cob they are impossible to control. Therefore it is important to control larvae early when they are exposed on the leaves or silks. Other growth stages such as seedling emergence, transplanting and the vegetative growth stage may be equally important in certain production regions.

Spray deposit uniformity will influence the ability of insecticides and fungicides to effectively control pests and diseases. There are several issues which influence spray uniformity:

1. The influence of application equipment on spray distribution.
2. The influence of crop canopy on spray distribution.
3. The influence of environmental factors on spray distribution.
4. The influence of silk position on spray distribution.

If the application equipment used to spray the crop is not delivering a uniform dose across the paddock then you are probably wasting your money by overdosing some sections and under-dosing others. Blocked nozzles, worn nozzles or even subtle changes in travel speed are factors that will contribute to variable application across the paddock.

The crop canopy has a large influence on the spray penetration and spray distribution on the plant. The distribution on the plant is very difficult to manipulate when spraying over the top with a boom. When spraying from over the top, the deposit is highest in the top part of the canopy and reduces rapidly as you move down the canopy. Unfortunately the cob is a long way down in the canopy and a large proportion of the spray volume will be filtered out by leaves before getting anywhere near the cob.

Some sweet corn varieties have large flag leaves surrounding the tops of cobs, others produce more tillers. There is also significant variation in canopy height amongst sweet corn varieties. All these factors will have an impact on the spray efficiency especially when there is additional foliage sheltering the silk or a greater distance for droplets to travel before they reach the silk.

Know Your Equipment

The most expensive sprayer will perform poorly if used inappropriately. Regular calibration of equipment is important, (measuring individual nozzle outputs, replacing worn nozzles and calculating the sprayer output), so the correct quantity of pesticide can be added to the tank. A range of nozzle types are available and each have specific operating requirements such as pressure, spacing and height to perform optimally. Controlled droplet application (CDA) equipment and sprayers using the air-shear principle for generating droplets have specific operating parameters to work efficiently.

Materials and Methods

Techniques for Assessing the Performance of Spray Equipment

There are numerous tools available for checking the performance and setup of spray application equipment used in sweet corn. Some of these techniques are used by researchers can also be used by growers for assessing the efficiency of application equipment in sweet corn.

i) Fluorescent dyes for visual observation
Fluorescent dyes that show up under black lights are ideal for visually inspecting the spray deposit over the entire sweet corn canopy. A pink or red coloured dye is best for observing the droplet deposits on sweet corn. Yellow coloured dyes do not show up as well on sweet corn due to the amount of yellow pigment in the leaves.
The spray deposit is best viewed on the crop in the field and at night. This requires a 'black' light and generator or power supply nearby. Viewing deposits in the paddock makes it possible to observe the interaction between adjacent plants on the spray deposit. If plants are removed and taken back to a dark room an appreciation of the influence of neighbouring plants is difficult and may lead to misleading evaluation of the equipment's performance.

ii) Water Sensitive paper
Although water sensitive paper (WSP) is useful, it has many limitations and the interpretation of spray deposit results can be misleading. WSP is produced on small cards of varying sizes depending on the situation where they are to be used. WSP has a yellow surface and when water based droplets hit the surface the droplet leaves a blue stain. Although WSP is relatively cheap and can be placed almost anywhere in the sweet corn canopy, they should be cut to size to match the target.

Some keys points to remember when using water sensitive paper:

- The card surface is sensitive to moisture and high humidity. Care must be taken when handling cards (wear gloves) and the cards must be stored in sealed plastic bags if you wish to keep them for extended periods.
- Spray droplets impacting the surface of the card leave a stain that is larger than the actual droplet size. This is called the spread factor. A spread factor of 2 means that the stains size is twice the true droplet size. For water sensitive paper the spread factor varies and depends on droplet size. Water sensitive paper should not be used to determine droplet size.
- Droplets smaller than 50μm will evaporate before leaving a stain on water sensitive paper. The card is therefore biased towards collecting larger droplets and will not give a true indication of the fine end of the droplet spectrum.
- To give a true indication of spray deposit and penetration, cards need to be the same size and orientation as the target.

iii) Quantitative recovery of fluorescent tracer
Fluorescent tracers can be used to provide a relatively cost and time effective method for obtaining quantitative spray deposits. They are generally used at very low rates (30 to 50g/ha). This was the main technique used to assess spray deposits on various parts of the corn canopy, including silks, tassels and other artificial targets placed above, in or at ground level. When a fluorescent tracer is applied to a crop, the target of specific interest can be collected and washed using a solvent that extracts the tracer. The quantity of tracer present on the target can then be quantified using a fluorometer. The process is similar to pesticide residue testing however in this case the residue is the tracer. The technique has inherent disadvantages, i.e. the tracers used are sensitive to sunlight and will break down over time. This makes it is important to collect

samples quickly usually within 1 hr of spraying. The spray deposit can then be expressed as the volume or quantity of tracer recovered per unit target size (cm^2 or weight).

iv) Relating Spray Deposit to Control

A useful technique for relating spray deposit to insect mortality is the bio-assay. A technique was developed in this project where silks collected from a sprayed field were used to assess the level of mortality in Heliothis larvae. Even though a fluorescent tracer can be used to determine the quantity of spray deposit high levels of tracer deposit do not guarantee 100% kill. When washing tracer residues from a silk or leaf surface the total tracer recovered can be established however this does not give an indication of the distribution and uniformity of the spray deposit on the target.

Evaluation of Spray Application Methods in sweet corn

The purpose of these trials was to assess the efficiency of different application methods on achieving coverage/ deposit on sweet corn silks. Sweet corn is inheritably difficult to spray, due to the structure, shape and also their growth habits of the plant. A lack of insect and disease control is a problem with sweet corn and this can be a result of spray failure due to insufficient coverage and a lack of penetration into the sweet corn canopy.

Experimental design:

A uniformity trial layout was used consisting of a minium of 30 plots but up to 100 plots. Each plot was 10m long x 2 rows wide. 3 to 10 plots were sampled along the direction the sprayers travelled and 10 samples taken across the sprayed area. For each treatment 30 to 100 samples were taken, consisting of whole silks.

Evaluation of spray coverage.

The technique used to assess Equipment performance and spray deposits on various parts of the corn canopy, was the quantitative tracer technique. The Fluorescent tracer used was Uvitex OB at 30 to 50g/ha. The fluorescent tracer was applied to the crop, silks were collected and washed using a solvent to extracts the tracer. The quantity of tracer present on the target can then be quantified using a fluorometer. The process is similar to pesticide residue testing however in this case the residue is the tracer. Spray recoveries were expressed either as microlitres (µL) of spray volume or nanograms (ng) of dye recovered per unit target area.

Treatments:

Throughout out the project a field trials were conducted to assess the efficiency of different spray application methods. These methods included the assessment of aircraft at a range of different settings, ground rigs using different operating parameters including air assistance, droppers, conventional booms and different speeds.

Results:

Where is the spray distributed in the crop?

Often the expectation is that most of an applied spray hits the intended targets. Unfortunately if the targets are the silks, then leaves above the silks filter out most of the spray applied. Only a small proportion finds it way to the silks. Table II shows a comparison of the deposit levels on various parts of a sweet corn canopy relative to the deposit on the silks. This data was collected from a sweet corn trial conducted using an aircraft delivering 60 L/ha. These values may vary for different application systems. These data show there is large variation in the deposit level between each of the surfaces, including the silks. The leaves above the cob collect a large proportion of the spray, the deposit on these leaves is equivalent to that on 117 silks. The deposit recovered from 1 square metre of soil is equivalent to the amount recovered from one silk. If the deposit were recovered from all the silks in one hectare of sweet corn, it would be less than 0.5% of the total spray applied to the crop.

Table II. Silk deposit compared to canopy and ground deposits (Aircraft 60 L/ha)

	Silks	**Leaves above cob**	**Tassel**	**Soil**
Units	Individual silk	cm^2	Tassel	cm^2
Average deposit*	64.6	1.02	346	0.06
Range	7 – 177	0.07 – 5.8	64 – 859	0.01 – 0.26
Deposit relative to silk		Deposit leaves above cob = 117 silks	Deposit on 1 tassel = 5 silks	Deposit on $1m^2$ = 1 silk

* In nanograms of dye recovered per unit of target for every gram of dye applied per hectare.

Droppers direct more spray to the silks

Emerging silks are an important target site for insecticide coverage. Equipment that directs spray to this region more precisely will give higher levels of spray deposits to this site. Several trials have been conducted using spray booms fitted with droppers. Two trials were conducted comparing the effectiveness of similar spray volumes with over the top spraying and directed spraying with droppers. One trial compared the amount of spray collected on silks using a boom fitted with droppers containing 4 nozzles directed at each plant in the cob region applying 564 L/ha and another sprayer applying a similar volume (600L/ha) but from above only. A Hardie linkage sprayer was modified with long droppers and the standard sprayer was a Hardie Twin (used without air). The spray volume collected from silks for each treatment is presented in Figures 1 and 2.

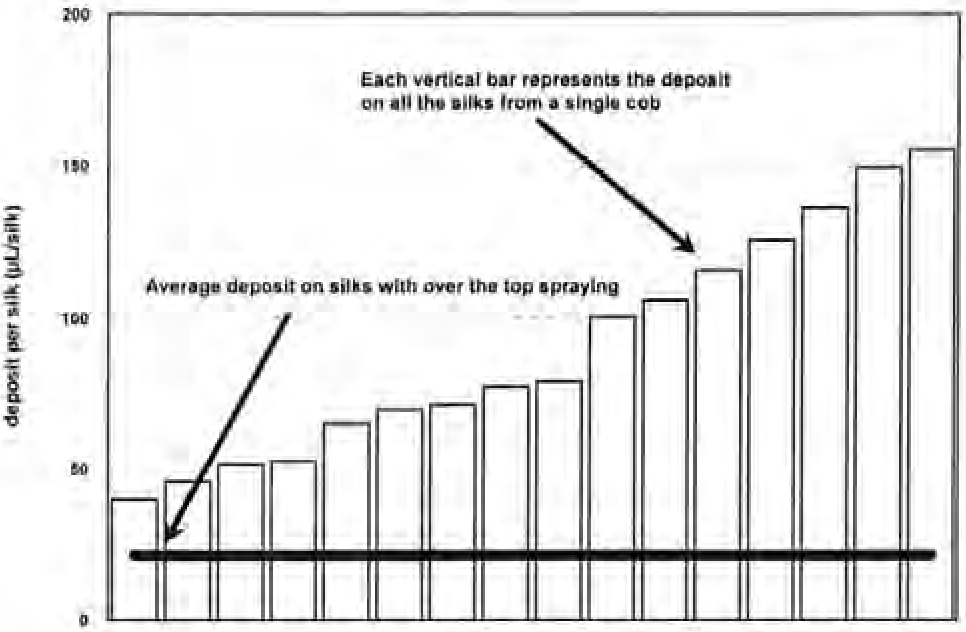


Figure 1. Range of deposit volumes collected from silks with a sprayer delivering 564 L/ha and equipped with droppers directing spray on to the cob regions (4 nozzles per plant). The heavy line shows the average deposit for over the top spraying.

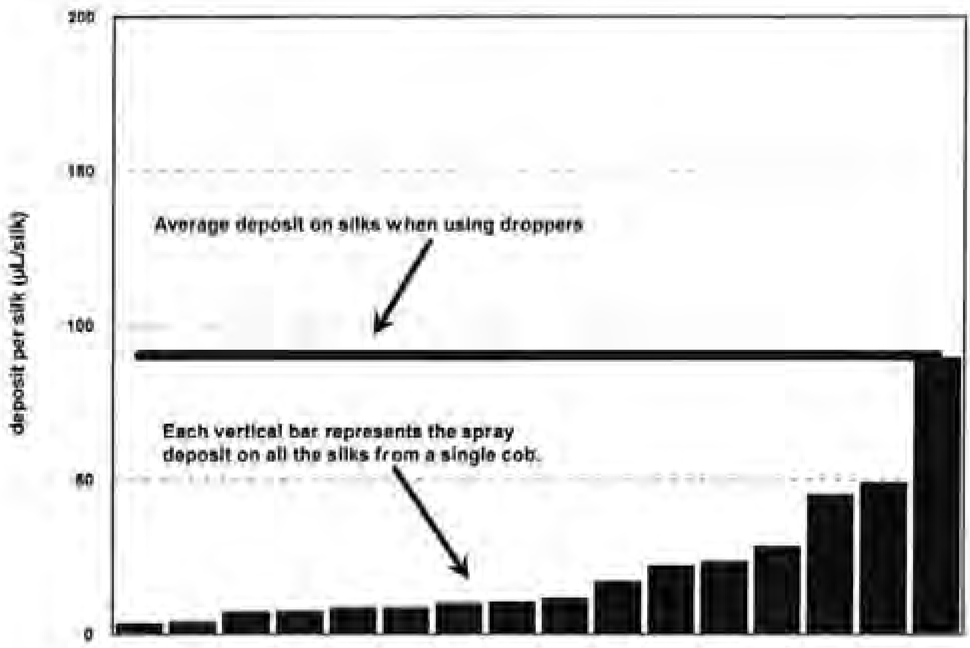


Figure 2. Range of deposit volumes collected from silks with a conventional boom delivering 600 L/ha over the top of the crop. The heavy line shows the average deposit for sprayer fitted with droppers.

There was a four-fold difference in the average deposit on silks between the two treatments. The average spray deposit on silks using droppers was 90.2 µL/cob and 21.4 µL/cob without droppers. Not only was the average deposit level higher with droppers but it was also more uniform. The coefficient of variation (CV) is a relative measure of variation between treatments. Lower CV values indicate greater uniformity. In this trial the CV for droppers was 51.4% and for over the top spraying the CV was 92.7%. Although droppers have the advantage of directing more of the spray to the desired target (cobs and silks), they cannot be used in all circumstances. Lodged crops are the greatest obstacle to their use.

Improving application when using Aircraft

The main areas where the performance of aircraft can be improved are (i) improving the uniformity of a single deposit pattern (ii) flying an appropriate swath width (iii) maintaining a consistent swath across the field and (iv) selecting nozzles that produce an appropriate droplet size range. Aircraft set up to apply insecticides to broad acre crops are not necessarily optimised for spraying sweet corn. Aerial operators should have their aircraft calibrated (pattern tested) so that the swath width they select for applying insecticides to sweet corn produces uniform deposits across a field.

An example of the ground deposit pattern from a single pass of an aircraft is shown in Figure 3. This deposit pattern was determined using a fluorescent tracer recovered from filter paper sections, (26x72mm) placed on a horizontal flat surface 20-40cm above the ground. Thirty-six collectors were positioned 2m apart and the aircraft flew once across this array at right angles.

From Figure 3, it can be seen that the spray deposit occurred in the pattern from 12m to 52m (over an approximate distance of 40m). The ideal swath width is much less than this distance as the pattern tapers off at both ends. The appropriate swath for this aircraft can be determined by taking the single pattern and theoretically overlapping the deposit data using a computer. A range of swath distances are selected, and the swath width that gives a low coefficient of variation (approximately 30%) is regarded as the most appropriate to use to produce uniform coverage. For this aircraft set up and this deposit pattern, the ideal swath width is 12m. The cumulative deposit that would be achieved across a field when flying 12m and 14m are shown in Figures 4 and 5 by the solid line. The dashed lines show the individual deposit patterns.

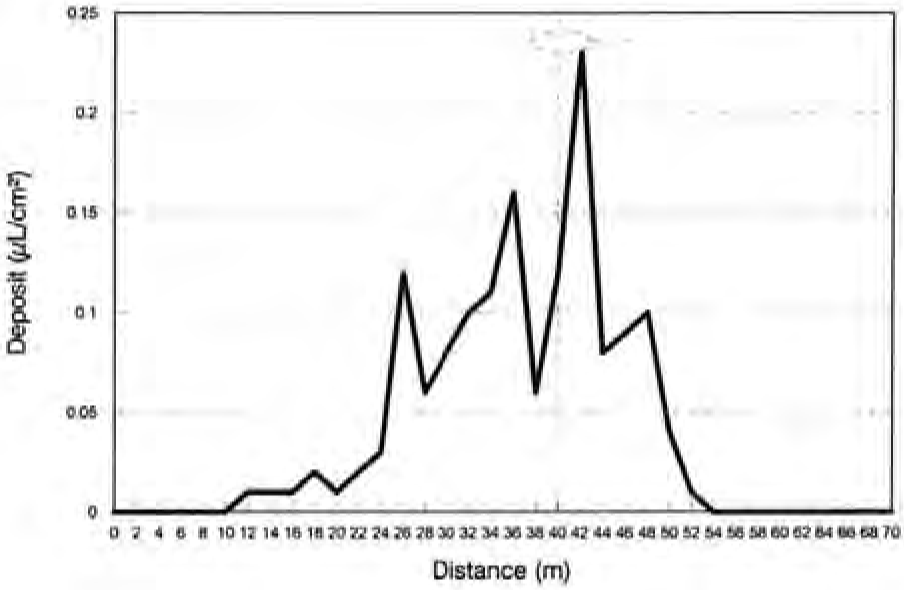


Figure 3. Deposit pattern of flat plates from a single pass of an aircraft (Cessna Ag Truck). The vertical line show the aircraft flight pass.

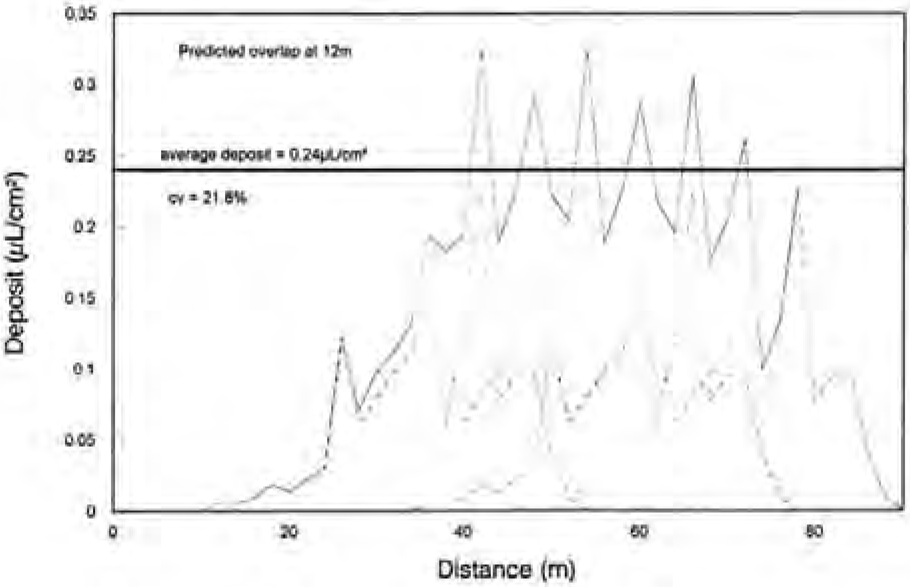


Figure 4. The cumulative deposit pattern computer simulated by overlapping a single deposit pattern at 12m intervals (data used from Figure 3).

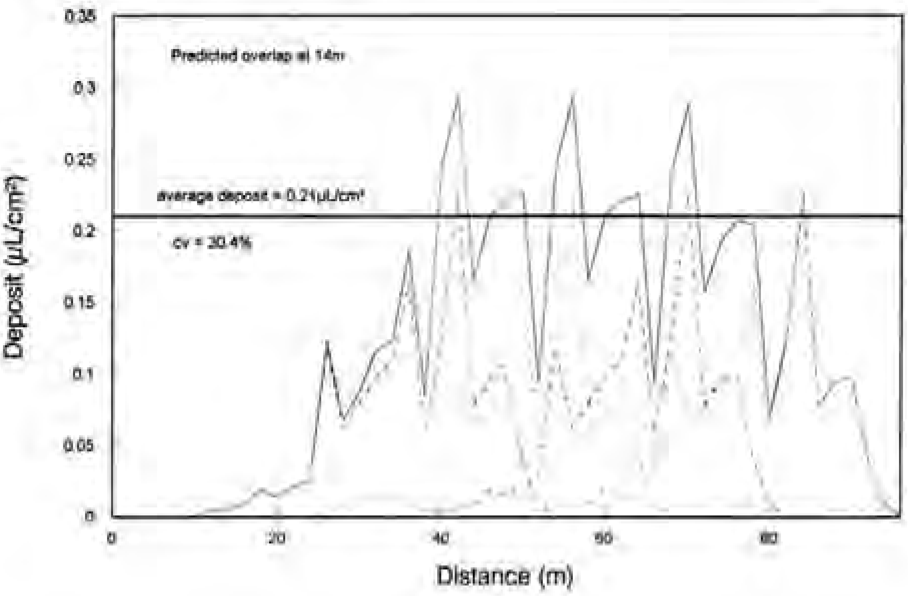


Figure 5. The cumulative deposit pattern computer simulated by overlapping a single deposit pattern at 14m intervals (data used from Figure 3).

There is a large difference in the uniformity of the overlapped deposit pattern between 12m and 14m swath widths as shown by Figures 4 and 5. In this instance an aerial operator using a 12m-swath width would produce a more even deposit than a 14m-swath width. At a swath width of 12m the CV is 21% and at a 14m-swath width the CV is 30%. Reducing swath width may assist improving penetration and deposition of sprays from aircraft onto key target areas such as the silks. Some aerial operators use this technique. Ensuring that a consistent swath width is flown across a paddock is also very critical. Reducing the swath width will reduce the aircraft work rate and result in increased operational charges. To maintain swath width it is imperative that markers or differential global positioning systems (DGPS) are used.

The deposit pattern at cob height using filter paper sections placed on flat plates in a crop for the same aircraft that produced the deposit pattern in Figure 3 is shown in Figure 6. Two treatments were flown, one using a swath of 12m and the second using a swath of 14m. There was very little difference in coefficient of variation for the spray deposit on the flat plates, 60% at 14m and 63% at 12m. The arrows indicate positions where leaves where partially or totally covering the flat plates. Even though some plates were covered by leaves there was spray deposited at all positions. The presence of spray on plates sheltered by leaves could be due to the turbulence created by the aircraft downwash moving leaves and allowing passage of larger droplets onto the flat surface, or smaller droplets moving in the turbulent air. Figure 6 shows that with the 14m swath there are three large peaks in the deposit pattern occurring at regular intervals across the paddock (12m, 26m and 40m). Regular peaks in deposit are also evident in the simulated overlap (Figure 4) using the single deposit pattern shown in Figure 3. There is scope to improve this pattern by reducing the height of the peak between positions 40-44m (Figure 3).

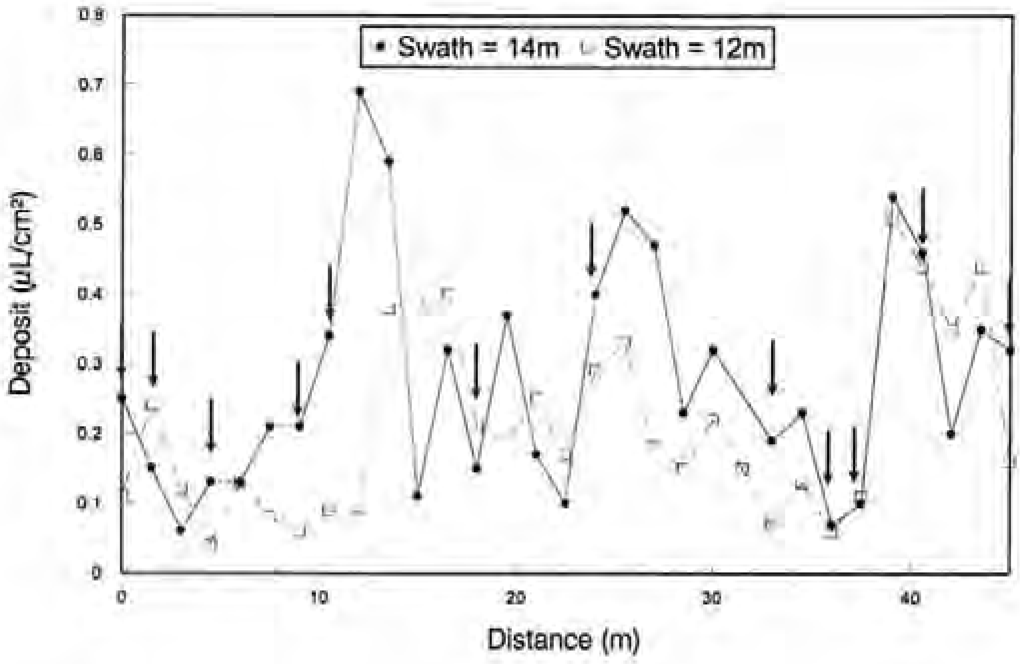


Figure 6. Deposit profiles recovered on flat plates placed across rows in a mature sweet corn crop. The two lines show the deposit profiles for 2 swath widths (12 and 14m).

Two field trial were conducted to assess the spray deposit variability on sweet corn silks with an agricultural aircraft fitted with Micronair AU5000 nozzles, one applying 40L/ha at two different droplet sizes (Fine and very fine droplets), and another applying 50L/ha at two different droplet sizes (Fine and medium droplets). The graph below shows the average deposits for each of the treatment. This shows that Fine (150 - 250µm) sized droplets give improved deposit for aircraft spraying sweet corn. The use of very fine (<150µm) droplets decreases deposit as droplets are lost due to off target losses such as drift and evaporation. The use of medium (250 - 350µm)droplets also decreases deposit as the droplets are less likely to move around in the canopy and are filtered out by the leaves of the sweet corn plant.

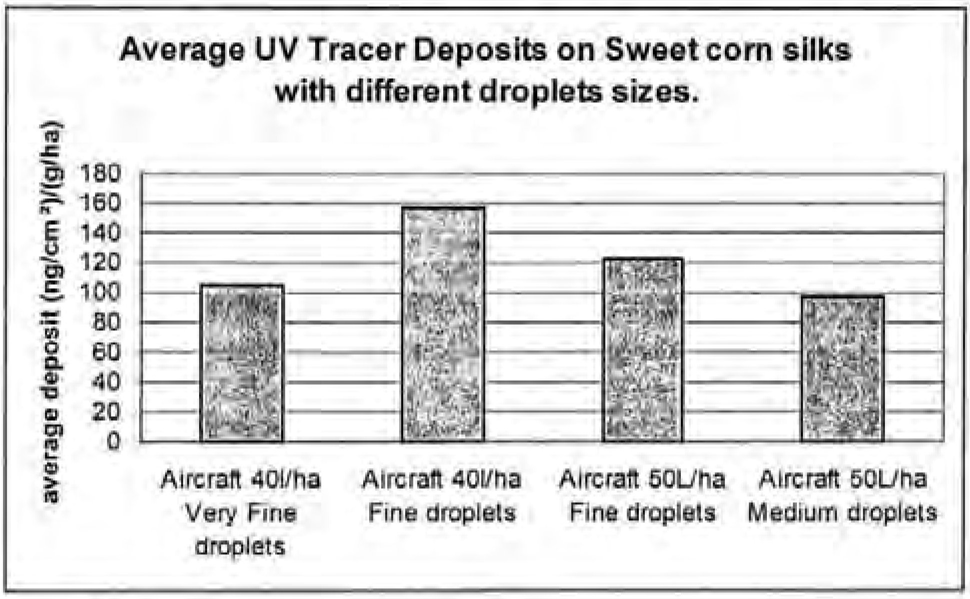


Figure 7

The results indicate that aircraft with fine droplets gave higher deposits on the silk than medium droplets, which is a direct result of the fine droplets having better penetration into the canopy and being able to swirl more around the plants canopy. medium droplets have a greater tendency to drop out of the air and hit other parts of the plant canopy, mainly the leaves which filter the spray before it can reach the cob. The very fine droplets have a greater tendency to be effected by wind and temperature, and as a result remain floating in the air or are evaporated before reaching the cob.

Air-assisted sprayers improve penetration and coverage

Air-assisted sprayers offer many advantages compared to conventional spray booms. An axial flow fan, usually hydraulically powered, is used to create air and this is then ducted through a bag attached along the boom. Along the bottom of the air bag this air is released as an air curtain. The air curtain produced by these sprayers assists in the reduction of drift and improves spray penetration into the canopy of crops. The air curtain also produces turbulence within the crop which can result in improved coverage on the undersides of leaves and hard to get at targets such as the silks on cobs. Some sprayers have the capability to alter the direction of the air curtain. Rather than straight down it may be orientated forward or backward to the direction of travel. This enables spraying to be undertaken in less than optimum conditions when strong wind may otherwise cause large spray losses. Even under ideal spraying conditions, spray penetration and coverage may also be improved in parts of some crops by having the air curtain directed forwards or backwards.

A field trial was conducted using a Hardie, Twin force air assisted sprayer to evaluate the spray deposit on artificial targets (pipe cleaners) placed in a sweet corn canopy (variety H5). The trial was conducted to assess the effect on air velocity and angle of air penetration on spray deposit at various heights within a sweet corn canopy. The sprayer was operated without air and at two air velocities as regulated by the fan speed, these were i) 50% of maximum fan speed which produced an air velocity of 11.6 m/s at the duct outlet on the boom and ii) 100% fan speed which produced an average air velocity of 16.2 m/s at the duct outlet. The air curtain was directed i) straight down, ii) half forward (15 degrees) and iii) full forward (30 degrees). The travel speed in this trial was 5.6 km/hr and the application volume was 106 L/ha. The artificial targets were placed at three heights in the sweet corn crop, tassel height (≈2.3m), cob height (≈1.4m) and just above ground level (≈0.2m). A fluorescent tracer was used to quantify the spray deposit on individual pipe cleaners. Silks were not collected as they had all browned off in this crop.

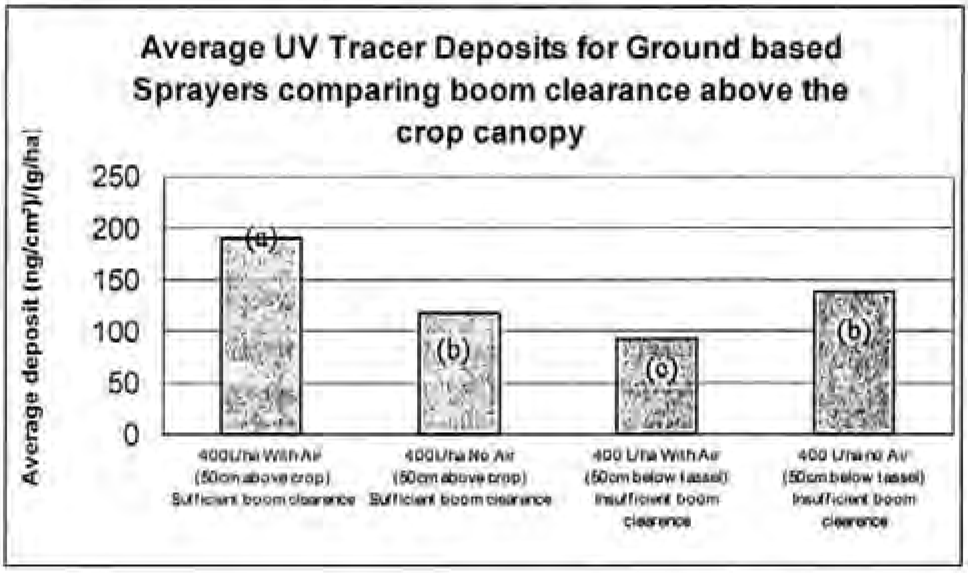
There were significant differences in the average deposit levels on the pipe cleaners between the 3 heights sampled. When deposits were averaged across all tests there was a 54% reduction in the deposit on pipe cleaners between the top and middle canopy positions and an 86% reduction in deposit between the top and bottom positions. There was no significant difference in the deposit levels recovered between the different air velocity and angle settings in the middle and bottom positions. The air curtain angled full forward with at the reduced air velocity produced higher deposit levels in the top position compared with all other settings. The highest average recovery across all zones was achieved using the reduced air setting and the air curtain angled full forward. The treatment with no air gave the second lowest average recovery (Table III).

Table III. Average spray deposits on pipe cleaners placed at 3 heights on sweet corn plants.

Test Configuration	Deposit (µL/cm²)			All*
	Bottom (0.2m)	Middle (1.4m)	Top (2.3m)	
50% Air - full forward	0.121	0.306	1.085	0.504
50% Air - straight down	0.133	0.364	0.65	0.382
100 % Air - half forward	0.115	0.498	0.874	0.496
100 % Air - full forward	0.092	0.358	0.828	0.426
100 % Air - straight down	0.119	0.396	0.781	0.432
No Air	0.097	0.367	0.734	0.399

* Average across all positions

It would have been better to compare the deposit levels directly on the silk using these equipment settings. The silks were not sampled as they had already dried off in this crop. The zone of primary importance is the middle zone as this is where the cob is located. No firm conclusions can be drawn from this trial regarding air velocity and angle. The results showed that increased air velocity angled 15 degrees forward gave higher recoveries in the cob zone. Trials were conducted comparing conventional spray booms and air assisted spray booms, to see what effect the air has on spray deposits. It was found that with air assistance it is critical to have sufficient boom clearance above the plant canopy. Trials found that when the boom cannot clear the canopy that spray deposits were reduced as the air velocity forced the droplets passed the silks resulting in lower deposits. Figure 8 shows the difference between having sufficient boom clearance with an air assisted boom and a conventional boom. There was a significant difference between the air assisted boom at 400L/ha when there was insufficient boom clearance above the crop compared to when there was. It was found that there was a 105% increase when there was sufficient boom clearance above the crop canopy. This shows how important boom clearance is for air assisted boom sprayers.



Although it was found that by having insufficient boom clearance that a conventional spray increased it's deposit on the silks by 15%, as the boom was closer to the cob area and the majority of the leaves were no longer filtering out the spray from above. Although it should be noted that this will also result in more unevenness across the field as the nozzles cannot achieve there correct overlap. With correct overlap it could result in spray failures or striping down the paddock and a poor result of control.

Discussion

Aircraft and Ground based sprayer are the common means of spraying sweet corn in Australia, the work conducted in this project shows that there is room for improvement in all types of sprayers and that some of the most basic models can find it difficult to get good coverage over the whole plant. The performance of these sprayers can be improved with the aid of air assistance or boom attachments such as droppers and GPS systems..

The performance of agricultural sprayers depends generally on the exact location of the chemical is deposited (Cayley et al., 1987). In the present study, ground based sprayers gave significantly better deposit than aircraft sprayers. Ground based sprayers fitted with droppers provided significantly higher deposits on the silk and cob area, where most heliothis larvae live.

The spray deposition on leaves or artificial substrates was assessed quantitatively using the fluorometric technique. Guo et al. (1998) reported that chlorophyll could reduce the actual dye concentration display when using a fluorometric technique to determine spray deposit on brassica crops. Preliminary trials in sweet corn found that the fluorometric technique to be unaffected by sweet corn and was the most accurate method of quantifying spray deposits in sweet corn. Spray coverage evaluated with water sensitive cards could not adequately substitute for aphid evaluation (Welty et al., 1995). The visual assessment method using pink fluorescent dye, however, is very simple, and can be used by growers to assess spray coverage.

Technology transfer : - Application Techniques

The demonstration and promotion of improved application techniques at **farm walks** occurred in all major sweet corn production areas. These farm walks were all conducted during the district's sweet corn season. Each farm walk commenced in the late afternoon and extended into the evening with the length of the farm walks ranging from 3 to 6 hours. A presentation on general spray application and trial results was followed by a field walk to look at the coverage of different application techniques using fluorescent dye. The evening was finished by an open forum discussion after a BBQ. Evaluation forms were distributed at the Gatton field day to provide feedback. The locations, dates and attendance at farm walks are listed in Table IV.

Table IV. Application technology farm walks.

Location	Bowen	Gatton	Cowra	Lindenow
Date	1st October, 1998	5th February, 1999	18th February 1999	24th February 1999
Attendance	30	22	~20	25-30
No. sweet corn growers	2	15	~20	25-30
Contact	Ross Wright	Brendan Nolan	Clarrie Beckingham	Rob Dimsey

Growers were also informed about improved application techniques through regular newsletters, media releases, application information kits.

Night walks were popular and generated a lot of discussion and interest. This follows similar experiences with similar activities in other cropping systems and regions. This type of activity has shown to be a very effective means of delivering information and demonstrating equipment through the use of fluorescent dyes in the field. The meal provided social interaction and alternative opportunities for discussion to that of the 'open forum' that followed presentations.

Changes in Application Techniques
Anecdotal evidence to date suggests there has been interest from all regions in alternative spray application techniques to what was previously used by the industry as documented in Milestone 2 report.

South East Queensland
One major production group has bought an air-assisted boom sprayer and another has brought droppers on a standard boom. A survey taken at the Gatton farm walk indicated that no-one was going to change to droppers immediately, however there was considerable interest in the results, and much discussion about alternative modifications to the prototype demonstrated.
At present aerial spraying of sweet corn is undertaken in the Lockyer Valley with volumes ranging from 40-60 L/ha. Aircraft are either equipped with Micronairs or hollow cone nozzles in the case of the helicopter operator. Due to the small block sizes sprayed and abundance of obstacles such as powerlines the use of a flight path guidance system such as DGPS is not all that feasible in the Lockyer Valley.

North Queensland
There is an increased use of ground based sprayers equipped with droppers used in North Queensland to apply insecticides to sweet corn. One grower is using an over the top boom with air-shear outlets. Aircraft are continuing to be used for spraying sweet corn, where appropriate or in bad weather.

New South Wales
Large areas of processing sweet corn are sprayed using aircraft. Aerial operators all are using very narrow swaths and track guidance systems. Contractors are using ground rigs equipped with droppers spraying large areas.

Victoria
Contract sprayers are available using high clearance equipment with and without droppers. Project team members have had a number of enquires following the workshop regarding specifications for dropper modification.

Western Australia
Project team members have had enquires on alternative techniques and droppers.

Recommendations

Many commonly used spray application techniques have been evaluated for their efficiency in targeting pesticides to silks. Using fluorescent tracers, spray deposits on leaves have been collected for a range of equipment types. Some of the techniques tested have produced improvements to conventional application methods. Even though the equipment used is important when applying insecticides to sweet corn the sweet corn canopy also has a large influence on the spray penetration and spray distribution on the plant. The distribution on the plant is difficult to manipulate when spraying over the top with a boom. The following conclusions can be drawn for the field trials undertaken so far.

- Calibration of ground based sprayers used in sweet corn is very important. Spray penetration and uniformity of spray deposition across a paddock may be improved by using reduced nozzles spacing s and reduced speeds.

- Boom sprayers fitted with droppers have the ability to direct more spray onto bottom part of the plant canopy compared with conventional over the top boom sprayers.
- Angling the boom 45° forward with air-assisted sprayers to achieve increased spray deposit , also having correct boom height clearance above the crop canopy to achieve better coverage.
- Calibration of agricultural aircraft used for spraying sweet corn is very important. Spray penetration and uniformity of spray deposition across a paddock may be improved with aircraft by using reduced swaths. This technique is used by some aerial operators. Ensuring a precise swath width is flown across a paddock is also critical. This can be achieved by using track guidance (differential global positioning systems DGPS) or by placing markers in the field so pilots know where to fly each pass.

- Boom sprayers fitted with droppers have the ability to direct more spray onto silks compared with conventional over the top boom sprayers and aircraft. Further trials will be undertaken to address comments raised by growers and contractors currently using droppers. These comments concern:

  (1) Dropper length.
  No broad recommendations can be made on the length of droppers required, as length will vary depending on the height of the variety and distance from the cob to the tassel. Some spray operators are using short droppers, with the nozzle placed above the top cob but directed downwards towards the cob. Longer droppers are more likely to become tangled and break off in crops that lodge. More trials are required with short droppers to assess their efficiency in targeting sprays on silks.

  (2) The number of nozzles required on each dropper
  The results reported in this report used droppers fitted with four nozzles directed to the cob region of a plant. Four nozzles are likely to give better spray deposition than two nozzles especially if leaves are constantly brushing up against nozzles and preventing droplets from reaching the target.

  (3) The type of nozzles to use.
  Most of nozzles used on sprayers with droppers employed to spray commercial sweet corn crops are wide-angle flat fans. The reason for using flat fan with a spray angle of 110° is the width of the spray pattern at a set distance (i.e. 50cm) is wider than most conventional hollow cone nozzles that have typical angles of 70°. There is considerable scope to investigate a range of different nozzle types (hollow cones, twin-fans and even fan nozzles) to determine whether they produce better spray deposit levels on silks compared to tapered flat fan nozzles.

  (4) Application Volumes
  Wide ranges of application volumes are used when applying insecticides to sweet corn (200 L/ha to 1300 L/ha). Increasing volumes will not necessarily increase spray deposit on the silks especially if the silks are drenched and run-off occurs.

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Pesticide Application (Cont.)

R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle, DNRE, Vic.

Introduction

In southern Victoria, pesticides have been applied by a range of ground rigs, including misters and boom sprayers. Aerial applications of pesticides are not carried out. Spray rigs used include Hiboys without droppers, a tobacco sprayer with droppers, standard booms and a mister has also been used by a contractor, to spray some crops. Spraying is done on around 7 day intervals, and more frequently when pest pressure is high.

Sweet corn monitoring results indicated that large differences in damage to cobs between crops might have been partly due to differences in pesticide application methods. One reason for poor pest control can be inefficient spray deposition on the target, although timing is also critical. The aim of these evaluations was to assess the efficiency of spray-machines in delivering insecticides to the target silks of sweet corn.

Materials and Methods

Five spray evaluations were conducted using four different types of spray machines. The evaluations were conducted according to the growers' spray practices (Table 1) and also according to a standard protocol (Rob Battaglia, QDPI Gatton).

Sprayer 1 Ex-tobacco sprayer with droppers

This has a 9.5m conventional boom with 13 droppers and 12 fan nozzles (Teejet 8003 VB) were fitted at 75cm intervals alternatively. Each dropper was 40 cm long and fitted with two cone nozzles at the end.

Sprayer 2 High-clearance hydraulic boom (I)

This hydraulic boom of 20 m was fitted with flat fan nozzles and the crop was sprayed over the top.

Sprayer 3 High-clearance hydraulic boom (II)

This hydraulic boom of 20 m spraying over the top was fitted with flat fan nozzles (Hardi 4110-18).

Sprayer 4 High clearance hydraulic boom (II) with droppers

The spray-machine was as same as at Evaluation 3, but the boom was fitted with 19 droppers at 100 cm spacing. Each dropper was 60 cm long and had 2 nozzles (Hardi 4110-18) at the end.

Sprayer 5 Supercannon air-shear

This machine is used to spray from the irrigation lines and headlands. Low spray volume has been the standard grower practice (75L/ha) and the crop was sprayed (single pass) from one side of the crop edge.

Table 1. Information on sweet corn crops and on sprayers used for the evaluations

Spray Machine	Cultivar	Row spacing (cm)	Average Plant height (cm)	Average silk height (cm)	Stage of Silking	Travel speed km/h	Spray volume (L/ha)	Plot size ha
High clearance boom with dropper	Madonna (Bicolour)	75	193.6	98.9	60-70%	3-4	500	0.4
High clearance hydraulic boom (no droppers)	Golden Sweet	80	229.3	110.4	70-80%	5	500	0.6
High clearance hydraulic boom (no droppers)	7831	100	199.5	80.2	60-70%	6	310	0.4
High clearance hydraulic boom with droppers	7831	100	199.5	80.2	60-70%	6	310	0.4
Super cannon mister	Cabaret (Bicolour)	75	173.3	78.3			75	0.4

The test blocks were sprayed with the fluorescent tracer (Helios 500 SC) at the rate of 40 g/ha to assess spray deposition. The spray volume was selected based on the grower's practice (Table 1). Cobs were sampled within 30 minutes of spraying and placed into brown paper bags (to avoid photo-degradation) and the concentration of tracer on the silks was measured.

Results

The average spray deposit recovered from the silk samples and statistics for the five evaluations are given in the Table 2. As these evaluations were conducted in different corn crops and with different spray setups, comparing the machines directly with each other is not appropriate. The coefficient of variation (CV) was used to measure the variation between silk samples (Table 2). The lower the CV value indicated the uniformity of spray deposit among the silk samples.

Evaluation 1: The average spray deposit on silks using droppers was 17.6 ng of tracer per gram of silk. The deposit on the samples ranged from 1.5–33.4 (ng/g)/ (g/ha). The coefficient of variation (CV) was 51.6% and is a measure of the variability of spray deposit among the cob samples.

Evaluation 2: The average spray deposit for over the top spaying was 9.1 (ng/g)/(g/ha). The cultivar (Golden Sweet) used for this evaluation was taller and denser than the crop in other four Evaluations and so this may have reduced the amount of spray deposited on the silks. The CV value (56.4%) was lower than Evaluation 3 and 4 that indicate there was more uniformity in spray deposits between silks.

Evaluations 3 and 4 were conducted using the same machine with and without droppers. In evaluation 3, with over the top spraying (without droppers) the spray deposit reached on the silks was higher than Evaluation 2. This may have due the wider row spacing (100 cm) used in the crop.

The average deposit on the silks with droppers was 19.7 (ng/g)/(g/ha) and 12.8 (ng/g)/(g/ha) for over the top spraying (without droppers). The results indicated that average spray deposit on silks was increased up to 1.5 fold when sprayed with droppers compared to the deposit on silks achieved with over the top spraying. Even though droppers have increased the spray deposit, the variability between silk samples was increased where the CV was higher (98.5%).

Evaluation 5 Average deposit data indicate that mean deposit on silks varies with the distances from the spray line when sprayed with a Supercannon machine. There were 50% reductions in deposit between 1st and 20th row positions. Reduction was further higher in far distances that cover by the machine. However it should be noted that spray was apply from one side of the block and spray from either side will give more coverage)

Discussion

For each evaluation, key issues to consider are the variability of spray deposits observed. The aim is to have sufficient deposit of insecticide on the silks to kill larvae. If 20 - 40% of cobs is "under-dosed" and 20% of cobs are "over-dosed" then under high pest pressures, substantial losses will be inevitable due to damage as well as inefficient use of the chemical. At low pest pressures, losses will be much lower since the chances that an under-dosed cob being infested will be reduced.

In this study droppers increased the spray deposit on silks. However the variation on the deposit between the silks was higher. The efficiency of droppers in targeting spray to silks also depend on other factors such as dropper length, number of nozzles on the dropper, spray volume and crop canopy. At this stage, we do not know what amount of spray deposit on silks is required to cause significant mortality on *Helicoverpa* larvae.
More detail on this work is published in proceedings of the 3rd Sweet Corn Industry Workshop.

Technology Transfer

Field demonstrations were conducted for the growers and the results were presented and published in:
Proceedings of 2nd National Workshop 1998.
Proceedings of 3rd National Workshop of HRDC project VG 97035. 1999.

Report : Milestone 4, Pesticide Application Techniques

Reports circulated to participating growers.
Spray Application Report – Dr Siva Subramaniam 17/2/00

Spray Field Day, Lindenow – 24/2/99

Recommendations

Amounts of spray deposit that required controlling the *Helicoverpa* grubs need to be investigated. Use of ground sprayers with droppers is more efficient than top spraying but issues such as angle, number and positioning need to be evaluated.

Acknowledgments

We thank Ross Ingram, Phil Hammond, Roger Woodward, Ross Galati and Graeme & John Hine for allowing us to use their sweet corn crops and for providing spray equipment; and also for the valuable time they have contributed to this study.

Pesticide Application (Cont.)

Dr Sandra McDougall and Tony Napier, NSW Agriculture, Yanco, NSW.

1998/99 season

Assessment of aerial pesticide application techniques in the Riverina was undertaken during the 1998/99 sweet corn season. Insecticide applications by aircraft on commercial crops were examined to see how effective the control program was. There were seven commercial blocks of sweet corn, which were scouted from before any spray program commenced, through until after silk browning. Scouting consisted of counting and recording the number of heliothis eggs and larvae found for each paddock. The growers made the decisions on what thresholds to spray and what insecticide types to use. No spray treatments were made while egg and larvae numbers were low. When higher egg lays and hatchings were found the grower used aerial insecticide applications as the control. Over the silking period 4 crops were sprayed twice and 3 crops were sprayed three times.

What the scouting results demonstrated was that there was a constant low level infestation of a few heliothis per 20 plants at any one time. Within this low-level infestation there was a distinct egg lay on the 19th of January. Over time there was a gradual increase in the age of the heliothis, as you would expect, but with no effect on the total heliothis numbers after each insecticide application. What this demonstrated was aerial applications of methomyl (at 1L/ha – ovicidal rate) or thiodicarb (at 2L/ha) gave no control on heliothis.

1999/00 season

With no apparent heliothis control in the 1998/99 season it was decided to compare ground operated boom sprays with droppers against aircraft for the application of synthetic insecticides.

Three commercial crops of sweet corn were selected and used for the trials on a property near Whitton in the 1999/2000 season. All three crops were treated as normal commercial crops up until the first aerial application of pesticides were due to be applied on the 7th February 2000. Large 30m strips were marked out in each paddock to leave untreated by air. Each paddock than had 3 plots marked out in them, one in the area to be sprayed by air and two in the strips to be missed by air. The two plots, in the strips to be missed by the aerial operator, were used for both the control plots and the boom spray treatments. All plots marked out were 40m long x 22.8m wide.

The aerial applications were applied by plane with micronair nozzles at a rate of 60L/Ha. The aircraft is a turbine air tractor with 14 miconair units and has previously been assessed for spray pattern uniformity to determine the optimum flight lane spacing and uses a global positioning system for accuracy. The boom spray applications were applied using a battery-powered backpack with a hand held boom. The boom was set up with 6 hollow cone nozzles spraying two rows of sweet corn in one pass. 2 nozzles were aimed at the tassel and 4 nozzles were on the end of droppers aiming at the silks at a rate of 135L/ha.

Scouting for heliothis commenced prior to silking and continued on a weekly basis until about a week before for each crop was due to be harvested. The timing of the aerial spray treatments was decided by the grower with the boom spray application applied as close as possible to the aerial treatments. All treatment applications consisted of both 2L/Ha of Lannate® (Methomyl) and 400ml/Ha of Dominex® (Alpha-Cypermethrin).

The results for these trials, during a year of high pressure, showed some level of control using both aerial and boom applications of synthetic insecticides but appeared not to be the major influence. The major influence on controlling heliothis damage came from egg parasitism by *Trichogramma.*

2000/01 season

Spray deposit trial

A field trial was conducted in a Riverina sweet corn crop to compare two different commercial spray application methods with a range of setups. The trial was conducted in a Jubilee crop to assess the spray deposit on where it is needed the most (the silks) with two types of application equipment. These were an agricultural aircraft, applying 50L/ha at two different droplet sizes (medium and coarse droplets) and a ground rig with and without short droppers applying 200L/ha.

The spray coverage to silks with the conventional boom and droppers was disappointing. Even though the coverage was the best, previous trials have shown spray coverage to silks of up to 4 times higher than aircraft. What contributed to the low spray coverage was the droplet size. This boom was set to produce droplets from 400 to 600 microns, which is considered too course to obtain the best results. A setting with droplets of 150 to 200 microns would have produced much better results. This trial demonstrates that you will not automatically improve your spray coverage in sweet corn by fitting droppers onto a boom. Correct nozzle selection and operating pressures is needed in gaining improvements with spray penetration

2000/01 season

Effects of de leafing

A trial was conducted in a commercial crop near Whitton to evaluating the removal of most upper leaves at silking and its effect on spray deposit on silks and crop yield. This treatment involved the removal of upper leaves at silking to minimize any shielding of silks from subsequent spray applications. It was hope that any advantages with increased pesticides deposits to silks (and hopefully better heliothis control) would outweigh any reductions to yield.

The trial was sprayed over the top of the crop with a hand boom at 50 l/ha to simulate the output of local aerial operators. Measurements of spray deposits on silks were assessed with a fluorescent dye mixed with the spray solution. After the dye was applied at a rate of 50 g/ha, silks were collected from all plots and measured for spray deposit. The trial area was also sprayed with 2 commercial aerial applications of insecticides after the de leafing.

Cobs were collected from all plots and assessed for both yield and grub damage. Results show that de leafing at 10% silking resulted in a significant reduction of yield (11%). There were no significant differences however between treatments with regards to grub damaged cobs or spray deposits to silks. With no improvement in spray deposits to silks or benefits in grub control there is no reason to recommend or further investigate this strategy

6. Secondary Pests

This activity and associated outcomes have also been reported in :-

- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 121 –122 & 128-129.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 76-81.

Secondary Pests (cont.)

Bronwyn Walsh, DPI, Gatton Research Station.

Introduction

Beside the caterpillar pest, heliothis, stakeholders in the sweet corn industry have reported evidence of other pests in their crops (Table 1). Fortunately no crop losses due to these other pests have been reported. They are currently is listed as minor and infrequent in Australia and overseas are. Armyworm is an exception since although it is a sporadic pest, when present in large numbers it is a major pest. Pests such as aphids, which can be found in the wrapper leaves, can also be major pests if the produce is to be exported to overseas markets such as Japan. In the case of leafhoppers and jassids it is the disease they transmit more than their feeding damage does that is the concern.

Table 1. A list of pests, other than heliothis, found in sweet corn crops in Australia and the part of the crop where they cause most significant damage.

Insect	Vegetative	Fruiting
Cutworm		
Earwig		
Mites		
Jassids		
Maize leafhopper		
Red shoulder beetle		
Thrips		
Armyworm		
Aphid		
Dried fruit beetle		
Sorghum head caterpillar		
Yellow peach moth		
Green vegetable bug		
Midges		

Control action levels are rare for Australian conditions and while overseas management strategies list action levels for most of the other pests, the relevance of these to Australia and in an IPM system is not clear.

For management of the other pests chemical control is available for most of them (Table 2). Unfortunately some of the chemicals are harmful to beneficial organisms and therefore can threaten the biological control that is being encouraged against heliothis. Another problem is that not all of the chemicals are registered for use on sweet corn crops or against the specific pest.

Table 2 Control options available for other pests found in sweet corn crops

Insect	Control options		
	Chemical[1]	Biological	Cultural
Cutworm	Y		Y
Earwig	Y		
Mites	Y	Y	
Jassids	Y		
Maize leafhopper	Y		Y
Red shoulder beetle	Y		
Thrips	Y	Y	
Armyworm	Y	Y	
Aphid	Y	Y	
Dried fruit beetle	Y		
Sorghum head caterpillar	Y	Y	
Yellow peach moth	Y	Y	Y
Green vegetable bug	Y		

1. A chemical is available for control of the pest **but** not necessarily registered for the specific pest in sweet corn crop.

Predators and parasites have a role to play in the control of some of the other pests, in the absence of detrimental insecticides. In some Australian crops predatory bugs and mites and parasitic wasps are already controlling aphids, thrips and mites. As is often the case with biological control, it may also need to be managed, depending on the system, to include inundative releases of beneficial organisms or other practices to promote their establishment and ensure pest populations stay below a damaging level.

Cultural practices such as selection of virus/disease tolerant varieties, different planting dates and crop hygiene can also reduce the impact of the soil dwelling or disease transmitting pests of sweet corn.

There is potential to incorporate control of the other pests using any of these options with the management of heliothis. In some cases chemical control of the other pests may not interfere with the biological system being encouraged for controlling heliothis due to the pests being present at different times. The biological system for heliothis management can also play a role in controlling the other pests, such as thrips and aphids for example due to the gregarious appetite of the predatory insects. The key to successfully managing heliothis and these other pests is knowledge of the level of each pest in the crop through monitoring and the availability and timely implementation of effective management tools.

Trials in sweet corn crops in the Lockyer Valley Queensland over two years have provided some information towards clarifying the role of other pests in sweet corn crops. In 1999/2000, a trial quantified the level of pests which appear in a summer sweet corn crop, identified where on the plant they are found, whether they cause damage that renders the cobs unmarketable and some potential management options. During the study observations on the presence and location of some beneficial insects that have been made in the past were also be quantified.

Two similar trials conducted in 2000 in a spring crop provided further information on the impact and management of other pests on sweet corn.

Each trial will be described in the following sections.

Trial 1. Summer crop

Materials and Methods
A planting of H5 sweet corn variety was established in a 1.0 ha area of Gatton Research Station, Queensland, December 9th, 1999. The planting was divided into plots measuring 20mx9m with buffers of 5mx9m between plots. The trial consisted of seven treatments, replicated four times.

Pesticides were applied using a hydraulic air assisted boom at 450L/ha. Six of the seven treatments were applied three times during early silking and twice before harvest (Table 3). The last treatment included a pre-tasselling spray.

Table 3. Details of pesticide treatments applied to the summer sweet corn crop.

No.	Active ingredient	Trade name	Rate	No. times
1	**Unsprayed**	-	-	0
2	Bt_a	Xentari®	@1kg/ha	5
3	NPV	Gemstar®	@375ml/ha	5
4	Spinosyn	Success®	@400ml/ha	5
5	methomyl	Marlin®	@2L/ha	5
6	deltamethrin (1)	Decis® (1)	@500ml/ha	5
7	deltamethrin (2)	Decis® (2)	@500ml/ha	6

The treatments were chosen based on pesticides that are registered or pending registration for use in sweet corn, and that have been recorded as having some activity on the types of secondary pests being considered in this trial. Application times were aimed at the critical period for pest control. An early application in treatment 7 aimed to disrupt the pests life cycle and therefore establishment in the crop.

The plots were monitored weekly during the vegetative stage and twice weekly after tasselling for pests and beneficials, recording the number of arthropods present. Beneficials that were recorded included *Trichogramma*, *Microplitus*, ladybirds, lacewings, predatory bugs and spiders.

Ten plants were monitored, randomly selecting plants within each plot on each monitoring event for the life of the crop. During the vegetative stage the whole plant was monitored however during silking the cob zone alone was monitored. At harvest 30 cobs per plot were picked and assessed for damage and presence and abundance of arthropods. The damage assessment included poor tip fill, blanking, degree of chewing damage, husk damage and contamination of the cob. Weather data was recorded using a weather station erected on the Station.

A secondary set of data was also recorded. Ten plants were destructively sampled to identify and count the location of pests and beneficials on the plant through the life of the crop. Six monitoring events were be used – two during the vegetative stages and four from tasselling – including at harvest.

Analyses of variance were used to compare the number of arthropods present between treatments and the number of cobs damaged between treatments. For the analyses of the proportion of cobs with Heliothis and sorghum head caterpillar data a logarithmic transformation was used.

Results and Discussion
The results will be discussed according to following topics, based on the questions frequently asked by growers.

1. Damage

Physical

The most obvious damage to harvested cobs was chewed tips. The significantly highest proportion of cobs with chewed tips was in the Decis® plots at an average of 28% chewed cobs (Figure 1). This was followed by the Marlin®, unsprayed and Gemstar® treated plots at an average of 17% chewed cobs. These were not significantly different from one another however Marlin® had the higher amount of damage of the three, followed by Gemstar® and then unsprayed treatment. The Xentari® and Success® treated plots had the lowest proportion of chewed cobs, only 4% of harvested cobs were chewed.

A similar pattern was found with holes in the wrapper leaves of the cobs and with silks chewed or absent (Figure 1).

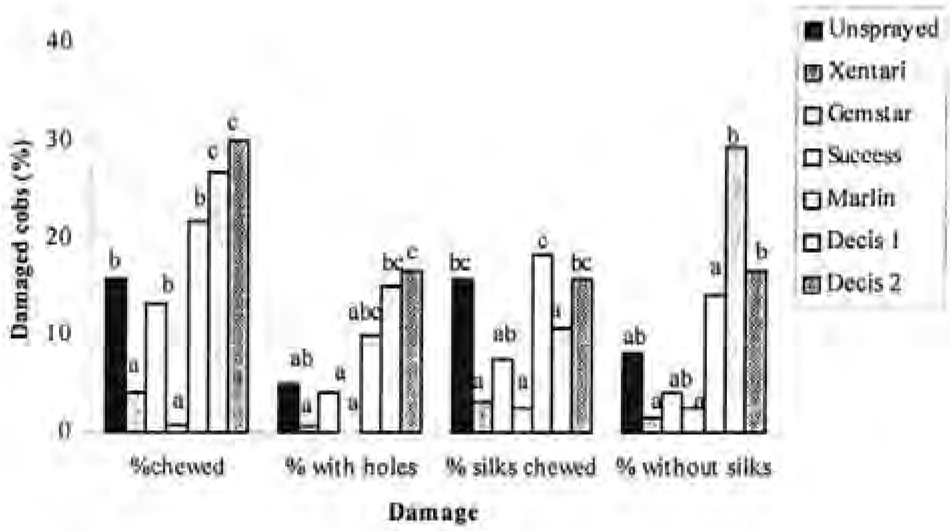


Figure 1. The proportion of different types of damage to cobs from a summer sweet corn planting on Gatton Research Station. Values with same letter, within each category are not significantly different.

Discolouration along the edges of the wrapper leaves, blanking and poor tip fill at an average of 64%, 5% and 13% of harvested cobs respectively, did not seem to be caused by pests at the levels reached in this trial as there was no significant difference between the treatments.

Contamination

Over 90% of the harvested cobs had pests present. Thrips and aphids contaminated the highest proportion of cobs (Figure 2). The plots that were treated with biological insecticides or Decis® had over 80% of cobs contaminated with thrips. Comparatively, the Marlin® and Success® plots had less than 50% of cobs infested with thrips.

In contrast, for aphids the plots that were unsprayed, sprayed with biological insecticides or Decis® had less than 50% of harvested cobs contaminated with aphids (Figure 2). The Marlin® and Success® plots had 69% and 85% of cobs infested with aphids respectively, significantly more than the other treatments.

Dried fruit beetles were present in all harvested cobs, but there was not significant difference between treatments. The average across treatments was 22.5% contaminated cobs.

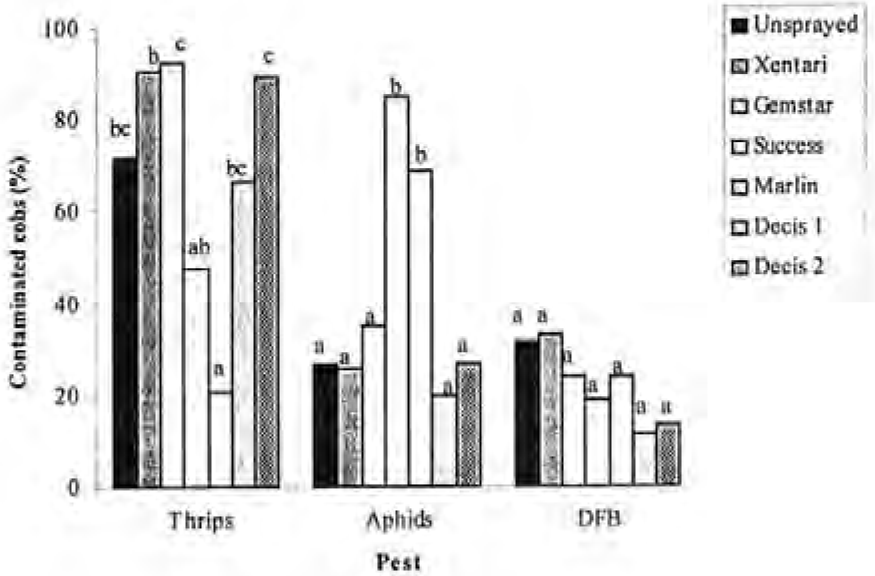


Figure 2. The proportion of cobs contaminated with thrips, aphids and dried fruit beetles (DFB) from a summer sweet corn planting on Gatton Research Station. Values with same letter, within each category are not significantly different.

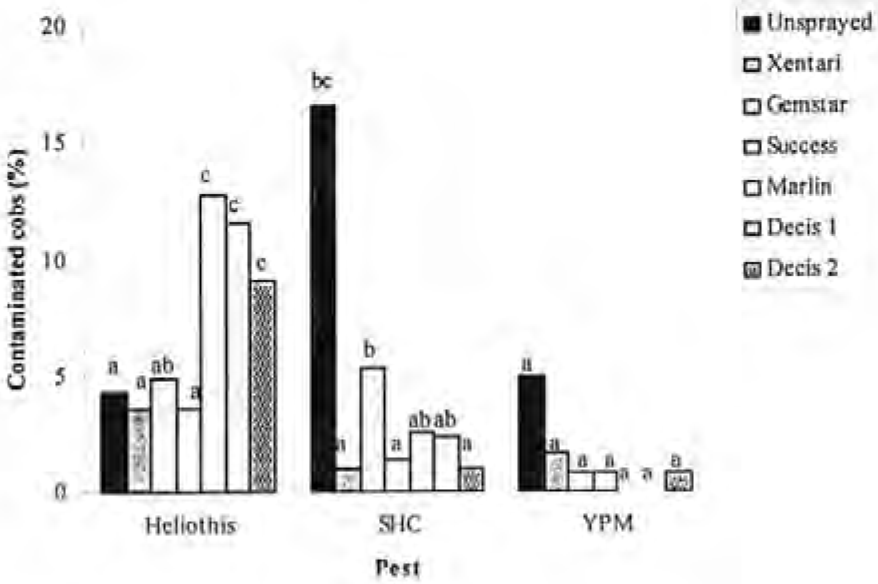


Figure 3. The proportion of cobs contaminated with caterpillar pests from a summer sweet corn planting on Gatton Research Station. Values with same letter, within each category are not significantly different. SHC = sorghum head caterpillar, YPM = yellow peach moth.

Lastly, caterpillars were found in less than 20% of cobs (Figure 3). In the unsprayed, biological pesticide and Success® treatments there was mostly less than 5% contamination by any of the caterpillar pests.

The chewed damage (Figure 1), typically caused by caterpillars, correlated with the presence of heliothis, sorghum head caterpillar and yellow peach moth in the harvested cobs. Heliothis was the predominant caterpillar pest in cobs from the Marlin® and Decis ® treatments, significantly more than in the other treatments. The highest proportion of cobs infested with sorghum head caterpillars was from the unsprayed plots at 16.6%. The lowest proportion of infested cobs with sorghum head caterpillars was from Xentari® and Success® plots at 1% and 1.4% respectively. Sorghum head caterpillars were mostly found in the silks and in the wrapper leaves where they cause less significant damage than that done to the tip. Yellow peach moth was also found in cobs but in very low numbers, less than 2% of cobs were infested. There was no significant difference between the treatments.

2. Pest management

Pests

The number of pests present at harvest is a significant indicator of the extent of control that was achieved with the pesticides used in the trial, as discussed above.

No one pesticide was sufficient to achieve an acceptable level of marketable produce, that is, with 5-20% damage or contamination. No pesticide applications, Xentari®, Success® or Marlin® achieved an acceptable level of chewing damage but of these only Marlin® reduced contamination to an acceptable level.

Beneficials

Predatory bugs, particularly *Orius* sp., were the most abundant of the beneficial insects and the only group to show a significant difference between treatments. They were at the highest level in the unsprayed, biological pesticides and Success® treated plots. Success® had the lower level of the four. Decis ® and Marlin® treated plots had significantly less predatory bugs, by at least 25% less, than in the other treatments.

The number of spiders present in the different treatments showed a similar pattern to the predatory bugs but there was no significant difference between the treatments. Ladybeetles and lacewings were very low in number. Parasitic wasps were present in the crop, accounting for close to 100% parasitism of armyworm, and parasitism of aphids however an accurate measure was not taken.

3. Phenology of pests and beneficials in the crop

Pests

Sorghum head caterpillar and yellow peach moth caterpillars were only found during destructive sampling a week before harvest and in the harvested cobs. The former were mostly found in the silks and wrapper leaves while yellow peach moth caterpillars were found between the cob and stem and in the silks. Heliothis was found throughout the life of the crop but was present in highest numbers during the first week of silking. Armyworm was also found in the crop around tasselling.

From the late vegetative stage, 46DAS, to tasselling, thrips were in the upper half of the plant, especially in the whorl. As the crop grew thrips tended to continue to be found in the upper/youngest part of the plant. Either at the base of leaves or in the silks and wrapper leaves of the developing cob. Thrips adults and nymphs were found in the whorl up to 4 leaves in and similarly in the developing cob. During monitoring it was noticed that by noon thrips had often retreated into the cob or protection of the leaf bracts.

Aphids were found on the underside of leaves in the vegetative phase of the crop. They remained in the lower part of the plant but gradually moved upwards and were found on the wrapper leaves of the cob.

Jassids were found low in the crop during the vegetative phase but adults could also be found in the whorl and higher in the crop.

Dried fruit beetles appeared in the crop at pollen shed and were found where the leaf meets the stem usually amongst pollen that had lodged there. Once silking commenced dried fruit beetle could also be found in the cob. During cob development beetles were found amongst the kernels, increasing in number the longer the cob was on the plant.

Beneficial insects
Spiders and predatory bugs were the first evident beneficial insects present in the crop. The predatory bugs were found where the leaves joined the stem. From 46 DAS, lower in the plant, predatory bug eggs were found in the same area and along the mid rib of the leaf to the outer ends of the leaves. Pirate bug (*Orius* sp.) nymphs and adults were found in similar areas while the black mirid adults were much more active and tended to be spread much further around the plant. As the crop grew the predatory bug nymphs and adults were also found in the whorl and tassel and then silks and cobs. This seemed to follow the pattern of where thrips and/or pollen were found.

All stages of ladybeetles and lacewings were more evident later in the crop's life. During silking they were prevalent on most sites where aphids were present.

1. Integrated pest management of sweet corn pests.
The greatest threat of these other pests pose is as contaminants in the harvested cobs, whether they be destined for local or export markets. For this reason control is important. The pesticides used in this trial were found to impact on the secondary pest population however there was also a significant impact on the beneficial insect population or an increase in heliothis damage.

All of the pesticides, except for Gemstar®, could potentially be used for control of the other caterpillar pests. Xentari® and Success® would be the least disruptive to managing heliothis. For the control of thrips and aphids however these options are less favourable. Of the 'heliothis management' friendly pesticides, Success® will manage the thrips population but will have an aphid problem.

The frequency of spraying was probably not necessary for targeting every pest however may represent the total number of spray events required in a crops life. For example, sprays need to be applied during early silking for control of heliothis. The other caterpillar pests were not evident until after this time so there may need to be further spray events to target these pests, if the damage they cause is significant to the target markets for the produce. Control of aphids and dried fruit beetles may need alternative products to what were used in this trial. The most effective time for control of these pests, along with thrips, so as not to disrupt the biological control of heliothis is still not determined. Spraying before harvest to clean up the cobs, after the critical heliothis control time – is one option however targeting the pests may be difficult at this stage. Promoting more beneficial activity to prevent the build up of aphids and thrips in the crop is another tactic that would complement heliothis management.

Other pests such as two-spotted mite and green vegetable bug were not recorded in this trial, their presence would further complicate the issue.

Recommendations – scientific and industry
The issue of thrips and aphid control needs to be further addressed. This could be in the direction of registration of a pesticide for sucking/rasping pests control for use in sweet corn and that was soft on beneficial insects. Promoting ladybeetle, lacewing and parasitic wasp activity in the crop earlier than took place in this trial would integrate well with heliothis management. Alternative

timing for pesticide applications could be tried as part of a best management trial and any other products already registered for use in sweet corn may have some potential

Success®, Xentari® and Decis ®, used wisely, offer short term options for managing the other pests. However, cob contamination by pests such as aphids and thrips, can still be high.

Therefore, future work should focus on understanding and enhancing beneficial insect populations and finding narrow spectrum pesticides that target these pests.

Trial 2 Spring crops

Two commercial plantings in the Lockyer Valley Queensland were used for the trials. Each trial will be described separately with a final discussion to draw conclusions from both sets of results.

Farm 1

Material and methods

A commercial crop of Goldensweet planted in September, 2000, was used on Farm 1. The crop was treated with Gemstar® pre-silking and Trichogramma were released during the vegetative stage.

The crop was divided into 20 plots. Treatments were assigned to plots randomly. For practical purposes the unsprayed plots were located at the beginning or end of plots along the length of the planting. Unsprayed plots were 20mx24rows. The remainder of plots were 24 rows x 180m, adjacent to one another.

The crop was monitored twice per week in the first week of silking and then once before harvest, recording heliothis and other significant pests present.

Eggs were collected before any treatments were applied during silking and reared in the laboratory to assess egg parasitism. Ninety percent of the eggs were parasitised. Larvae were also collected and reared on artificial diet to assess the level of nuclear polyhedrosis virus (NPV) present in the heliothis population. Seventeen percent of heliothis larvae collected were infected with the virus.

At harvest 40 cobs per plot were assessed for the presence of pests and the extent of damage to each cob. Growers considered between 20 and 30% damaged cobs acceptable level of control for the local market. Control of minor pests such as thrips and a lower damage level was required for export market quality produce.

The planned pesticide treatments during silking were based on previous BMO/insecticide trials, with timing based on egg pressure as monitoring results were available (Table 1). Pesticides were applied at 400L/ha; 750L per tank. Pesticides were applied using a Hardi Alpha air assisted sprayer.

Table 1. Planned pesticide treatments on Farm 1

Pesticide[1]	Timing	Comment	$/ha
Gemstar® (NPV) only 300ml/ha *Gemstar*	Four applications @ 2,3,4 and 6 days from egg lay.	Last spray was not possible due to rain. Subsequent spray Day 14.	$90
Success® (spinosad) only 600ml/ha *Success Med.*	Two applications @ 3 and 7 days from egg lay	Only day 3, too wet to apply second application. Subsequent spray Day 14.	$187
Grower practice: Success® & Gemstar® as required. 800ml/ha *Success High*	Two-four applications depending on the pressure in the first 10 days of silking	The grower's timing was also interrupted by rain. The result being the timing for this treatment was the same as the Success® treatment, except for rate. No Gemstar applied.	$250
Fastac®/Marlin® (alpha-cypermethrin/methomyl) 400ml/2L/ha *Marlin/Fastac*	Applications every 2 days from egg lay.	Spraying was interrupted due to rain so only applied on Day 2 and 4 and then Day 14	$113
Unsprayed	Receive no pesticide applications		

1. Items in italics indicate term used to reference this treatment

Table 2. Spray diary and weather conditions of Farm 1, November 2000. Shading marks day of application or scouting. Lighter shading indicates planned spray times that were cancelled due to rain.

Gemstar®																	
Success®																	
Grower practice																	
Fastac®/ Marlin®																	
No spray																	
Weather						Rain	Too wet	Too wet	Rain								
Crop	80% silk																Harvest
Scout																	
Day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**18**	**21**
Nov	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**27**	**30**

Results

Grower's practice, Success® High, had the lowest proportion of damaged cobs at 11% chewed cobs (Figure 1). The Gemstar® and Success® Med. treated plants showed the next acceptable level of damage at 16% and 17% respectively. Although higher, they were not significantly different from the Grower's practice. Unsprayed plants had 22% damaged cobs while Marlin®/Fastac® treated plants had close to an unacceptable level of damage at 28%.

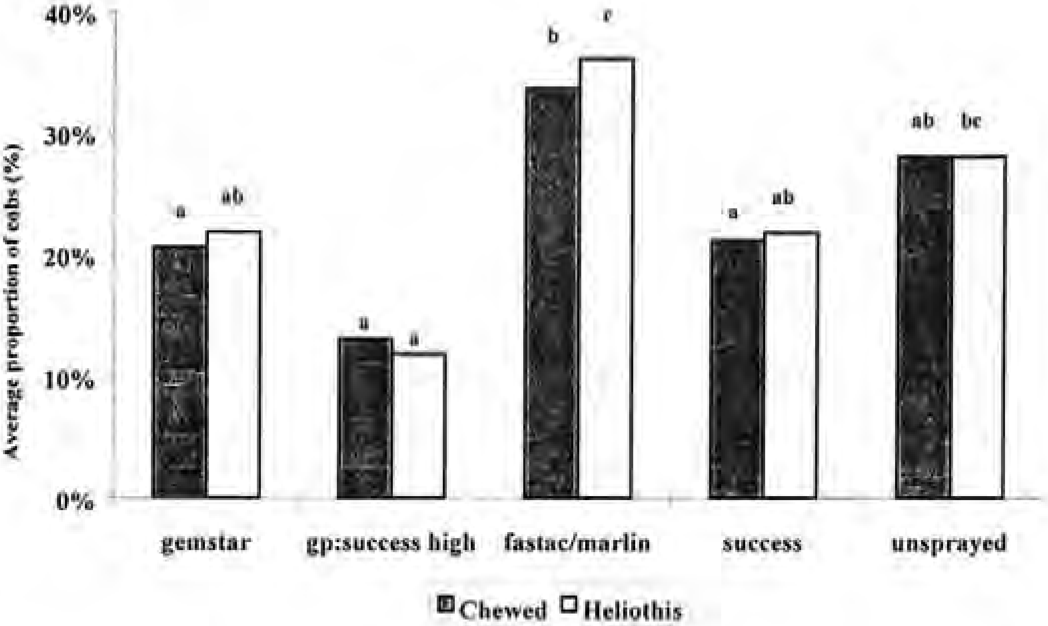
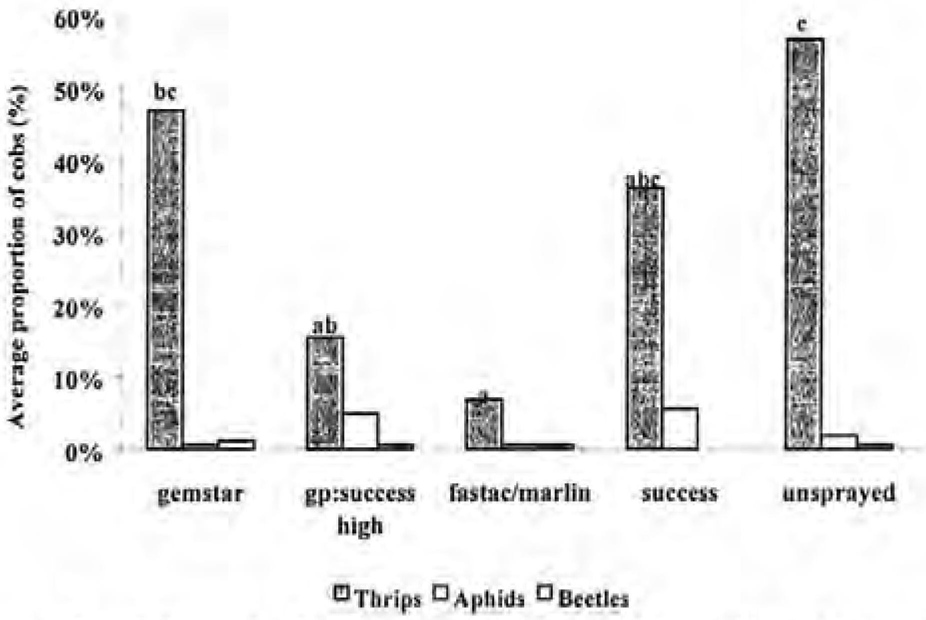


Figure 1 Harvest assessment for heliothis from a commercial planting on Farm 1, November, 2000. Values with the same letter, within each category, are not significantly different.

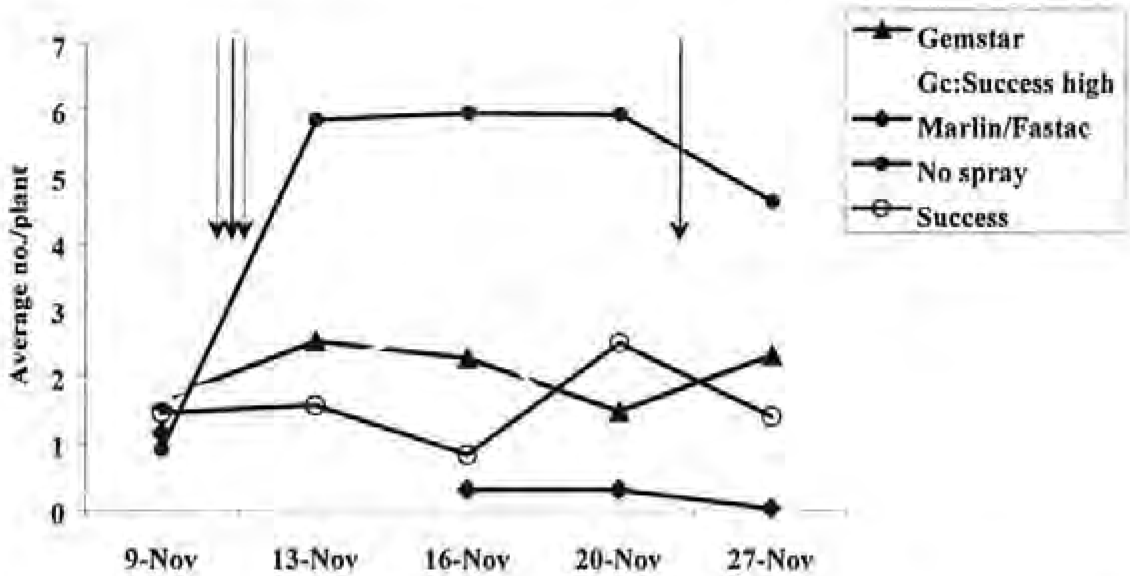
Thrips were the most significant minor pest that contaminated cobs (Figure 2). Fastac®/Marlin® treated plants had the lowest proportion of cobs contaminated with thrips (5%), significantly less than from Gemstar® or unsprayed plants (38% and 48% respectively).

Figure 2. The proportion of cobs with thrips, aphids and beetles present at harvest of a commercial



planting on Farm 1, November 2000. Values with the same letter, within each category, are not significantly different.

Figure 3. Average number of thrips per plant in each treatment from Farm 1. Arrows mark times of sprays. Refer to Table 1 for specific spray information.



Thrips, *Frankliniella williamsi* a common thrips found in maize, were present in the silks from the commencement of silking. Spraying prevented the number of thrips increasing 6-fold within four days (Figure 3). Plants that received pesticide applications maintained the same level of thrips, while that on unsprayed plants increased. Even an application of Gemstar® (specific to heliothis) maintained the level of thrips at 2.5 per plant. Despite the relatively low number of thrips in the Gemstar® and Success® treatments on the last day of monitoring, four days prior to harvest. The application in late November did not decrease the average number of thrips per plant but decreased the proportion of plants infested.

From all treatments there were less than 5% of the harvest contaminated with aphids or beetles (Figure 2). Plants treated with Success® had the highest proportion of cobs contaminated with aphids at 5% infested. There was no significant difference between treatments in the proportion of beetle contaminated cobs.

Summary

The Grower's practice of 2 applications of Success® at 800ml/ha, at Day 3 and 14 after 80% of the crop was in silk achieved the best control of heliothis and thrips. Gemstar® and Success® at 600ml/ha achieved similar heliothis control however thrips were not as well controlled. These results were achieved at heliothis pressure of an average of up to 2 eggs per plant.

Farm 2

Materials and methods

A commercial planting of Goldensweet planted in September 2000 was used for the trial. The whole planting was treated with Gemstar® prior to silking.

Twenty plots were marked within the crop. The unsprayed plots were 15m x 30m and the remainder were 15m x 50m.

Pest and harvest assessments were the same as for Farm 1. Egg parasitism was 61% at the start of silking and nuclear polyhedrosis virus infection at 15%.

Pesticide applications differed from Farm 1 (Table 3 and 4) however and were applied at L/ha using a John Deere 4200 air assisted boom sprayer with droppers.

Table 3 Planned pesticide treatments in trial on Farm 2

Pesticide [1]	**Timing**	**Comment**	**\$/ha**
Gemstar® (NPV) only 500ml/ha **Gemstar/Success**	Four applications @ 2,3,4 and 6 days from egg lay.	Success sprayed Day 11	\$215
Success® (spinosad) only 400ml/ha *Success low*	Two applications @ 3 and 7 days from egg lay	Success sprayed Day 11	\$190
Grower practice: Success® & Marlin® as required. 400ml/ha;2L/ha *(Success/Marlin)*	Two-four applications depending on the pressure in the first 10 days of silking	Success sprayed Day 11	\$215
Marlin® (methomyl) 2L/ha *(Marlin/Success)*	Applications every 2 days from egg lay.	Success sprayed Day 11	\$135
Unsprayed (*Late Success*)	Received no pesticide applications	Success was sprayed late in silking, Day 11	\$ 62

1. Items in italics indicate term used to reference this treatment

Table 4 Spray diary and weather conditions of Farm 2 from November to December, 2000. Shading marks the day of application or scouting.

Early Gemstar®/ late Success®											Success application							
Success®																		
Grower practice: Success®/Marlin® + late Success®			Success		Marlin		Success											
Early Marlin®/ late Success®																		
Early unsprayed/ late Success®																		
Crop	80% silk																	Harvest
Scout																		
Day	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**19**	**22**
Date (Nov/Dec)	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**1**	**4**

Results

Results from Farm 2 are yet to be statistically analysed so the discussion below is based on trends in the data.

The Success® and Grower's practice of Success® and Marlin®, treated plants had the lowest proportion of chewed and heliothis infested cobs at 11% chewed cobs and less than 5% cobs with heliothis present (Figure 3). Gemstar® treated plants had the next highest proportion of heliothis infested cobs at 20% chewed and 17% with heliothis present. Marlin® and unsprayed plots had close to unacceptable damage from 25-30% chewed cobs.

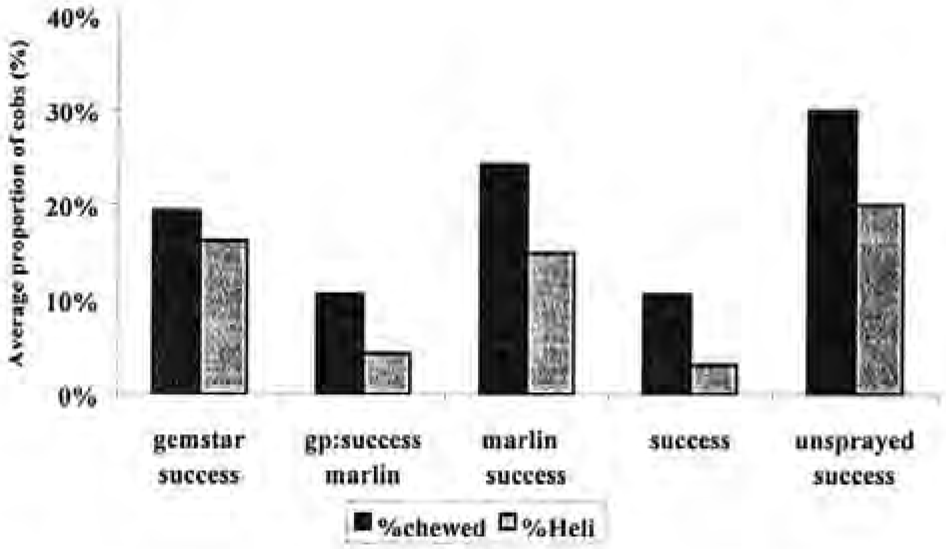


Figure 3. Harvest assessment for heliothis from a commercial planting on Farm 2, December, 2000.

The proportion of cobs infested with thrips was very low on Farm 2, with less than 10% infested from any treatment (Figure 4). This is despite there being a high level of thrips found (Figure 5), up to 30 thrips per plant on the silks and cob.

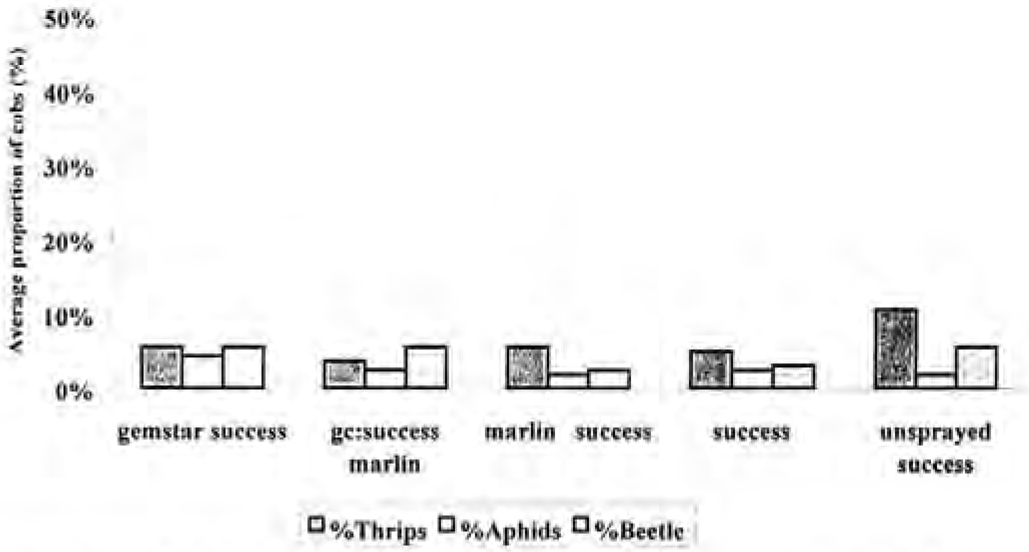


Figure 4. The proportion of cobs with thrips, aphids and beetles present from a commercial planting on Farm 2, December 2000.

The thrips species found on Farm 2 was a *Tubuliferan*, not a common pest thrips species. However it followed a similar pattern in activity to the thrips found on Farm 1, including sprays preventing the population increasing rapidly as silking proceeds. The application of Success® in late November across all treatments dramatically reduced the number for thrips present.

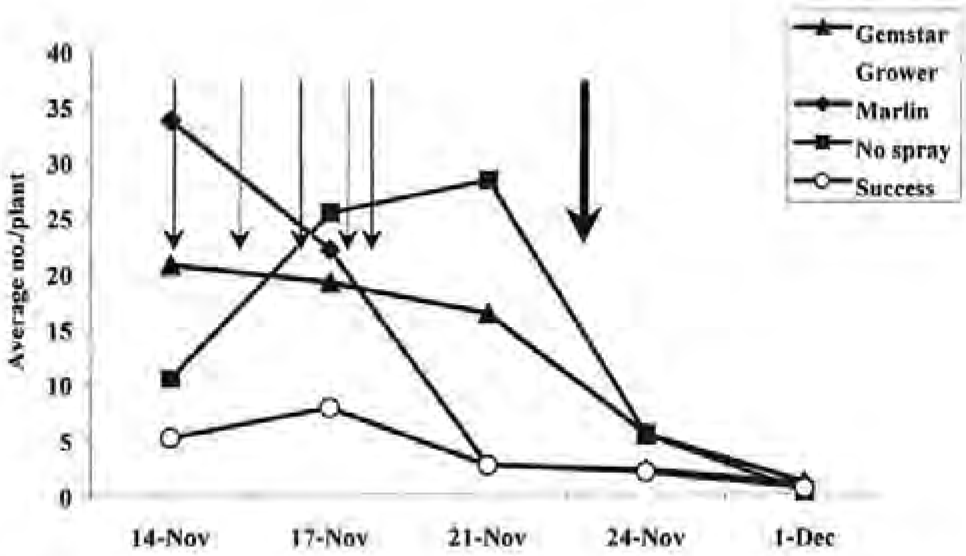


Figure 5. Average number of thrips per plant in each treatment applied to a commercial planting on Farm 2, November to December 2000. For exact spray information please refer to Table 4.

From all treatments there were less than 5% of the harvest contaminated with aphids or beetles (Figure 4).

Summary

The Grower's practice of alternating Success® and Marlin®, Success® and Gemstar® treated plants, accompanied by a late application of Success® on Day 11 after 80% of the crop is in silk, produced the best harvest results. This is considering both cob damage and contamination by pests. A late application of Success® or Marlin® during silking, followed by Success® in late silking, was close to inadequate control.

Discussion

Similar trends were seen on both properties. Success® and Gemstar® applications during silking achieved good management of heliothis while Success® and Fastac®/Marlin® and Gemstar® applications impacted on the thrips population. There may be some flexibility in rates and timing to achieve better results.

Despite similar levels of thrips present in plants close to harvest on the two commercial plantings there is a remarkable difference in the level of cobs infested with thrips between the properties (Figure 2 and 4).

Table 5. Summary of harvest results from Farm 1 and 2, including the number, type, rate and cost of pesticide applications.

Treatment	Rate ml/ha	Spray Early	Late	Heliothis % cobs	Thrips % cobs	Cost $/ha
Unsprayed		0	0	28	58	Nil
Late Success	400	0	1	30	10	62
Gemstar	300	3	1	20	48	90
Gemstar/Success	500/400	4	1	20	5	215
Success Low	400	2	1	10	5	190
Success Med	600	1	1	20	35	187
Success High	800	1	1	12	15	250
Success/Marlin	400/2L	2/1	1	12	5	215
Marlin/Fastac	2L	2	1	32	8	113
Marlin/Success	2L/400	2	1	23	5	135

Recommendations
Significance to pest management in sweet corn

- Two to three sprays of Success® or Gemstar® during silking of a spring crop under low Heliothis pressure (average less than one egg/plant) produced less than 30% damaged cobs.
- Monitoring is essential, despite the traditional high levels recorded in spring (Oct/Nov) it was not evident in 2001. A calendar spray program would have resulted in unnecessary applications.
- To achieve export market quality, total pest management is critical.
- Extending the range of management options for spring heliothis management is essential, as heavy reliance on Success® is not sustainable. Alternative biological or narrow spectrum pesticides will need registration. Recommendations for Trichogramma releases or other natural enemies are also required.

Technology Transfer
Trial results were presented at project workshops, in project newsletter and at a field day in Gatton, March 2000.

Recommendations – scientific and industry

The issue of management of other pests, especially thrips and aphid, in both spring and summer sweet corn needs to be further addressed. This could be in the direction of:

- Registration of a pesticide for sucking/rasping pests control for use in sweet corn, with an added feature of being soft on beneficial insects.
- Understanding and enhancing beneficial insect populations, such as ladybeetle, lacewing and parasitic wasps, early in the crop
- Alternative timing for pesticide applications could be tried as part of a best management trial and any other products already registered for use in sweet corn may have some potential

In the short term, assuming registration, Success®, Xentari® , Marlin® and Decis ®, used wisely, offer options for managing the other pests. The impact of each pest should always be considered before management takes place so as not to jeopardise management of other pests such as heliothis.

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8. Cultivar Assessment

This activity and associated outcomes have also been reported in :-

- Milestone 7. – "Cultivar evaluation trials to assess quality, yield and tolerance to pests and diseases" (2001).
- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – p 47.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 71 –84.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 110-112.

Cultivar Assessment (cont.)

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1. Introduction

The fresh sweet corn industry in Australia is relatively undeveloped. Per capita consumption of fresh sweet corn is low at around 4kg, about half that in the United States (Pataky and Mosely, 1995). In the USA, sweet corn is the third most consumed vegetable whereas in Australia it is the ninth most consumed vegetable (Pullar et al, 1993). Production in southern states is limited by shorter growing seasons while Queensland, with potentially longer growing seasons, is well suited to filling the production gaps and replacing a substantial portion of imported processed product with fresh sweet corn.). NSW produces 53% of the Australian tonnage from 2200 ha, mostly for the processed market while Queensland produces 19% of the Australian tonnage, mostly for the fresh market. Victoria produces 10% of the Australian tonnage for fresh domestic and export markets.

The industry is based on supersweet temperate cultivars which are less suited to production in the warmer months of tropical and subtropical Queensland. Many temperate corns have been of no value in the tropics where they grow very small with low leaf number and extreme earliness (Brewbaker, 1981). He found in tropical Hawaii all maize lines tested show some photoperiod sensitivity when comparing 12 and 16 hour days in the field. However, phenology studies in subtropical Bundaberg and Gatton in Queensland found that temperature was the most important factor contributing to development rate and photoperiod did not influence rate in the group of tropical and temperate hybrids which contained supersweet, (sh2) sugary extender (se) and sugary (su) types. (Olsen et al, 1993) In a separate study at Bundaberg, performance results for 6 temperate supersweet corn cultivars at three separate planting dates suggested that temperate supersweet (shrunken-2 or sh2) cultivar production should be limited to a midwinter sowing in subtropical Bundaberg because of higher disease incidence and heat stress encountered in later plantings. (Olsen et al, 1990).

The fresh market sweet corn industry in Australia has been heavily dependent upon temperate sh2 germplasm imported from the United States. The Snowy River Seeds Cooperative Ltd has been the major supplier of seed to this industry and has maintained a sweet corn breeding program for some years. While widespread testing of hybrids is undertaken by the company in the major sweet corn growing areas, adaptation to subtropical and tropical environments during the warmer periods of the year is often not satisfactory. The temperate hybrids often lack resistance to leaf blight *Exserohilum turcicum*, some are susceptible to common rust *Puccinia sorghii* and all lack resistance to the major virus disease, Johnson Grass Mosaic Virus *JGMV*. This virus affects sowings from November onwards in Queensland's largest sweet corn production areas of the Lockyer and Fassifern Valleys. Occasional incidence of *JGMV* has also occurred in North

Queensland. Just as the temperate germplasm is less well adapted to the tropics and sub-tropics, so is the tropical material poorly adapted to the temperate sweet corn growing regions of Southern Australia where the long summer days cause huge delays in flowering and plant height is excessive.

While this part of the "Insect Pest Management in Sweet Corn " project has been to evaluate cultivars for quality, yield and tolerance to pests and disease, emphasis has been on cultivar tolerance to insect damage. Anecdotal evidence has suggested that there are differences between some of the sweet corn cultivars grown in Australia in their susceptibility to heliothis damage. Field observations have shown that cultivars with more tropical adaptation such as *H5* and *Florida Staysweet* are more resistant to attack than temperate cultivars such as *Goldensweet*. The main difference observed between cultivars appears to be mechanical, with very tight husks and good husk coverage likely to provide some impediment to movement of larvae through the silk channel and consequently reduce the likelihood of reaching the cob and causing damage. This has been found in the USA where in a study of 27 commercial sweet corn hybrids, Wiseman and Isenhour (1994) found that damage ratings due to corn ear worm, Helicoverpa zea, were significantly correlated with husk tightness ($r = - 0.83$). The husk layer has also been implicated as a factor in the susceptibility of corn hybrids to infection by *F. moniliforme*. Farrar and Davis (1991) reported that Fusarium ear rot incidence was correlated with husk looseness at the brown silk stage of ear development.

Field trials to compare the susceptibility of a range of cultivars in Australia to heliothis damage as well as cultivar quality and performance assessments were carried out at Bowen in North Queensland in the 1998 and 1999 seasons and at Lindenow in East Gippsland in Victoria over the 1998 -1999 season. The following reports the findings from those investigations.

2. Materials and Methods

2.1 Bowen (R. M. Wright)

2.1.1 Cultivar Effects on Corn Ear Worm Damage

An experiment was conducted during the 1998 season using the major commercial sweet corn cultivars grown in Queensland to evaluate their attractiveness to heliothis. The cultivars were all supersweet types and were selected from temperate, tropical and temperate x tropical breeding programmes. The cultivars selected in this trial were *Goldensweet, Gladiator, Florida Staysweet, Pac 377, Punchline* and *H5*. They were sown over a period of seventeen days in order to have each cultivar flowering at the same time. Sowing dates for the cultivars tested were as follows:

H5 – 30-3-98 ; *Pac 377* – 7-4-98 ; *Goldensweet* – 8-4-98 ; *Gladiator* – 9-4-98 ; *Florida Staysweet* – 9-4-98 ; *Punchline* – 16-4-98 .

No pesticides were applied to the trial and the level of heliothis and other insect damage was recorded along with yield measurements, phenological events and cultivar characteristics. At maturity, cobs were harvested from two-row plots 5m in length, containing 40 plants per plot. Cobs were divided into various categories depending on the degree of heliothis damage. The damage categories used were as follows :

1. Nil damage. Can be packed as fresh whole cobs.
2. Silk damage only. May be trimmed and packed as fresh whole cobs (acceptable but not preferred by market) or used in pre-pack.
3. Tip damage (may include silk damage). May be trimmed and packed or used in pre-pack. Classified as fresh whole cobs for this experiment.
3. Tips damaged 0-2 cm. Pre-pack only.

5. Tips damaged 2-4 cm. Pre-pack only.
6. Tips damaged 4-6 cm. Pre-pack or reject if cob size is small; need minimum of 7 cm undamaged cob for pre-pack. Classified as reject for this experiment.
7. Tips damaged > 6 cm. Reject.

During the 1999 season, a second field trial was established comparing a range of supersweet cultivars for their tolerance to corn earworm damage. Five temperate and one tropical cultivar were selected. The cultivars were *Goldensweet, Gladiator, H5* (tropical), *Punchline, Sunsweet* and *Shimmer*. Unlike the previous seasons trial where the cultivars were sown over several weeks in order to have each cultivar flowering at the same time, all cultivars were sown on the same day, 21-5-99. A larger plot size was used in this experiment with plots being eight rows wide and 30m in length with two replications.

Pesticides were withheld from the trial and the level of corn earworm damage was measured in cobs at harvest. Five random sections within each plot consisting of a double-row with ten plants in each (twenty plants in each sub-plot) were sampled, giving a total of 100 plants in each of two replications per cultivar. Cobs were divided into various categories depending on the degree of corn earworm damage. A more simplified system of damage categories was also used employing only four categories. They were as follows:

Nil damage. Packed as fresh whole cobs.
Silk damage only. May be trimmed and packed as fresh whole cobs (less preferable) or used in pre-pack.
Cob damage at tip to as far as 4cm along cob. Pre-pack only.
4. Damage extending > 4cm. Reject.

2.1.2 Spray Penetration Trial (R.M. Wright, R. Battaglia)

In addition to the agronomic data collected from the 1998 trial, the opportunity was taken to examine the cultivar effect on spray penetration into the crop canopy. Strings were set up across each plot in the experiment at the tip of the tassels over the canopy and at silk height of the top cobs. Water containing dye was applied by two methods, i.e. by aerial and ground based application. In both instances, strings were collected and analysed for the reduction in dye penetration into the canopy from the top string to the string at the silk level, for each cultivar.

2.1.3 Cultivar Performance and Quality Aspects

Three cultivar trials were grown in the 1998 season. In the first trial sown in late May, eighteen cultivars were evaluated. These included the standard commercial hybrids as well as a number of new experimental hybrids from Snowy River, Hendersons, Yates, PAC Seeds, and Novartis. The second trial sown in early July was planted as a yield trial with 12 cultivars and 3 reps. A further evaluation of these 12 cultivars was made in an early September planting and used for a grower farm walk in early November. Cultivars tested are listed in Table 1.

In the 1999 season a cultivar screening trial to compare new available hybrids with the industry standards was grown in a late April sowing. This included twelve of the hybrids grown in the 1998 season and an additional five experimental hybrids. A further planting of all the available cultivars from the screening trials with some additional previously tested hybrids was sown in mid June 1999 for the benefit of industry members to view and examine at a field day in mid September. In a further planting sown in early August 1999, twelve cultivars were selected for a replicated yield trial. This included the industry standards for the region, (*Goldensweet* and *Gladiator)*, several which are being grown elsewhere such as the Lockyer Valley (*H5)* and southern Australia (*Sunsweet, Sovereign),* experimental hybrids which have had some commercial testing and others which have little or no commercial exposure (*Mecca, Pac377 ,H141, Shimmer, 1039, 1094, Dominion).*

2.2 Lindenow (R. Dimsey, Siva-Subramaniam, P. Ridland)

2.2.1 Evaluation of the Impact of Cultivar on Corn Earworm Damage and Cultivar Yield Comparisons

The aim of the 1998-99 field trial was to compare the susceptibility of a range of Australian cultivars to damage by H. armigera. Cultivars were planted in December so that plants would be silking when the period of peak insect activity was likely. In East Gippsland, based on data collected over the last 5 years, this occurs around the middle of February onwards.

The trials were planted on 21/12/98 in Lindenow, the centre of the main sweet corn production area in East Gippsland but away from commercial crops. The plots were established on the northern edge of a bean paddock. This paddock is broken up into segments using maize as windbreaks established prior to planting the trial. The maize is not sprayed with any pesticides and the trial plots were untreated with any pesticide.

Cultivars planted: *Golden Sweet, Krispy King, Dynasty (Improved), Shimmer, Gladiator, HY769, HY720, HY941, Golden Pearl, GS7831, Sno Sweet, Honey Sweet, Flair.* The cultivars were all planted at the same time and consequently there was some difference in the commencement of silking. This has the disadvantage that variation in damage may occur due to differences in moth activity at times of silking. The other option of staggering planting dates so that silking of all varieties coincided , would not be exact and some cultivars would be in exposed to a higher pest pressure over a longer period and this was deemed to be less satisfactory. The plots were planted using a hand seeder and later thinned. The plots were 4 rows wide, 6 metres long and replicated 3 times. Only the middle 2 rows and 4 metres of each plot were sampled.

Measurements.
Fifteen cobs were sampled from each plot and evaluated for grub damage. Husk tightness was evaluated on a subjective basis and rated 1-5. This ranged from extremely tight (1) to the cob being exposed (5). The length of the husk channel from the tip of the husk to the tip of the cob was measured but a loose husk could mean that a cob could be exposed and still have a long husk channel.

The position of the grub or damage was also rated from 1-6.
1 - silk damage only.
2 – the tip of the husk channel.
3 – middle of the husk channel.
4 – base of the husk channel
5 – cob tip (this also included side damage where it occurred).
6 – base cob damage (this occurs with loose husks and the grub enters the cob after going between the loose husk to the base).

The cobs were also rated as undamaged and marketable whole, marketable as a trimmed (topped and tailed) cob or suitable as domestic market with slight damage. The level of damage was rated from 1-3 with 1 = 0-2 cm of tip damage, 2= 2-4 cm of tip damage and 3= 4-6 cm of tip damage. The lowest level of damage (1) was rated as a potential domestic cob as a rough pass.

Thirteen cultivars were planted but for the yield and quality assessments only ten could be evaluated due to poor emergence of three cultivars.

3. Results

3.1 Bowen

3.1.1 Cultivar Effects on Corn Ear Worm Damage

In terms of susceptibility to heliothis damage, the characteristics recorded which would be expected to be of most importance are cob husk cover and tightness ratings. Overall, these ratings were best for *H5* and worst for *Goldensweet*, with the remaining cultivars intermediate. However, this expected damage trend is not borne out by the data for undamaged cobs (Table 2) where *H5* has the lowest % of undamaged cobs and *Punchline* the highest, with *Goldensweet* intermediate. This lower level of undamaged cobs in *H5* (significantly lower than *Punchline* and *Florida Staysweet*) may possibly be due to earlier planting and exposure to higher insect pressure in warmer conditions experienced soon after sowing. The insect population presumably remained in this cultivar through to silking in the absence of pesticide applications. *Punchline* on the other hand was sown latest of all and the cooler conditions may have been less conducive to build-up of the insect population in the pre-flowering stages. When fresh cob % (undamaged plus minor silk and tip damage) is compared (Table 2), *H5* fares better while *Punchline* is again the highest and *Goldensweet* the lowest.

Marketable cob yields (fresh plus pre-pack) were significantly higher for *H5* than all other cultivars except *Pac377*, which in turn out-yielded *Gladiator*, *Florida Staysweet* and *Punchline*. The % of marketable cobs however did not differ significantly between cultivars and revealed quite a high level of usage (73-87%) despite the high % of damaged cobs. However this usage of damaged cobs comes at a price with growers reporting an additional cost of around $4-00 per carton to undertake pre-packing.

TABLE 2

TOTAL YIELD AND COMPONENTS

Cultivar	Undamaged Cobs t/ha	% Undamaged Cobs (by number)	Fresh Cobs (including undamaged) t/ha	% Fresh Cobs (by number)	Pre-pack Cobs t/ha	Total Mkt. Cobs t/ha	% Mkt. Cobs (by number)	Reject Cobs t/ha	Total Cob Yield t/ha
Golden sweet	0.97	6.97	5.79	28	6.09	11.88	80.3	2.64	14.52
Gladiator	0.57	4.50	5.52	36	5.77	11.29	82.9	2.07	13.36
Florida Staysweet	1.25	8.54	5.04	39	4.60	9.64	73.6	3.00	12.64
Pac 377	0.84	5.09	6.84	34	8.24	15.08	80.6	3.04	18.12
Punchline	1.47	12.53	7.25	54	3.64	10.89	87.5	1.40	12.29
H5	0.10	0.55	9.94	44	6.90	16.84	80.8	3.56	20.40
LSD 5%	1.01	6.66	3.33		2.78	3.77	11.4	1.58	3.30

Cob numbers per plant formed (Table 1) did not translate into mature cobs as measured by total cob number per plant at harvest (Table 3). Potential cobs per plant over the cultivar range of 1.1 to 1.6 were not realised with a total mature cob per plant range actually harvested of 0.9 to 1.1, with *H5* and *Pac377* having significantly higher total cob yields (marketable plus reject) than the remaining cultivars.

TABLE 3

COB NUMBER / PLANT AND COB SIZE

Cultivar	Fresh Cob No/plant	Average Cob size g.	Marketable Cob no/plant	Average Cob size g.	Total Cob No/plant
Goldensweet	0.46	265	0.92	240	1.15
Gladiator	0.36	281	0.75	281	0.90
Florida Staysweet	0.34	275	0.66	276	0.90
Pac 377	0.43	293	0.94	301	1.16
Punchline	0.57	236	0.87	232	1.00
H5	0.53	351	0.87	362	1.07
LSD 5%	0.218		0.231	25.8	0.171

For the 1999 experiment, time to silking and time to harvest along with husk tightness and cover ratings for the cultivars tested are shown in table 4.

TABLE 4

CULTIVAR CHARACTERISTICS

Cultivar	Days to Silking	Days to Maturity	Husk Tightness Rating	Husk Cover Rating
Goldensweet	58	84	2.5	2
Gladiator	60	85	3.2	3
H5	68	94	5.0	4
Punchline	52	76	3.9	3
Sunsweet	54	78	2.8	2
Shimmer	62	88	3.5	3

Husk Tightness Rating

5 = very tight
4=tight
3 = firm
2 = loose
1 = very loose

Husk Cover Rating

5 = very long, 75mm beyond tip
4 = long, 50-75mm beyond tip
3 = average, 25-50mm beyond tip
2 = adequate up to 25mm
1 = ears protrude

As in the previous seasons experiment, the protection from corn earworm damage afforded by the husk cover and husk tightness characteristics were best for *H5* and worst for *Goldensweet*, with the other cultivars intermediate between these. However, this is not reflected in the damage caused to cobs as shown in Table 5.

TABLE 5

CULTIVAR DAMAGE CLASSES FROM CORN EARWORM

Cultivar	% Undamaged Cobs	% Silk Damage	% Pre-pack Cobs	% Total Marketable Cobs	% Reject Cobs
Goldensweet	74.3	3.8	21.3	99.5	0.5
Gladiator	78.3	4.4	15.2	97.9	2.1
H5	54.6	30.8	14.0	99.5	0.5
Punchline	62.8	6.8	24.7	94.3	5.7
Sunsweet	55.8	2.0	29.8	87.6	12.4
Shimmer	59.8	7.0	26.9	93.7	6.3
LSD .05	9.9	8.7	10.6	4.2	4.2

Goldensweet and *Gladiator* both had significantly more undamaged cobs than all other cultivars with *H5* having the highest level of damaged cobs, although not significantly different from

Punchline, Sunsweet and *Shimmer*. The major difference between *H5* and the other cultivars was the high level of damage to just the silks of *H5*, significantly higher than in all other cultivars. This was accompanied by a lower level of damage to the actual cobs of *H5*, as reflected in the percentage of pre-pack cobs. *H5* had significantly less cob damage than *Punchline, Sunsweet* and *Shimmer* but not significantly less damage than *Gladiator* and *Goldensweet*.

The high percentage of marketable cobs (and low percentage of reject cobs) reflects the moderate pressure from corn earworm experienced in this experiment. While the damage levels to any part of the cob were in the approximate range of 20%-40%, the degree of damage was relatively low. With the exception of *Sunsweet* which had significantly more reject cobs than all other cultivars, loss of yield through complete rejection was quite low (0.5%-6.3%).

3.1.2 Spray Penetration Trial

The cultivar characteristics (Table 6) which could be expected to influence spray penetration (plant height, cob height, leaves above cob, tiller number) appeared to have little influence from the results obtained in the spray penetration investigation. The deposit on string sampled at approximately cob height was reduced by 74-84% with aerial application and 37-63% with ground based application equipment (Table 4). Although there were some trends in the means an analysis of variance showed there was no significant difference in the average percent reduction in spray deposit between the varieties.

TABLE 6.

Average % reduction in spray deposit between two canopy heights and plant data for the aircraft and ground rig application.

Variety	% Reduction in deposit*		Tassel Height (m)	Cob Height (m)
	Aircraft	Ground Rig		
Goldensweet	83.4	45.9	2.31	1.00
Gladiator	83.3	52.7	2.28	1.03
Florida Staysweet	83.7	62.9	2.06	1.03
PAC377	82.3	63.0	2.28	0.98
Punchline	77.1	55.8	2.01	0.92
H5	74.2	37.4	2.56	1.07
Average	80.8	55.4		

* % reduction refers to the reduction in spray deposit from the top string to the bottom string expressed as a percentage of the top string deposit.

There was a consistent trend for the cultivar *H5* to exhibit lower reduction in spray deposit with both the aircraft and ground rig application. This variety was the tallest in the trial as its tassel height, 2.56m, exceeded all other varieties. It is unusual that the spray penetration was the best with this variety as the distance between the bottom string and top string at tassel height was the greatest with this variety. It would have been expected, given the greater depth of canopy, that the penetration of droplets between string collectors to be the lowest in this variety. This may suggest that there is something unique about the canopy structure (i.e. leaf orientation or possibly number of leaves) that offers less resistance to the passage of spray droplets through the canopy.

3.1.3 Cultivar Performance and Quality Aspects

For the 1998 season trials the entries tested and their performance are listed in Table 7. Results are from unreplicated plots. The 'B' grade cobs refer to the smaller or insect damaged cobs which are used in pre-packs.

Of the new experimental hybrids, *Shimmer* and *Sunsweet* showed the most promise, the major drawback with both being their paler kernel colour. Both have good husk colour and cover and attractive appearance. *941* had good cob appearance and good kernel colour but cob size was too small. *GSS7831*, a more disease resistant version of *Krispy King* produced cobs of good appearance with reasonable eating quality. Pericarp was slightly tough and texture was slightly starchy. It appears that this cultivar may pass through maturity fairly rapidly in tropical environments. *H141* produced quite good quality cobs but tip cover was variable with some tips exposed. Variation in kernel colour and reddish-pink tinges in the silks also detracted from its appearance. *PAC377* produced good quality cobs, but tip cover was variable, as was cob size. Basal blanking in some cobs was also of concern. This hybrid produced well but plant type has undesirable characteristics with tall, vigorous tillers.

Illini Gold yielded very well but cob quality was only fair with tip blanking, relatively pale kernels and below average sweetness and flavour. While *H5* yielded well and has been commercially available for some time, this cultivar is not popular with fresh market growers in the dry tropics region. The visual appearance and eating quality are considered inferior to cultivars such as *Goldensweet* and *Gladiator* despite the superior disease resistance of H5. Its major attribute is its resistance to Johnson Grass Mosaic Virus or JGMV which seriously affects sweet corn production in the Lockyer Valley but is of minor importance in North Queensland.

The second trial sown in early July was planted as a yield trial with 12 cultivars and 3 reps. However, heavy rain and strong wind at early silking caused severe lodging of the entire trial block which did not recover. The resulting pollination was nil to poor resulting in several cultivars producing almost no kernel set while a few cultivars produced reasonable set. Severe leaf blight (*Exserohilum turcicum)* developed in the block and the only useful data gathered was a rating for *Turcicum* blight. This is included in Table 7 for the cultivars tested. The only additional cultivar tested in trial 2 was the bicolour *Madonna* that produced some excellent quality cobs despite the conditions and also had a low incidence of *Turcicum* blight. This cultivar is well worth further testing.

A further evaluation of these 12 cultivars was made in an early September planting and used for a grower farm walk in early November. Conditions for leaf blight were again favourable and growers were able to see the large cultivar differences in susceptibility. The earlier ratings for this disease were confirmed. Grower interest in the cultivar *Shimmer* was strong with its high level of resistance and good quality attributes. Of the cultivars which had a high incidence of leaf blight, *Goldensweet* is a major cultivar used in North Queensland and this susceptibility is a concern expressed by growers. The higher level of resistance in *Gladiator* makes it a choice for early season plantings in North Queensland when the likelihood of wet weather is higher promoting the higher risk of *Turcicum* blight occurring.

Table 7. (Combined trial 1 and 2 results 1998)
Cob Maturity Yield and *Turcicum* Ratings

Variety	Days to 50% silk	Days to maturity	Marketable Cobs/plant	Av cob size in husk (g.) A grade	B grade	Total Mkt yield t/ha	% A grade cobs	Turcicum Blight Rating (1-10)
Golden Pearl	53	77	1.05	356	201	17.8	76	-
Honeysweet	49	73	0.70	-	272	10.1	0	-
Florida Staysweet	58	84	1.35	304	187	20.3	81	-
Illini gold	55	81	1.80	309	209	26.5	67	8.0
H5	68	92	1.00	414	271	26.1	73	-
Cabaret	54	78	1.05	297	194	15.4	81	-
Green & Gold	51	75	0.90	*Av	336	16.1	6	8.0
Mecca	57	82	1.35	338	251	23.1	81	3.0
Sunsweet	54	78	1.00	*Av	338	18.0	35	3.0
Punchline	52	76	1.15	276	159	15.3	78	1.0
H141	66	90	0.95	407	227	20.1	95	-
Headstart	55	80	1.50	333	225	23.5	63	8.0
Goldensweet	57	82	1.15	305	206	17.6	83	6.0
Shimmer	60	86	1.00	334	207	16.8	85	2.0
GSS7831	55	80	1.15	345	188	20.3	91	7.0
PAC 377	60	86	1.40	298	195	20.6	79	6.0
941	58	82	1.15	257	160	14.2	74	8.0
Gladiator	59	84	1.00	335	-	17.8	100	3.0
Madonna	-	-	-	-	-	-	-	3.0

* Separation of A and B grade cob sizes unavailable

Rating 1 – Nil affected; 10 – 100% affected

. Maturity and yield data from single plots in the 1999 screening and maturity time for the field day planting are shown in Table 8. The maturity data are shown as sowing 1 and sowing 2 for the screening trial and field day trial respectively. The plantings in 1999 were relatively free of disease so no assessments on cultivar susceptibility to disease could be made in these trials. The days to maturity in Table 2 demonstrates the large difference in maturity time as temperatures experienced become cooler. Maturity time differences between cultivars in warmer periods are much less obvious.

Table 8

1999 Sweet corn Cultivar Screening

Cultivar	*Days to Maturity*		Mkt. cob Number/ Plant	Mkt. Cob wt t/ha
	Sowing 1	Sowing 2		
1076	68	80	0.90	12.73
Punch line	70	-	0.95	11.69
720	71	79	0.95	13.52
Sovereign	73	85	0.95	16.04
Head start	73	84	1.00	12.45
Madonna	75	82	0.95	15.37
Shimmer	75	87	0.95	12.93
Goldensweet	75	88	0.95	13.43
Mecca	76	86	1.00	14.69
1032	77	85	1.10	15.54
Pac 377	77	90	1.00	13.53
Florida Staysweet	77	-	1.00	15.37
Gladiator	77	87	0.90	12.95
1100	78	-	0.80	12.38
1094	78	91	0.95	13.80
H141	88	96	1.00	17.34
H5	92	99	0.85	16.86

For the August 1999 planting, maturity and yield data for the twelve cultivars in the replicated yield trial are shown in Table 9. Fresh cob yield is that which can be packed as whole cobs while the smaller and damaged cobs are in the pre-pack category.

Table 9
1999 Sweet Corn Cultivar Yield Trial

Cultivar	Days to Maturity	Fresh Cob Yield t/ha	Pre-pack yield t/ha	Total Mkt Yield t/ha
Shimmer	74	11.80	2.99	14.80
Mecca	73	14.78	1.70	16.49
Sovereign	73	9.06	6.20	15.26
Sunsweet	72	12.32	4.25	16.57
Goldensweet	74	12.22	2.11	14.33
Gladiator	75	11.84	3.00	14.85
Dominion	75	12.23	3.21	15.45
1039	71	12.05	3.65	15.71
H5	84	16.98	2.37	19.35
H141	81	15.48	7.69	17.18
PAC 377	75	12.62	4.96	17.58
1094	75	9.68	4.19	13.87
LSD $\leq$ .05	-	2.88	2.61	1.73

Of interest in the yield data presented in the three tables is the relatively consistent higher yields obtained with the tropical hybrids *H5* and *H141* and the tropical x temperate hybrid *Pac377*. By comparison, the temperate standard cultivars *Goldensweet* and *Gladiator* tended to be towards the lower end for total marketable yield. This is particularly so in the replicated trial where these cultivars significantly out yielded *Goldensweet* and *Gladiator* for total marketable yield. In this trial, the five highest yielding cultivars for both fresh cob and total marketable yield are *H5, H141, Pac377, Mecca* and *Sunsweet*. None of these cultivars are grown in the dry tropics region of North Queensland, although *Mecca* and *H5* have had limited commercial use. The industry standard cultivars *Goldensweet* and *Gladiator* and the promising newer hybrids *Dominion, Shimmer* and *1094* were in the middle to lower order of yields in both categories. These cultivars also were of most interest at the 1999 field day.

3.2 Lindenow

3.2.1 Evaluation of the Impact of Cultivar on Corn Earworm Damage and Cultivar Yield Comparisons

Poor germination and stands resulted in plant stands too poor to harvest for 3 cultivars. These were *Krispy King, GS7831*, and *Dynasty Improved.* This was in part due to heavy rain just after seeding however the remaining 10 cultivars produced adequate stands and plant densities.

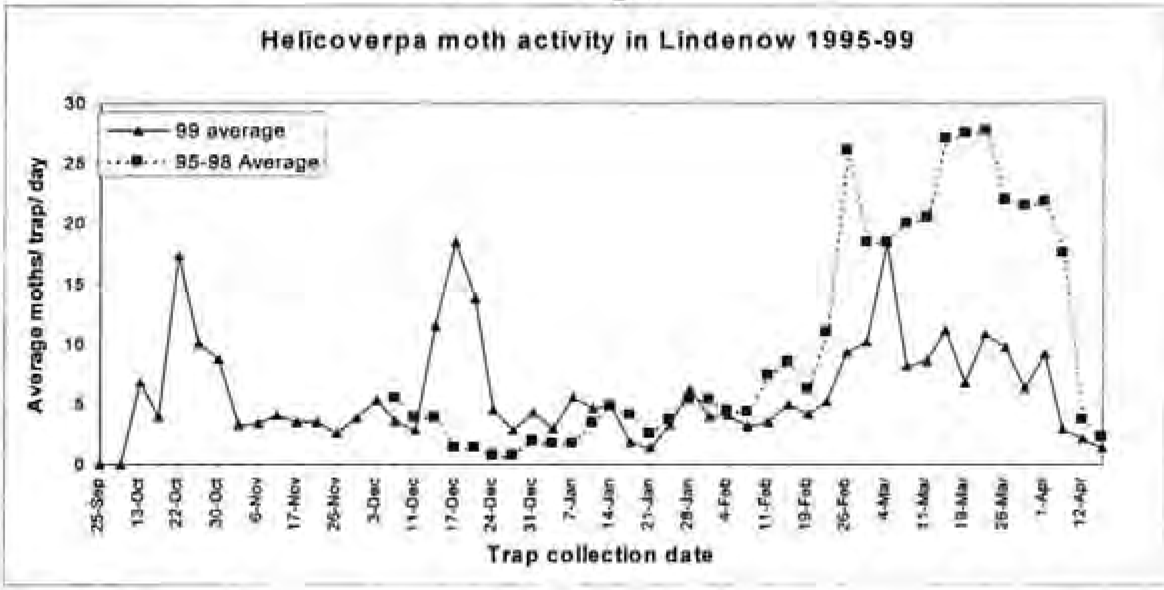
The harvest dates and days to planting are shown in the table 9 as well as a comparison of the physical parameters, husk tightness and the length of husk cover from the tip of the cob to the end of the husk channel. Husk tightness was rated on a scale of 1-5 with and extremely tight husk (1) and an exposed cob (5).

Table 9

Cultivar	Harvest Date	Days Planting to Harvest	Husk Tightness 1-5	Husk Cover Length mm
Honey Sweet	10/3	77	4.1	36
HY769	10/3	77	2.5	34
HY720	23/3	90	3.6	35
Flair	23/3	90	4	35
Golden Pearl	24/3	91	4	44
Sno Sweet	24/3	91	2.9	38
Golden Sweet	29/3	99	3.7	23
HY941	29/3	99	3.3	34
Gladiator	1/4	102	3.8	27
Shimmer	1/4	102	3	32
			$LSD_{.05}$=.38	$LSD_{.05}$=7.5

The earliest silking cultivars were *Honey Sweet* and *HY769* with silking beginning around the 10th of February. Moth activity in the area is shown in the following graph (Fig. 1) and indicates more consistent activity during this period in comparison with earlier in the year.

Fig 1.



The cultivar *HY769* had a significantly tighter husk than any of the other cultivars. *Sno Sweet*, and *Shimmer* also had tight husks but there was a marked difference between those and *HY769*.

Husk length was much more variable but differences were still evident between cultivars. However husk length was irrelevant when considering whether or not the cob was exposed for it was quite possible to have an exposed cob with a long husk channel, the cob being exposed out the side of a loose husk.

The results of the cultivar comparison are shown in table 10.

Table 10

Cultivar	Undamaged Cobs %	Damaged Cobs %	Domestic cobs %	Tip Damage Rating 1-3	Not Marketab le %	Grub Damage Position 1-6
Honey Sweet	13.3	66.7	26.7	2.2	3.3	4.9
HY769	43.3	53.3	53.3	1.2	3.3	4.3
HY720	23.3	73.3	33.3	1.7	3.3	4.8
Flair	28.7	66.7	21.0	1.8	6.7	5.0
Golden Pearl	11.7	85.7	22.7	2.0	2.7	5.0
Sno Sweet	30.7	58.7	7.7	1.6	10.7	4.6
Golden Sweet	23.3	76.7	30.0	1.8	0	5.0
HY941	30.0	70.0	40.0	1.6	0	4.5
Gladiator	23.3	76.7	16.7	1.8	0	5.1
Shimmer	20.0	76.7	20.0	1.9	3.3	4.9
	NS	NS	NS	NS	NS	LSD $P_{.05}$=0.33

The only statistical difference between cultivars was in relation to the position where the grub damage occurred. Only one cultivar, the tightest husked *HY769* had an average value approaching 4 indicating that in the majority of cases where damage occurred, the grub did not penetrate the end of the husk to the cob tip. *HY941* which also had a reasonably tight husk was similar to *HY769*.

A rating above 5 it indicates that there was damage at the base of the cob. This was the case where the husk (not just the tip) was very loose and occurred on Flair and *Gladiator*.

Although *HY769* appears to have a higher level of undamaged cobs there was still some variability within plots with a number of different cultivars having some plots with similar numbers of cobs unaffected by grubs. Consequently there were no differences between cultivars.

There were very few cases where cobs were considered unmarketable and it was due to either side damage or base damage of the cob rendering them unsuitable for topping and tailing and marketing as a trimmed pre pack product.

The tip rating indicates the amount of grub damage to the cob. It would be expected that the looser the husk and the easier access to the cob would result in those cobs showing greater levels of damage. This was not demonstrated by the trial results probably due to the variability of damage, the impact of different silking times and timing of moth flights.

Impact of Husk Characteristics on Damage

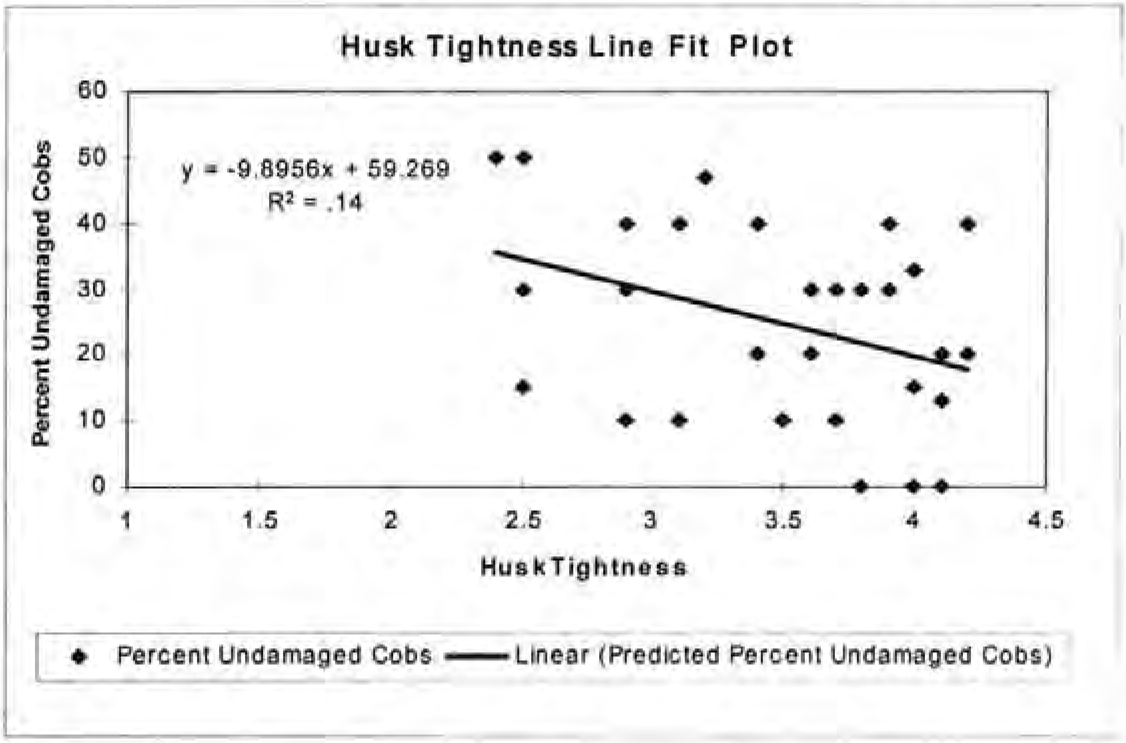
There was no significant correlation between the degree of husk tightness and husk length covering the tip ($P>.05$, $r=0.07$). This was due to situation where a cob could be exposed out the side of a loose husk but still have a long husk cover.

There were no correlations of husk tightness against the percentage of cobs suitable for domestic market or suitable for the production of trimmed prepacked cobs. The latter because all damaged cobs are suitable for pre-packs, as long as there is a minimum useable length of 7cm of cob.

There were significant correlations between the husk tightness and the percentage of undamaged cobs ($r = 0.38$), the grub damage position ($r = 0.68$) and the damage rating level ($r = 0.49$).

With an increasing level of husk tightness the, going down the scale the number of undamaged and marketable cobs increased. As can be seen from figures 2, 3 & 4 this relationship is not as strong as for the other two parameters.

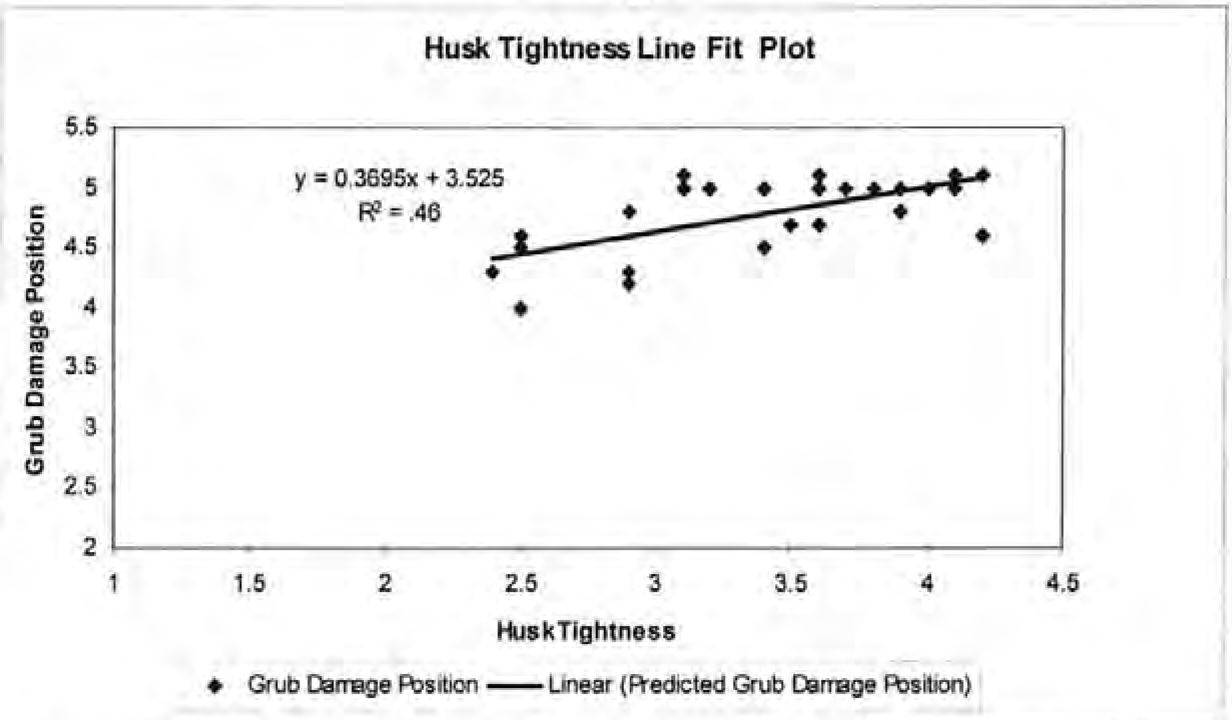
Fig 2.



The correlation of increasing husk tightness with the grub damage position is stronger as can be seen in the following graph. As husk tightness increased the number of grubs that made it all the way to the tip of the cob decreased.

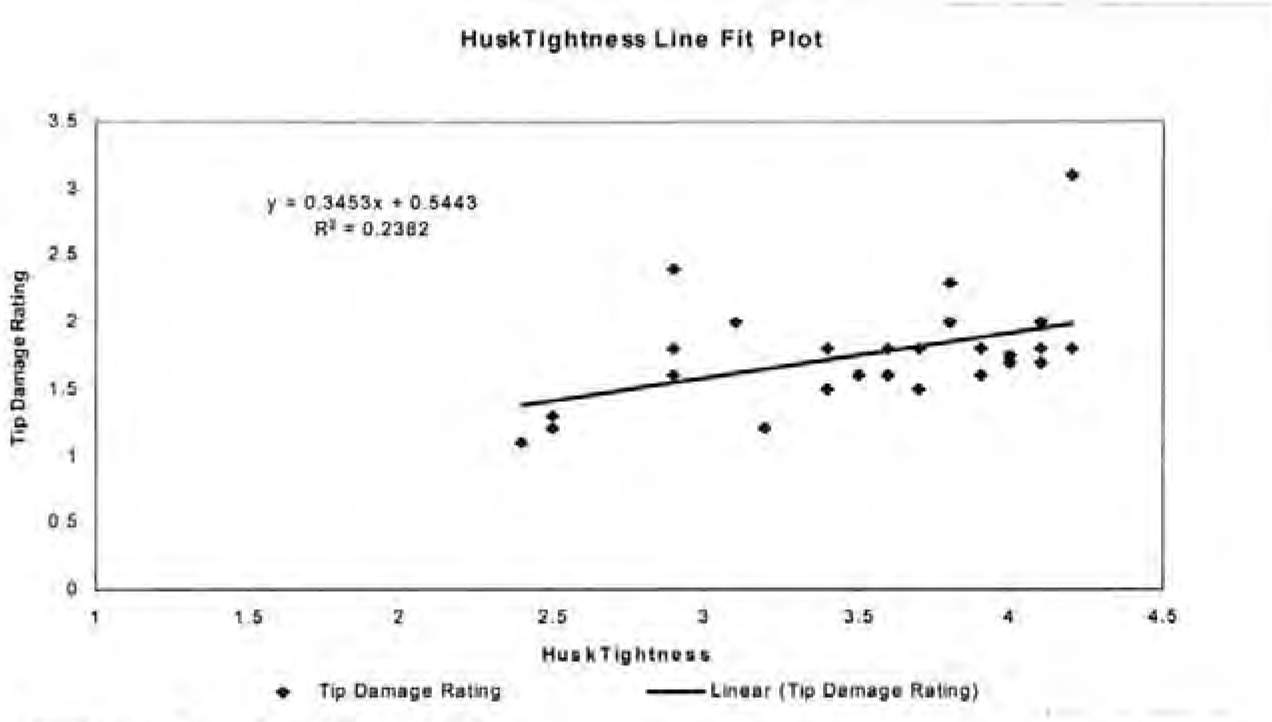
This indicated that the degree of husk tightness could provide some impediment to the movement of the grub into the tip of the cob.

Fig3.



There is also a very strong correlation of husk tightness with the degree of damage to the cob with a tighter husk reducing the amount of damage when grubs did get to the cob. This presumably again is a function of slowing down the progress of the grub through the silk channel and into the cob.

Fig 4.



Yield Comparisons from Cultivar Trial

Thirteen cultivars were planted, but the plant stands from *GS 7831*, *Krispy King* and *Dynasty* were too poor in this planting to evaluate these cultivars. This was due to a low plant population due poor germination and consequent low emergence.

Of the cultivars compared for yield, *Golden Pearl* had a lower germination percentage than most of the other cultivars. This consequently results in a low yield per square metre. The yield results are indicated in table 11.

Table 11

Cultivar	Cob weight with husk gm	Husked cob weight gm	Husked cob length mm	Husked cob diameter mm	Tip fill 1-10	Yield of 1st cobs/m^2 kg
Honey sweet	356	270.6	196	47	9.1	1
Hy 769	339.6	224.9	191	44	10	1.03
Hy 720	408.2	335.6	207	50	9	1.32
Sno sweet	425	324.6	199	50	8.7	1.05
Flair	443.1	367.1	197	53	8.7	1.55
Golden Pearl	475.6	387.8	203	54	9.6	0.78
Hy 941	366.2	281.4	182	49	9.7	1.05
Golden sweet	441.2	345.3	199	51	9.4	1.47
Shimmer	448.8	335.4	194	52	9.2	1.27
Gladiator	442.4	354.3	201	53	8.6	1.4
LSD=.05	35.8	35.63	10.9	2.3	0.4	0.35

The yield per square metre is based on the 4 metres of double row sampled with 0.8 metres between rows and based on 6.4m^2

The best yielding cultivars were *Flair*, *Golden sweet*, *Gladiator*, *Hy 720*, and *Shimmer* on an area basis. This is a function of plant population and the cob weight.

There were significant differences between cultivars in relation to tip fill but since all cultivars were planted at the same time silking was not the same for all cultivars and it is the conditions at silking that have a significant impact on tip fill. Consequently the tip fill comparisons may not accurately reflect the comparative performance of the cultivars. *Hy 769*, *Golden Pearl* and *Hy 941* were the better performing cultivars in relation to tip fill.

Golden pearl, *Flair* and *Gladiator* produced the largest cobs after the husk was removed and *Golden Sweet* and *Shimmer* were not significantly less in weight than *Flair* and *Gladiator*.

However in terms of flavour and tenderness subjective assessment rates *Hy 941* and *Golden Sweet* as the best cultivars followed by *Hy769*, *Golden Pearl*, *Krispy King* and *GS 7831*.

Other pests and diseases were not a major issue in this trial with some small amounts of rust present on susceptible cultivars. *Gladiator*, *Golden Sweet* and *7831* have rust resistance and *Golden Pearl* some rust tolerance. There an outbreak of aphids within the trial but since no pesticides were applied this was quickly cleaned up by natural predators. This natural control would have been helped by the isolation of the trial from other corn crops and the low incidence of pesticides used on the adjoining bean crops.

Northern leaf blight occurs occasionally and when it does may cause some problems. However its incidence varies from year to year and when it does occur is generally late in the season when its impact is limited. In this cultivar evaluation there was no incidence of the disease and tolerance could not be assessed.

Of the cultivars evaluated currently the main ones grown in Victoria are *Honey Sweet*, due to its earliness and *Golden Sweet*. *GS 7831* will probably be grown more extensively in the future. For the cultivars evaluated, this trial produced no evidence that any of the other cultivars were significantly better in terms of yield and quality.

Discussion

4.1 Bowen

4.1.1 Cultivar Effects on Corn Ear Worm Damage

For the 1998 trial, the lack of confirmation of the anecdotal evidence for consistent differences between cultivars in their susceptibility to heliothis damage may be partly due to the conditions of the experiment in terms of plot sizes and sowing time differences. The behaviour of the insect and its interaction with cultivar phenology and environment are undoubtedly complex and the simplistic approach taken to withhold pesticides and aim for uniform flowering stages may not be appropriate, since this does not occur under commercial conditions where cultivar differences have been observed. Further trials will test larger plot sizes and simultaneous sowings. The use of BMO's may also add a further dimension to these studies.

Again in the 1999 experiment, consistent differences between cultivars in their susceptibility to corn earworm damage have not been established in these relatively small plot experiments. The only indication from this experiment was the possibility that the tight protective husk cover of *H5* may have slowed down the movement of larvae along the husk channel to the cob. However this is uncertain due to the differences in flowering times and the relatively low levels of damage in cultivars with less husk protection.

While these experiments have been unable to establish a benefit of superior husk protection in reducing corn earworm damage in the range of cultivars tested, the field experience of industry members suggests that cultivar differences exist as well as evidence from the US study. While other cultivar characteristics such as husk colour, kernel colour, eating quality and market acceptability are more likely to influence cultivar choice than a perceived level of resistance to corn earworm damage, nevertheless a high level of husk protection is desirable to eliminate water from entering cobs during wet weather and to provide protection to the kernels during harvesting and transport operations. Good husk cover protection on cobs is a desirable plant breeding objective and should be aimed for in the production of new cultivars.

4.1.2 Spray Penetration Trial

From the spray penetration trial the results need to be treated with some caution since the small size of the experimental block may have influenced the aerial application results. Additionally, the high application rate with the ground rig of 1320l/ha was not commercially realistic. Further experiments are required to verify results before too many conclusions can be drawn.

4.1.3 Cultivar Performance and Quality Aspects

Growers have indicated that while yield is a consideration, cob quality is of utmost importance and demand is higher for the more attractive and superior eating quality cultivars. Important features noted by growers were a dark green husk colour, relatively tight husk cover with good cover over the tips of the cob, presence of flag leaves, straight kernel rows, 16-18 rows, bright yellow or golden kernels, deep kernels with flattened rather than rounded ends, tender kernels with high sweetness and flavour, cylinder shaped cob with rounded rather than tapering end. Plants should be erect and not prone to lodging, cobs at medium height, few or no tillers, resistant to common rust (*Puccinia sorghi,)* leaf blight (*Exserohilum turcicum)* and preferably *JGMV* and with good seedling vigour and high germinability.

From the trial data collected and the observations made, a summary of the cultivars tested and their likely place in the fresh market industry in the dry tropics is as follows:

Industry standard cultivars.
Goldensweet - Currently the major cultivar grown in the dry tropics region. Excellent eating quality and cob appearance with bright golden kernels, tender pericarp and dark green husk with abundant flag leaf. Grown through the main season, not high yielding but fairly consistent. Main disadvantages are its loose husk cover, high tillering tendency and susceptibility to leaf blight. This cultivar has dominated the industry for many years and major efforts to replace it have been intense. Recent improvements in seed quality have assisted this cultivar.

Gladiator - Has become established since the mid 1990's as a robust cultivar. Used often for early and some late plantings. Has relatively good leaf blight resistance, good eating quality, tight husk cover, dark green husk colour and few tillers. Main disadvantage is the paler kernel colour. Cob size can sometimes be too large.

Occasionally used cultivars.
Florida Staysweet - Has been grown on occasions in earliest plantings. Tight husk appears to afford some insect protection and this cultivar can produce high yields. Eating quality is average. Main disadvantage is its susceptibility to common rust which is more problematic in late season sowings. An old cultivar which has generally been replaced by *Gladiator*.

Headstart - More recent cultivar (mid 1990's) which has similar eating quality to *Goldensweet*. It matures earlier than *Goldensweet* and has been used as a catch-up option when normal sowings are delayed. Main disadvantage is its susceptibility to common rust and leaf blight.

Commercially tested but generally not grown.
Krispy King - Attractive cob, good eating quality, used elsewhere for processing. Main disadvantages are the low cob height in this environment which causes problems with harvesting and its high susceptibility to diseases. Poor seed quality problems have also been an issue with this cultivar.

H5 - High yielding cultivar due to large cob size. Resistant to *JGMV*, common rust and moderate resistance to leaf blight. Popular cultivar in Lockyer Valley for fresh market and processing due to *JGMV* resistance. Main disadvantages for fresh market are its lack of flag leaf, tough pericarp, tip blanking and lower eating quality than the standard cultivars.

Punchline - Attractive cob, good eating quality, very uniform plants, early maturing. Has been considered as a catch-up cultivar, but main disadvantage is its smaller cob size under North Queensland conditions. It is also susceptible to common rust.

Mecca - High yielding cultivar, average to good eating quality. Main disadvantage is the tedency for the plant to lodge making harvesting difficult. Tapering cob shape is also less desirable.

Pac377 - High yielding cultivar, first of the tropical x temperate hybrids. Attractive looking cob with good tip-fill. Disadvantages are its relatively tough pericarp, lack of flag leaf, variable degree of tip cover, non-uniformity of cobs, basal blanking(lack of kernel set at the base of the cob) in some cobs, produces many large tillers. Likely to be discontinued.

Tested experimentally and commercially and showing promise.
Shimmer - Newer cultivar with attractive cob and good eating quality. Kernel colour paler than *Goldensweet* but acceptable. Has good resistance to leaf blight. Results from commercial testing in 2000 have been mixed with some problems of poor cob setting. Future for this cultivar is undecided.

Dominion - Only limited testing so far. Attractive cob with dark green tight husk, good kernel colour. Amongst the better yielding temperate cultivars after limited testing Some problems with harvesting have been reported but still appears to have promise.

1094 - Similar quality attributes and cob and plant appearance to *Gladiator* but with improved kernel colour. This cultivar may replace *Gladiator*.

Experimentally tested but unlikely for commercial production.
720 - Early maturing cultivar which showed promise for catch-up plantings. Good eating quality. Major disadvantage is the high proportion of 'fasciated cobs'(flattening of the cob lengthwise to give an oval shape in cross-section), also referred to as 'bears paw'. This condition has been found in 30%-50% of cobs in experimental plots and was observed at high levels in a commercial trial in 2000.

H141 – Tropical cultivar with significantly more tender pericarp than *H5* and showed promise earlier as a possible improved quality tropical type. Major disadvantages are its variable kernel colour with varying shades of yellow, shallow kernel depth, tendency for the cob to become exposed through the husk at the tip, pale green husk and lack of flag leaf.

Sunsweet – Showed some promise with a reasonable level of leaf blight resistance, good husk cover and attractive appearance. Main disadvantages are its pale kernel colour and lower eating quality lacking sweetness with a starchy texture.

*Sovereign (*formerly *GSS7831)* – Similar cob shape and size to *Krispy King* but with a higher cob height. Has resistance to common rust. Main disadvantage is its tougher pericarp and susceptibility to leaf blight.
Illini Gold – High yielding in limited testing. Main disadvantages are its poorer sweetness and flavour than the standard cultivars, tip blanking and pale kernels.

1039 – Attractive cob, good eating quality, early maturing. Main disadvantage is its small cob size.

941, 1032, 1076, 1100 – All tested experimentally but have been discontinued.

4.2 Lindenow

4.2.1 Evaluation of the Impact of Cultivar on Corn Earworm Damage and Cultivar Yield Comparisons

The main objective of the trials was to assess the impact of cultivar on susceptibility to corn earworm. The evaluation in terms of yield and other pest and disease incidence was secondary.

The trials demonstrated that there were no clear differences between the varieties tested, in their susceptibility to attack by corn earworm. It did demonstrate that there are cultivar differences in husk tightness, length and other physical parameters but this was known. What was unknown was the effects of these, if any, on the potential to resist attack by corn earworm. For the current and potential commercial cultivars grown in southern Victoria the differences in these physical characters were not large enough to provide significant resistance to attack by corn earworm.

It must also be remembered that different cultivars silking at different times may be exposed to different levels of pest pressure due to the timing of moth flights. The earliest silking cultivar, Honey Sweet, when scouted during the period of silking of the majority of cultivars had the highest numbers of grubs already present.

The trials however did indicate a relationship between the tightness of the husk and the number of undamaged cobs, the penetration of the grub into the cob and the amount of damage to the cob caused by the grubs. A tighter husk appears to retard the movement of the grub through the husk and into the cob. However none of the cultivars evaluated, had what could be deemed as the tightest possible husk, that is, something as tight as maize or the Queensland cultivar *H5*. Consequently that extreme could not be tested.

However given that no such variety is commercially available, the trial data shows no difference between cultivars, even though a tighter husk appears to have reduced the impact of earworm attack on the cob. There were also no new outstanding cultivars identified in terms of yield and the impact of pest and disease.

It may be that an extremely tight husk, if such a commercial cultivar were available, may provide enough additional resistance to grub movement to aid in control and reduce the amount of damage. It must also be remembered that although the trial was carried out at the time of peak pest pressure that the pest pressure in Victoria is much lower than in other production areas such as Queensland.

The issue will be to balance yield and quality parameters with the physical parameters for tight husk to slow down the incursion of Helicoverpa. Unless cultivars with good commercial characteristics and an extremely tight husk becomes available there would appear to be no benefit in pursuing this line of investigation further. The development of resistant temperate cultivars remains a challenge for Australian researchers.

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8. Near Infra-red Technology

This activity and associated outcomes have also been reported in :-

- Milestone 8 – "Assessing Near Infra-red technology for use in mechanically sorting damaged sweet corn cobs" (2001).
- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 51-52.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 86 –93.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – p 109.

Near Infra-red Technology (cont.)

Near Infra-red Spectroscopy to detect insect larvae(*Helicoverpa armigera* – heliothis) / insect damage in sweet corn cobs

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Introduction
Near infra-red reflectance spectroscopy (NIRS) is a non-destructive procedure that uses optical data rather than wet chemistry methods to analyse both liquid and solid products for chemical composition. Near infra-red reflectance spectroscopy has been used for over twenty years to analyse grain products for protein, oil and moisture (Shenk and Westerhaus 1993). The use of the technique however has been limited to low moisture materials, as water absorbs strongly in the near infra-red (NIR) region of the electromagnetic spectrum of radiation. The advent of powerful personal computers, fibre optics, improved sensor technology and chemometric software packages has allowed this technology to be applied to high moisture materials (such as fresh whole fruit) in an in-line situation, in the last decade.

Near infra-red is a small part of the electromagnetic spectrum of radiation (700 - 2500 nm). At one end of this spectrum are the high energy waves such as x-rays and gamma rays, while at the other end of the spectrum are the low energy waves such as micro waves and radio waves. Near infra-red is between the visible and the infra-red regions of the spectrum. The area of the electro-magnetic spectrum of interest is between 700 and 2500 nm and concerns the bending and stretching of electronic bonds (C-H, N-H and O-H). These bonds are involved in most organic compounds, such as sugars, protein, lipids and water. Near infra-red spectroscopy is a secondary method of measurement and so must be calibrated against a primary or reference method, such as a refractometer reading (°Brix). Because of this requirement, the technique is only cost effective with large sample numbers. The calibration may be established in either a quantitative (e.g. linear regression of Brix content) or qualitative (e.g. discrimination between groups) basis.

Ridgway and Chambers (1996) and Chambers and Ridgway (1995) used NIR reflectance spectroscopy to detect external and internal insect (grain weevil) infestation of intact wheat kernels. Large spectral differences were observed between non-infested kernels and kernels infested internally with *Sitophilus granarius* (L) (grain weevil) larvae or pupae, arising from both a changed chemical composition and physical structure. Single non-infested and infested kernels were distinguished by their second derivative (d^2) spectra. For both external and internal infestation there was substantial evidence that insect protein and/or chitin and moisture were being detected. Near infra-red spectroscopy should be useful as a rapid method of detection. Further work by Chambers and Ridgway (1998) with single wheat grain kernels internally infested with pupal stages of the grain weevil showed the possibility of detecting such infestation by measuring just two NIR wavelengths (1202 and 1300 nm). These workers used the 1100-2500 nm region of the spectrum and discriminated infested from non-infested samples simply by the increased reflectance (decrease in absorbance) of infested kernels due to the increase in specular radiation from the internal cavities (as a result of insect feeding) and from the insect itself.

Materials and Methods

Sweet corn cobs fruit were harvested from two locations in Queensland, namely the Lockyer Valley and the Burdekin irrigation areas. Cobs were selected to include clean cobs, cobs with poor grain tip fill, cobs with grub damage and cobs with grubs present. Sweet corn cobs were transported under dry ice (8-10° C on arrival) and assessed within three days of harvest. Near infra-red spectra were collected from the cob tassel end (first 7 cm of tip) of individual cobs. Spectra were collected from two commercially available research instruments, the NIRSystems 6500 (700 – 2500 nm, remote reflectance probe), and the Perten DA 7000 (700 – 1700 nm, interactance probe), and a purpose built unit based on the Zeiss MMS1 miniature spectrometer (700 – 1050 nm). Various optical configurations were used to gather spectra from the sweet corn cobs (Figs. 1). Integration time for spectral acquisition varied from 100 to 160 milliseconds per cob (four scans per spectra), to maximise the signal to noise for the Zeiss unit. Discriminant equations were developed using partial least squares regression analysis within the WinISI II (vers. 1.02a) chemometric package.

Four experimental runs were undertaken over the season using various spectrophotometers and optical configurations (Table 1 and Fig. 1). In run four, the tip (tassel) of the corn cob was halved longitudinally and presented to the instrument sheath uppermost. In this experiment, spectra were acquired of 80 cobs (20 of each category), of which five were randomly selected from each of the four groups for validation of the discriminant equation (developed on the remaining set). The spectral data was analysed using the discriminate function of the WinISI II vers. 1.02a chemometric software package (Table 2 and 3). In the discriminant analysis, spectral data were pre-treated with regard to derivatives, smoothing and scatter correction.

Results and Discussion

According to Shenk and Westerhous (1993), discriminant analysis is best undertaken with no scatter correction (particle size and scattering of light may assist in sample discrimination) and first derivative to eliminate base line error. A mathematically pre-treatment of first derivative derived over four data points with no smoothing, was found to give the optimum results and subsequently used.

The Perten DA 7000 spectrophotometer was unable to discriminate between groups although it operates with a high intensity tungsten halogen lamp (42 watt) and covers an area of the electromagnetic spectrum from 700-1700 nm, using both silicon (Si) and (InGaAs) photodiodes. This unit was operated in the interactance mode (Fig. 1(a)) and as such, the area viewed by the probe was relatively small (e.g. less than 10% of the area viewed by the remote reflectance fibre optic probe of the NIRSystems 6500). The bifurcated fibre optic bundle carries incident light down the outside bundle and the reflected light from the sample back to the detectors through the centre fibres. However, the high intensity light and interactance mode should have resulted in good light penetration of the sample. The poor result cannot be explained except by the fact that the instrument was on loan for a short time period and was possibly not set up optimally with regard to integration time. Possibly, the interactance mode was not the ideal configuration, or gathering information over a very small area of sample with the potential to miss the localised defect.

The experimental run utilising the Zeiss MMSI spectrophotometer in a side and tip presentation of the sweet corn cobs (Table 1 and Fig. 1(b &c)), again showed an inability to discriminate between the various groups of sweet corn cobs (clean, damaged, poor grain tip fill and grub presence). Both these optical configurations utilised the transmission mode. Because of the difficulty in sealing the shroud containing the fibre optic bundle (carrying transmitted light to the detector array), the poor result could be best explained by the intrusion of excessive specular radiation. Also most of the light reaching the detector would have arisen from the sheath with little useful information regarding the actual defect.

The third experimental run utilised a high intensity quartz halogen car lamp (100 watt) with a parabolic reflector to deliver light to the object, operated in the transmission mode (Fig. 1e). Again poor discrimination occurred and this could be attributed to the transmission mode reducing the proportion of the signal containing defect information reaching the detectors. In the fourth experiment, discrimination was achieved using the same configuration but reduced sample thickness.

In the fourth experimental run, good discrimination also was achieved (Table 2 and 3, Fig.1 (d & f)) with the NIRSystems 6500. In this run, the transmission mode was utilised but only half of the tip of the cob was viewed. The slightly better results of the 6500 could be attributed to the operation of the remote reflectance fibre optic probe in a light proof box (no ambient light adding to the signal) and the general precision of the instrument compared to the photodiode array of the Zeiss. Discriminant analysis for the 6500 as reported in Table 2 and 3, was carried out on the full spectrum (700-2300 nm). However, separate analysis also was undertaken on 700-1100 nm (as with the Zeiss) and 1100-2300 nm areas of the spectrum. These results demonstrated the region of 700-1100 nm gave better results than the 1100-2300 nm region alone.

In a plot of the first derivative data obtained form both the Zeiss and 6500 instruments (experiment 4) the areas of the spectrum showing most divergence, occurred around 960 and 1030 nm. These areas could be attributed to water and protein, respectively

Clean cobs were always distinguished (by both instruments) from damaged ones. However, there was some confusion with poor tip fill cobs sometimes misdiagnosed as insect damaged. Also, the discriminant equation could not always differentiate between damaged and damaged with grub.

With both the Zeiss and 6500 (experiment 4), in distinguishing the groups and various combinations of the groups (Table 2 and 3) on no occasion was a defect cob (i.e. damaged, poor tip fill or grub present) included in the clean group.

Table 1 **Discriminant analysis of the spectral data obtained from the various instruments and configurations, using the chemometric package WinISI vers. 1.02a. Inability to distinguish between groups occurred when <20% correctly identified.**

Experiment		No. of spectra	*Instrument*	Optical configuration	Groups distinguished
No.	Date				
1	18/09/98	198	Perten DA7000	Interactance (42 watt)	No
2	24/11/98	410	Zeiss MMSI	side –transmission (50 watt)	No
		410	Zeiss MMSI	tip –transmission (50 watt)	No
3	25/11/98	106	Zeiss MMSI (700-1100 nm)	large lamp – transmission (100 watt)	No
4	25/02/99	80	6500 (700-2300 nm)	Reflectance (75 watt)	Yes
		80	Zeiss MMSI	Half cob tip transmission (100 watt)	Yes

Table 2. Discriminant analysis of sweet corn cobs into 4 groups using partial least squares regression (WinISI II vers. 1.02a).

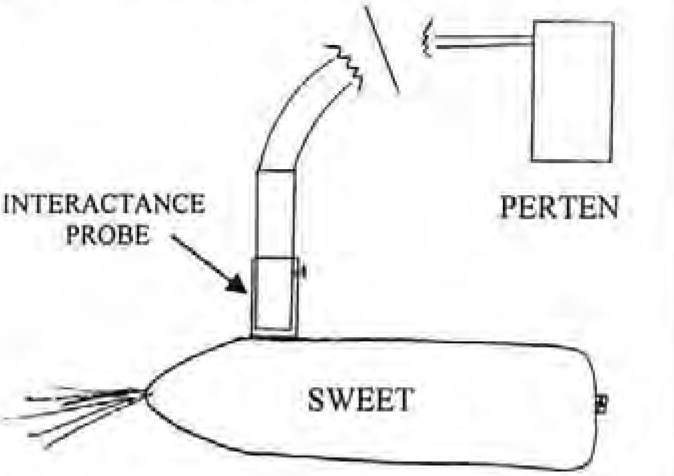
Groups	Instrument	Diagnosis (out of 5)	Correct (of diagnosed)	Incorrect diagnosis
1 Tip fill (T)	6500	5	3	1D, 1G
	Zeiss	5	4	1G
2 Clean (C)	6500	5	5	
	Zeiss	6	5	1T
3 Damaged (D)	6500	5	3	2T
	Zeiss	3	2	1G
4 Damaged + grub (G)	6500	5	4	1D
	Zeiss	6	3	3D

The discrimination was undertaken on four groups of sweet corn cobs with 15 samples in each calibration set and 5 samples in each validation set. The number of samples from the validation set (Diagnosis column) correctly assessed is given under the heading 'Correct out of diagnosis' and the misdiagnosed in the final column.

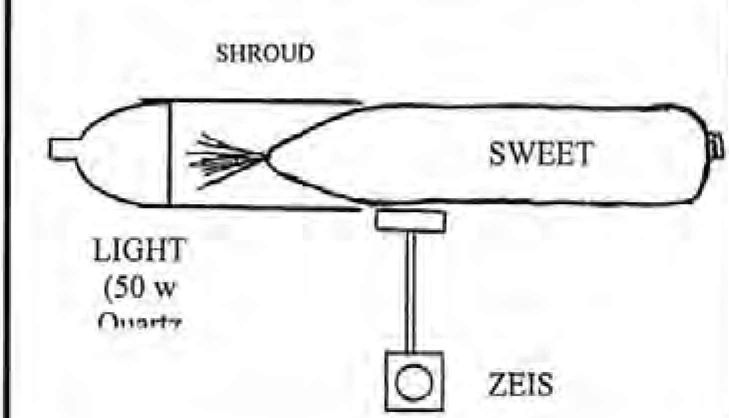
Table 3. Discriminant analysis of sweet corn cobs into 2 groups, using partial least squares regression (WinISI II vers. 1.02a) analysis. Data of Table 2 (recatergorised).

Groups	Instrument	No. in calibration set	No. in Validation set	Diagnosis	Correct	Incorrect
1. Clean vs Damaged	6500	30	5C,5D	10	**10** (5C,5D)	
	Zeiss	30	5C,5D	10	**10** (5C,5D)	
2. Clean vs Damaged with grub	6500	30	5C,5G	10	**10** (5C,5G)	
	Zeiss	30	5C,5G	10	**10** (5C,5G)	
3. Clean vs Tip Fill	6500	30	5C,5T	10	**10** (5C,5T)	
	Zeiss	30	5C,5T	10	**9** (4C,5T)	1 T
4. Clean vs Tip fill, damaged, grub	6500	45	15TDG,5C	20	**20** (15TDG,5C)	
	Zeiss	45	15TDG,5C	20	**18** (15TDG,3C)	2 TDG
5. Tip Fill & Clean vs Damage & damage + grub	6500	60	10DG,10CT	20	**17** (10DG,7CT)	3 DG
	Zeiss	60	10DG,10CT	20	**19** (10DG,9CT)	1 DG
6. Clean vs Damaged & Damaged + Grub	6500	45	5C,10DG	15	**15** (10DG,5C)	
	Zeiss	45	5C,10DG	15	**14** (11DG,4C)	1 DG

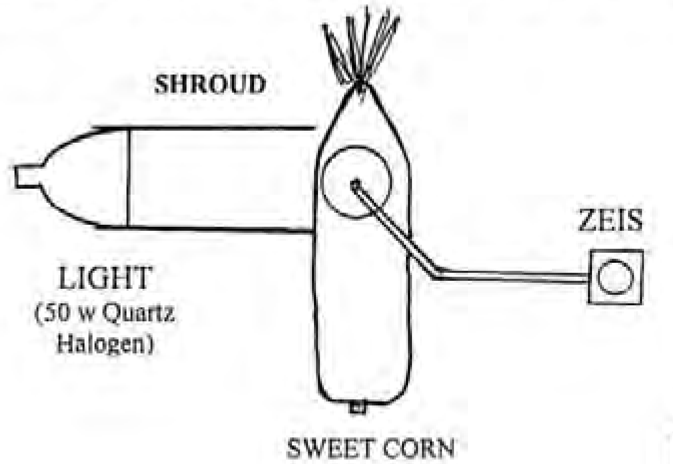
a. **PERTEN – INTERACTANCE** (Experiment 1)



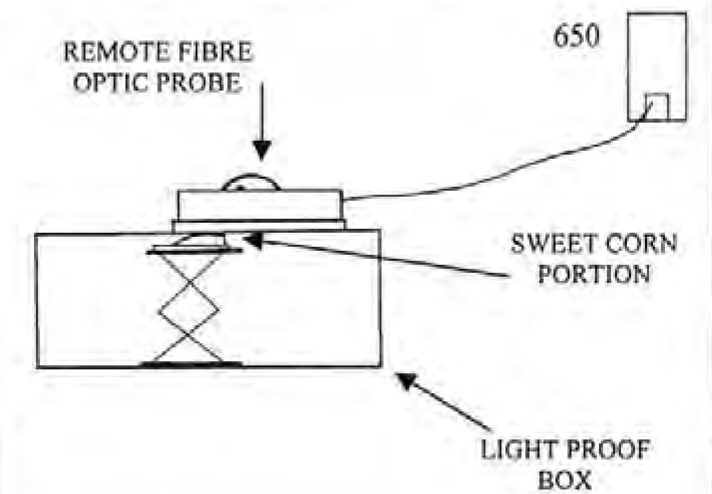
1b. **ZEISS MMSI – TRANSMISSION** (Experiment 2A)



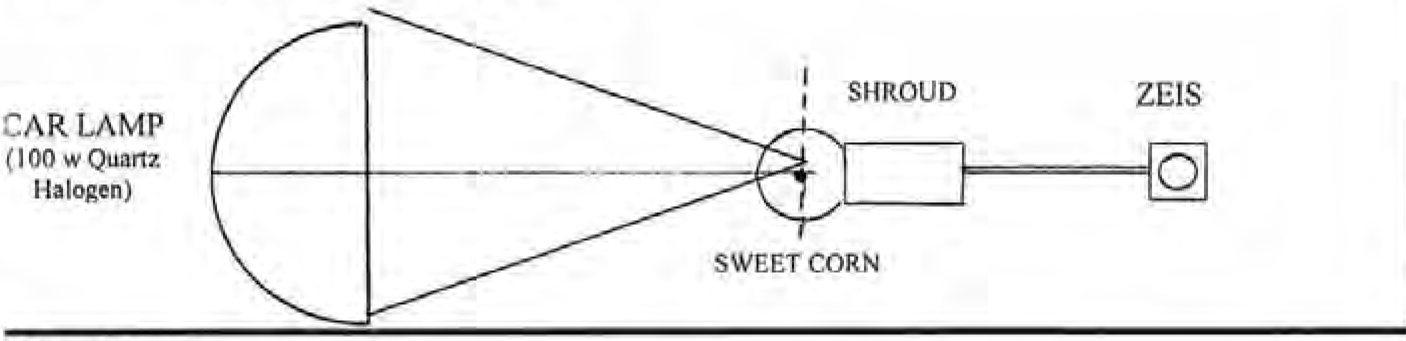
c. **ZEISS MMSI – TRANSMISSION** (Experiment 2B)



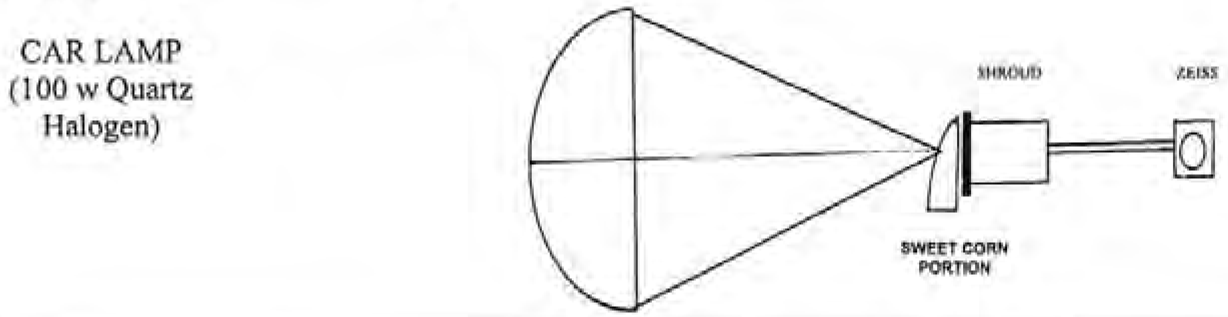
1d. **6500 – REFLECTANCE** (Experiment 4A)



e. **ZEISS MMSI – TRANSMISSION** (Experiment 3)



1f. ZEISS MMSI – T



Discrimination of the defects of sweet corn cobs (poor grain tip fill, insect damage and presence of the heliothis grub) from clean cobs can be achieved non–invasively by near infra-red spectroscopy. The NIRSystems 6500 scanning spectrometer and the Zeiss MMSI miniature spectrometer (coupled with a high intensity quartz halogen lamp -100 watt) can achieve this discrimination. However, in a practical packing shed operation the relatively rapid and inexpensive Zeiss MMSI spectrometer offers the most promise. Further work needs to be undertaken to improve the signal to noise ratio of the optical configurations. This will involve further experimenting with optical configurations, integration times for spectral acquisition and light intensities.

Acknowledgments

We thank Perten Australia for the loan of the DA7000 unit. The project is funded by the Horticultural Research and Development Corporation (VG7036).

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9. Crop and Pest Monitoring

Further details of **Crop and Pest Monitoring** activities and outcomes have been reported in :-

- Milestone No. 5 – "Insect scouting protocols have been documented for each of the major sweet corn production regions in Eastern Australia" (1999).
- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 29-30 & 40-44.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 104-134.

Crop and Pest Monitoring (cont.)

Summary of research conducted to develop scouting protocols for *Helicoverpa armigera* and other insects in Queensland sweet corn.

Brendan Nolan, Senior Experimentalist, Gatton Research Station, QDPI

Introduction

Managing insect pests in sweet corn can be achieved through various control practices, ranging from systematic spraying of synthetic chemicals to integrated pest management practices (IPM). The use of either type of control practice relies heavily on the ability to collect information about insect pest and beneficial activity within the sweet corn crop.

The aim of crop monitoring in sweet corn is to provide information that allows the grower to become more familiar with the level of insect activity in their production system and enabling the correct selection and implementation of a control option. Through scouting, which is the corner stone of successful IPM, a variety of information can be collected and recorded. This information can then be assessed so a conclusion can be determined and a recommendation made. Without the aid of monitoring information an understanding of what is happening in the crop will not occur. Therefore, the chance of the correct control option being implemented is reduced.

Research was coordinated to develop a monitoring protocol for sweet corn production systems in Queensland.

Materials and Methods

Queensland project team members identified that variation in the methods used to monitor for insects that occur during the sweet corn crop's growth, attack different sweet corn cultivar grown and the between growing seasons and districts. To standardize the different monitoring techniques employed throughout Queensland, project researchers developed, through consultation and experimentation, a standard monitoring process incorporating the different monitoring techniques employed.

A standardized protocol was achieved firstly through the consultation with growers and consultants. They were contacted via telephone, e-mails and at workshops. Through this consultation, a baseline was developed on current monitoring practices. Secondly these techniques were regularly tested and refined during insect management trials.

A number of drafts were developed and send to growers and consultants for further comment. Through this process a standardized protocol was developed for Queensland sweet corn production.

Results

The result of discussions with growers and consultants was the development of a monitoring protocol for Queensland growers. The Queensland protocol can be viewed in the milestone report 'Insect Scouting Protocols' 43 pp, P. Ridland (ed.) *HRDC Project - VG97036 Final report* November 1999.

Similarly, workshop proceedings list research that has narrowly focussed on modifying crop monitoring protocols. For example, monitoring sample sizes and critical insect monitoring populations were analysed.

Discussion

The management of damaging insects in sweet corn is very important due to the potential reduction in crop yields and the need to satisfy the consumer's demand for corn free from insects and damage.

Successful management of damaging insects relies heavily on the ability to know what is happening in the crop. The monitoring protocol can be used successfully to give information about insect numbers and biology within the crop. This information, coupled with climatic conditions and the experience of the person monitoring the crop, will enable the appropriate insect pest management recommendation to be derived.

Technology Transfer

Through the HRDC Project " Insect pest management in Sweet Corn" (Project No. VG97036) insect scouting protocols that accurately identify insect pest activity during critical growth stages in sweet corn have been developed. Accurate information allows effective timing of insecticides thereby reducing crop damage and insecticide usage. Insecticide reduction limits risks of contamination to food and environment, and provides safer and enjoyable working conditions for the farming community. The scouting protocol has been adopted by industry and DPI has incorporated it into the farm note 'Heliothis in Sweet Corn' (Deuter, 2000).

Recommendations

The Queensland monitoring protocol outlines a proven method of monitoring a sweet corn crop in Queensland. The protocol is a guide only and may require adaptation for other Australian production areas.

While the Queensland scouting protocols is satisfactory, any additional research and the development of new monitoring tools will mean that the protocol will need to be modified.

Acknowledgments

Thank you to the Queensland Department of Primary Industries staff, growers, consultants and agribusiness for providing technical and field assistance during the development of a Qld Monitoring Protocol. With out the contribution of these people the research would not have been successfully completed.

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Nolan, B.F., McDougall, S., Napier, T., Walsh, B., Ridland, P., Dimsey, R., Subramaniam, S., Endersby, N. and Deuter, P. (1999). Insect Scouting Protocols Milestone Report 43 pp, P. Ridland (ed.) *HRDC Project - VG97036 Final report* November, 1999.

Crop and Pest Monitoring (cont.)

R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle, DNRE, Vic.

Introduction

The aim of this work was to collect more baseline data on corn earworm and its impact on crops in East Gippsland. Timing of spraying is critical to *Helicoverpa* control and there is a need to determine appropriate methods of assessing pest pressure within a crop in order to better target pesticide application and improve control. Southern Victoria is has lower pest pressure than in northern Australia but damage to crops can be just as significant and the impact is more critical for export crops where whole clean cobs are required.

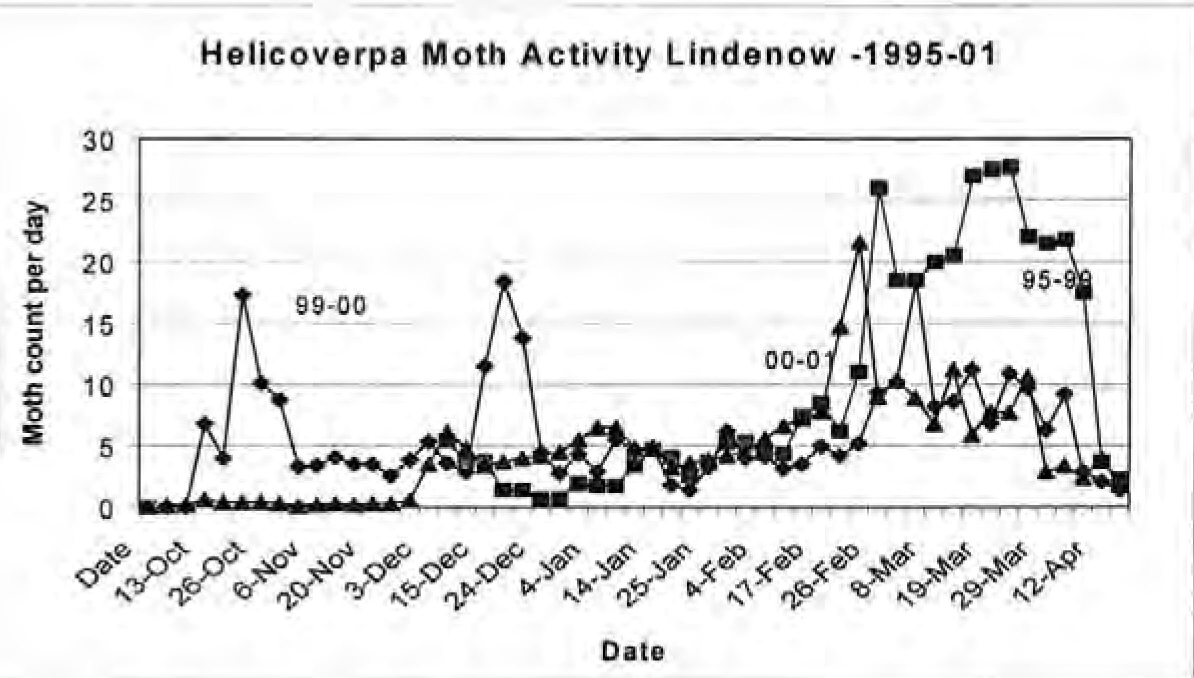
Materials and methods

Scentry® pheromone traps were established in the production areas in East Gippsland from October to May of the following year from 1995 to 2001. The moth numbers were counted twice a week. When higher moth activity was detected in traps crops were scouted for eggs and grubs. During the 1998/99 season 80% of planting were monitored. Records on sowing date, cultivar, planting area, crop spacing tasselling period, silking period and, harvest data were collected.

Results

The five year data shows (Fig 1) that the general pattern of the moth activity in Lindenow area. With the exception of the extreme year in 1999/00 moth numbers generally remain low (below 10 moths per day) until February when pest pressure peaks (over 25 moths per day) until April.

Fig 1. Helicoverpa moth counts at Lindenow during 1995 to 2001



This picture is consistent across southern Victoria. These results are also consistent with the levels of damage experienced in crops. There is a good correlation (r = 0.68) with moth counts at silking and damage levels at harvest and high counts have also correlated with high egg lays in the field.

Discussion

Pheromone trapping has been used to decide when and if scouting is necessary and thus reduces the time entailed in continuous checking of crops. High moth catches have proven to be useful indicators of pest pressure and are used by industry to plan their control programs.

Technology Transfer

Growers were made aware of the outcome of this work through field days and farm walks 30/3/99

Grower Information Nights – 21/10/98
11/11/99
11/2000

Proceedings of First National Workshop May 1998, Gatton Qld.

The East Gippsland industry has been advised by weekly fax and e-mail on pest pressure and traps are monitored weekly early season and twice weekly from early summer.

Recommendations

There needs to be a better understanding of population dynamics and pest movement. Resistance levels are consistent with other *Helicoverpa* populations around Australia. However it would appear that the extreme pressure was due to local populations but the cause of extreme pressure and pest dispersion is unknown.

Crop and Pest Monitoring (cont.)

Dr Sandra McDougall, NSW Agriculture, Yanco, NSW.

Day-long **crop monitoring workshops** were held in Narromine (December 1997, August 1998, December 1998). Brendan Nolan was a guest speaker for the December 1997 workshop. A scouting identification field day was held in the Sydney basin (January 1999, 2000).
A protocol was agreed to and a crop monitoring notebook was designed and distributed for use.

Feedback from participants was that the workshops helped clarify the issues and share information between participants, for some it taught them what to look for in the paddock and encouraged more regular monitoring of crops. However the original intention of all the participants filling in the crop monitoring notebooks and sending in the carbon copy results for the season was not achieved. A small number of growers or processing field officers returned monitoring data. On follow up many did not record their results or necessarily follow the protocol each check. In processing sweet corn only 2-3 sprays are economical and tend to be timed to the crop growth rather than to egg levels in the paddock. Thresholds perhaps have limited value if the total number of sprays to be applied is limited and that in general the most vulnerable stage is during silking. So perhaps prior to tasselling quick checks are made and at tasselling a full monitor be made and a decision about whether a pre-silk spray is needed and keep the remaining 2 sprays for 25% and 75% silking if monitoring indicates eggs are present.

Crop monitoring is an integral part of an IPM system and the training of growers, processor field officers and local agronomists was important. The sharing of information benefited all participants and raised questions for further research. A systematic and routine monitoring of all plantings was not achieved and the benefit of keeping detailed records was not considered by the participants to be worth the time given other pressures in the height of the sweet corn season. Employment of a full-time professional crop monitor/s to cover as many of the crops in the one region is the best option.

10. Evaluating Best Management Options

Further details of work programs and outcomes associated with **Best Management Options** have been reported in :-

- Milestone No. 6 – "Best Management Options (BMO's) have been compared with standard practice in each of the major production regions of Eastern Australia" (2000).
- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 20-25.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 35 –69 & 131-150.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 94-108.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 3-37 & 73-85.

Evaluating Best Management Options (cont.)

Summary of research conducted to develop Best Management Options for *Helicoverpa armigera* and other insects in Queensland sweet corn.

Brendan Nolan, Senior Experimentalist, Gatton Research Station, QDPI.

Introduction

Heliothis is the most damaging pest with which the sweet corn industry has to contend (Deuter, 1995). Insecticide resistance in Heliothis is a major factor contributing to management difficulties in sweet corn. Since 1992, resistance levels ranging from 10 to 100% have been detected in all major sweet corn production districts in Australia. Synthetic pesticides are declining in their effectiveness and total reliance on them to manage Heliothis is clearly not sustainable. Alternatives to this management technique are needed.

To reduce the dependence on synthetic insecticides for managing Heliothis, the national HRDC Project " Insect pest management in Sweet Corn" (Project No. VG97036) has developed a Best Management Option (BMO) system. BMOs are designed for the management of insect pests found in sweet corn grown in all major production districts in Eastern Australia. A BMO is a practical strategy that utilises a broad range of appropriate insect management tools and these will continue to be developed and refined over the life of the project.

One major aim of the sweet corn project was the investigation of Best Management Option's (BMO) as alternatives to repeated applications of synthetic insecticides.

The BMOs are practical strategies aimed at reducing crop loss from Heliothis by incorporating a broad range of appropriate insect management tools into a system.

Examples of tools for use in BMOs in various regions are: -

• **Cultural**	Crop and site selection and planning; Cultivar selection; Crop and farm hygiene.
• **Pesticide**	Biological insecticide; Synthetic insecticide; Insecticide resistant management strategies.
• **Pesticide Application**	Improved targeting; Improved timing of sprays;

Sprayer maintenance.

- **Crop Monitoring** — Scouting for insects and beneficials; Record keeping.
- **Beneficials** — Protection of naturally occurring beneficial Insects; Mass-reared beneficial insects; Naturally occurring pathogens.

Materials and Methods

BMO system and standard grower practice comparison trials were completed in South east Queensland between 1998 and 2001. The field experiments were conducted on the Queensland Department of Primary Industries Gatton Research Station (GRS) and on grower's properties. Golden Sweet and H5, the main commercial cultivars used by growers, were the only cultivars used during the experiments. Both small-plot and commercial scale fields were used to assess the performance of both methods of insect management.

What is a BMO system?

BMOs utilise a broad range of effective insect management tools. Selection of the available tools that are most appropriate for the problems encountered are incorporated into a system designed to achieve the lowest level of crop damage from insect and mite arthropods. Examples of BMO insect management tools available for use in different production regions are listed in the milestone report 'Best Management Options' Milestone Report, B. Nolan (ed.) *HRDC Project - VG97036 Final report* May, 2000.

What is a Standard Grower Practice?

Standard practice is the traditional method of managing insect pests, mainly *H. armigera* in sweet corn. While the traditional method for managing insect pests in sweet corn is with synthetic insecticide during silking, variations in its implementation can occur.
For example, at the beginning of the project (1998) the fresh market industry in South East Qld traditionally spray every 2nd day during the silking stage. The South East Qld standard practice was used in the comparison experiments.

Field Trials

Comparison trials were used to compare the BMO system with a synthetic insecticide system and a no spray system by assessing the ability of each to reduce crop loss from Heliothis attack. Research designed to develop a successful BMO system followed the following three steps: -

2. Benchmark comparison experiments
   - Initial experiments conducted between 1998 and 1999 focussed on establishing a benchmark BMO system. The benchmark BMO system included a selection of the BMO tools listed in the introduction.

4. Improvements to benchmark BMO system
   - During this step the performance of the initial BMO system was assessed. Individual tools that did not perform well in the system were identified through analyses and were modified through experiments for better performance.

5. Improved comparison experiments
   - Combined original and modified BMO tools into an improved BMO system, which was again tested against a grower standard practice.

Project team members regularly discussed experimental designs and objectives with growers and industry stakeholders through media (newsletters, paper, radio), and through project meetings, seminars and conferences.

Results

The following lists the main outcomes from biological insecticide experiments: -

1. Benchmark comparison experiments
   - Benchmark experiments produced results (Cob damage: Gemstar® 60%, synthetic insecticide 75%, and the control 66%) showing the BMO was significantly better at reducing cob damage compared with synthetic insecticides, but was not significant compared to the control.
   - Analysis of experimental results indicted
     i. the application of the biological insecticide Gemstar® did not appear to provide any affect to decreasing heliothis populations.
     ii. the long spray droppers, while proving significant increases in the coverage of insecticide, were cumbersome and difficult to use, contributing to reduced management.
     iii. Monitoring information, which was used to time insecticide applications, was not effective in providing accurate information about heliothis larvae activity during critical crop growth stages.

2. BMO improvement research
   - The following experiments were conducted so improvements to the initial BMO system could be made: -
     i. Monitoring experiments
        - Ecology experiment identified 60% of heliothis larvae hatching from eggs laid on silks occurred during 3 consecutive days, suggesting a control window exists.
     ii. Insecticide application.
        - Shorter dropper experiments. Short droppers were able to apply 2-3 times more converge with insecticide. Shorter droppers are easier to use within the crop canopy
        - Experiments focused on improving the effectiveness of the biological insecticide Gemstar®. Tests were performed on its efficacy return results showing it killed 95% larval mortality). Petroleum oils did not protect Gemstar® from the damaging effects of ultraviolet light.

Improved comparison experiments

- The improve comparison experiments combined new information from the BMO improvement research with initial BMO system trials. The experiment produced results (Cob damage: Gemstar® 14%, synthetic insecticide 35%, and control 46%) that showed the improved BMO system was significantly better than both the standard grower practice and control.

Technology transfer is an integral part of this project. Growers and industry representatives were exposed to BMO research conducted in all major production areas through newsletters, media releases and by conducting farm walks and field days. Methods used to promote BMO research to date and in the future include: -

1. Newsletters, milestone reports and workshop proceedings

An established network of 400 stakeholders regularly received a copy of the official project newsletter the 'Sweet Corn Ear' milestone reports and workshop proceedings. These project information packages contained information about the BMO research and field days, as well as other aspects of the sweet corn project :-

April 1998; July 88; December 98; April 99; January 99 ; September 99; March 00 and May 00.

2. Media releases

Newspapers, magazines articles and radio interviews helped promote BMO research results and field days.

Workshops and field days

Four annual project workshops were organised, enabling included research presentations on BMOs and interactions between researchers and stakeholders. The first was conducted in Gatton, Qld in 1998, the second was in Bathurst, NSW in 1999, the third was conducted in Bowen, North Qld in 2000, and the forth and final workshop was conducted in Bairnsdale, Victoria in 2001.

Field days promoting BMO research and other improved insect management practices have been conducted in all major production districts. These field days were very important in information transfer as they allow sweet corn growers to see first hand any improvement in insect pest management and provide an opportunity for grower input into the direction of research and development and in further testing the outcomes on farm.

Discussion

Results from trials conducted during 1998-1999 indicate that the BMO, in most instances, is better than standard practice, however some results would be considered commercially unacceptable. For example, in SE Qld a BMO trial conducted in October 1998 achieved 15% less cob damage than the standard practice, but still received a total cob damage of 60%. This result reflected the difficulties associated with the development a benchmark BMO for the sweet corn industry. Through focussed research designed to make improvements to the benchmark BMO The Queensland project team was able to develop an improved was conducted between 1999-2000.

Results from experiments conducted between 2000-2001 show the improved BMO system can significantly reduce the insect pest damage in sweet corn. The BMO system provides growers with an alternative insect management system that does not rely on the sole application of synthetic insecticides, which are not sustainable and are disruptive to the environment.

Promotion of the comparison trials has been conducted successfully in each region. Through newsletters, grower meetings, project workshops and field days, sweet corn growers and industry representatives have been provided an opportunity to assess BMO research first hand. This has been a very valuable exercise for growers and team members. Firstly, it has allowed team members to receive feedback from industry on how to improve the BMO and secondly it has allowed growers to rapidly adopt any insect management improvements developed by project team members. The final project evaluation will detail trends in industry practice and determine the impact of these BMO extension activities.

It is important to note that the development of a BMO is an ongoing process. As additional research and the development of new insect management tools become available the current BMO system will need to be modified.

Technology Transfer

The HRDC project has contributed to the development of new market opportunities. Through the development and implementation of BMO systems sweet corn growers have lower insect presence in crops resulting in reduced damage to the sweet corn. The positive outcome of the research has enabled growers to consistently produce sweet corn with as little as 5% insect damage. In 2001, sweet corn was exported to Asia and Japan from Queensland for the first time in10 years.

In addition to the adoption of the BMO system concept, the project has have effected change in industry by contributing to research outcomes that have focussed on the development and adoption of insect pest management tools. These include: -

- Nationally sweet corn growers have modified insecticide spray booms with spray droppers as a result of research showing they will apply 4 times more insecticide to silks than a boom without droppers.
- Queensland and interstate sweet corn growers have adopted insect monitoring protocols, which provides growers with field specific information about insect populations (both beneficial and pests) and crop injury. This information is essential tool in a BMO system. It enables growers to determine if, when and what level of BMO insect management tool that needs to be implemented to reduce crop loss caused by insect feeding.
- BMO research has enabled permits to be issued by the National Registration Authority (NRA) for the use of 2 new biological insecticides in sweet corn crops.
- My research has assisted in opening new market opportunities and meeting market requirements through reduced chemical usage.

The BMO research has contributed to community expectations for the environment and food safety by:

- The BMO system has enabled the development sustainable production practices by reducing the dependence on synthetic insecticides for pest management.
- Limited opportunities for environmental contamination by developing BMO system that promotes non-chemical IPM strategies.
- BMO systems contribute to consumer food safety by meeting the HACCAP 9000 standard, which is an international food safety standard. To achieve HACCAP 9000, growers need to reduce critical control points such as synthetic insecticide usage.

Recommendations

The BMO and Standard Practice comparison experiments served as an indicator to the industry as to where improvements might reasonably be made in achieving improved pest management in sweet corn.
It is important to note that the development of improved Best Management Options is an ongoing process. Also, the comparison experiments reflect insect and management issues unique to each region.

Acknowledgments

Thank you to the Queensland Department of Primary Industries staff, growers, consultants and agribusiness for providing technical and field assistance during the development of a Qld Monitoring Protocol. With out the contribution of these people the research would not have been successfully completed.

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Evaluating Best Management Options (cont.)

R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle, DNRE, Vic

Introduction

In East Gippsland, sweet corn crops for fresh market are sprayed 4 to 8 times from early silking until harvest. In spite of these spray applications crop damage of 20 to 50 % is not uncommon and can be up to 90%. Resistance testing conducted on *Helicoverpa armigera* larvae collected from commercial Victorian sweet corn in the past few years has confirmed high level resistance of *Helicoverpa armigera* to current insecticides. There is a need to evaluate alternative management strategies to manage corn earworm in sweet corn. Biological insecticides such as Gemstar® or Success® in the presence of an egg parasitoid, *Trichogramma pretiosum* may be an option to manage this pest in an integrated program. Three trials were conducted in successive seasons (1998/99 and 1999/2000) to evaluate this in southern Victoria.

Trial 1 (1998/99)

Materials and Methods

The BMO trial site was a part of commercial corn crop grown in Lindenow, in Victoria. Sweet corn (cultivar 7831) was sown at 100-cm row spacing in Dec 1998. There were 16 plots (15m x 16 m) arranged in a randomised block design with four replicates. The crop commenced silking 57 days after sowing (DAS).

1. Success® (spinosad) - applied four times at 400-600ml /ha. The first spray was timed at 10-20% silking (65 DAS) and then sprays were applied weekly.
1. Gemstar® (Nuclear Polyhedrosis Virus- NPV) sprays were applied seven times at recommended label rate of 750 ml /ha. The first application was at early silking and then at 3-5 days intervals.

2. Dominex ® (alpha-cypermethrin) was selected as a standard insecticide for comparison (commonly used by growers). The sprays were applied five times at 400ml/ha. The first application was at 25% silking and the subsequent applications were made at 5-7 days intervals.
3. Unsprayed control - No insecticides were applied.

*Trichogramma pretiosum (*egg parasites of heliothis) were released to all the plots at a rate of 120 capsules/ha in four releases.

Results

Damage assessment

At harvest, 30 cobs per plot (120 cobs /treatment) were sampled from the middle three rows. Another 120 cobs were sampled in a parallel transect from the commercial crop. The cobs were evaluated for grub damage and marketability and damage index was calculated based on assigned damage score as follows:

Damage level	Damage score	Marketability
Nil damage (clean cobs)	0	Export quality
Damage at silk tip only	1	Export quality
Deep damage to silk	2	Domestic market
Slight damage at cob tip	3	Domestic market
0-2 cm of tip damage	4	Trimmed cob (pre-pack)
2-4 cm of tip damage	5	Trimmed cob (pre-pack)
4 -6 cm of tip damage	6	Trimmed cob (pre-pack)
> 7cm of tip damage	7	Unmarketable
Side damage	7	Unmarketable

There was moderate egg pressure (0.2 - 0.4 eggs/ plant) during the tasselling and silking period. Egg lay peaked during early silking. The larval numbers increased throughout the silking period in all plots. Moth activity was very high (average of 24 moths/day) during early March and that led to high grub infestation (1 larvae/cob) in the following week.

The five sprays of Dominex® failed to reduce larval numbers and led to a high level of infestation. When the spray program ceased (a week before harvest) Success® and Gemstar® plots had the lowest larval infestation (0.12 larvae/ cob) compared with Dominex® (0.5 larvae/cob) and unsprayed (0.56 larvae/ cob) plots. The first two sprays of Gemstar® did not greatly reduce the larval numbers, but the subsequent sprays caused up to 70% larval mortality.

The performance of the treatments on cob damage is shown in Table 1. Full clean cobs (nil damage without grubs) were highest (70.0%) in Success® plots compare with Gemstar® (36.6%), Dominex® (27.5%) and unsprayed (13.3%) plots. The four Success® sprays greatly increased the percentage of export quality cobs (nil damage or slight silk-tip damage) to 74% and even the remaining 26% of damaged cobs had only moderate silk or slight tip damage (0-2 cm).

Table 1. Results of BMO trial showing cob damage level and percentage of marketable cobs.

Treatments	No. of sprays	Spray interval	Mean damage % *			Mean marketable % *			
		(days)	NIL	Silk	Cob	Export	Domestic	Trimmed	Unmarketable
Success® (spinosad)	4	7	70 a	7.5	22.5	74.2 a	5	20.8	0
Gemstar® (NPV)	7	3-4	36.6 b	14.1	49.2	40.0 b	14.2	38.3	2.5
Dominex® (α-cypermethrin)	5	6	27.5 bc	8.3	64.2	30.8 bc	8.5	50.0	10.8
Control	nil	-	13.3 c	8.3	78.4	18.3 c	5.8	69.2	6.6

(* Column means followed by the same letters are not significantly different at $P \leq 0.01$, ANOVA followed by planned pair wise comparison)

In this trial, the Gemstar® spray program was commenced from early silking, this may be too late to kill the larger larvae already in the tassels. In future, we believe that the Gemstar® spray program should start at the early tasselling stage.

Discussion

The BMO trial results clearly demonstrated that four sprays of Success® during silking period gave a high level of damage control even with the high grub pressure occurred at that time. However, the Success® sprays failed to control secondary pests, mainly aphids, *Rhopalosiphum maidis* and *R. padi.*

Trial 2 & 3

Materials and methods

Two trials were established on a commercial scale using commercial crops and compared with other commercial crops, which were treated according to standard practice within the district for the season. The standard practice for commercial crops within the district for the 99/00 season was to apply Success® at the first sign of silking. Three applications around 7 days apart were made. An aphicide or clean up spray may be applied as a 4th spray or an aphicide may be applied with the final Success® application.
In the best management option trials, the following strategy was applied:

Management Option **Timing**

T.pretiosum release (twice)	tassel emergence and 7days later
Pre-tasselling spray-Gemstar® (twice)	50% tassel emergence and 4 days later
Success®	silking (<10% silking)
Success®	need or timing determined by pest pressure
Synthetic pyrethroid or Success®	need or timing determined by pest pressure
Synthetic pyrethroid or Success®	need or timing determined by pest pressure
Synthetic pyrethroid or methomyl	need or timing determined by pest pressure

Trial 1 was planted in early December. Tassel emergence commenced in early February and first silking started in mid February when moth activity was expected to increase to peak levels for the season. Trial 2 was planted in late December with first silks being evident in late February when pest pressure had peaked at unprecedented levels.

At harvest, a sample of cobs from each crop was assessed for damage. The cobs were rated as

- undamaged and marketable whole (suitable for export)
- slightly damaged at the silk tip only or extremely slight damage to cob (suitable for domestic market)
- marketable as a trimmed cob (topped and tailed) (suitable for domestic market)

The level of damage for trimmed cobs was rated from 1-3 with 1 = 0-2 cm of tip damage, 2= 2-4 cm of tip damage and 3= 4-6 cm of tip damage.

Trichogramma Release and Egg Numbers

Trichogramma were released from 60 egg cards on the 4th of February and again one week later. The level of parasitism peaked 6 days after the first release with 45% of eggs parasitised and then gradually declined In the comparison crop there was a low level of parasitism which gradually increased over the next two weeks, but only peaked at around 18%. Egg numbers per plant were high for this planting, peaking at 1.5 eggs per plant. Egg numbers were similar in both crops and followed the same pattern over the life of the crop, gradually increasing.

Numbers of larvae were similar when monitored in both crops, but in the BMO crop significantly increased ten days after silking.

Results

Since these were not replicated trials, the two trials were compared for their fit in a normal distribution within the 95% confidence limits. There were significant differences between the Best Management Option and the grower comparison within the 95% confidence limits. The BMO planting had 44% undamaged cobs and the grower comparison 13.5% undamaged cobs

Both crops did not receive the ideal spray treatments at the appropriate intervals due to management reasons.

Trial 2

Trichogramma Release and Egg Numbers

Parasitism was at 18% at release and two weeks later was above 70% of eggs sampled. In the grower comparison parasitism increased similarly, but was at around 4% at the release date and at 19% two weeks later. Egg pressure was high at the point of *Trichogramma* release at 1.2 eggs/plant, but by silking was back to normal levels for this time of the year at 0.3 eggs/plant.

Results

Since these were not replicated trials, the two trials were compared for their fit in a normal distribution within the 95% confidence limits. There were significant differences between the Best Management Option and the grower comparison within the 95% confidence limits. The BMO planting had 95% undamaged cobs while the grower comparison had 87% undamaged cobs (estimate for p (1)-p(2) 0.0859 P=0.005) (Figure 1).

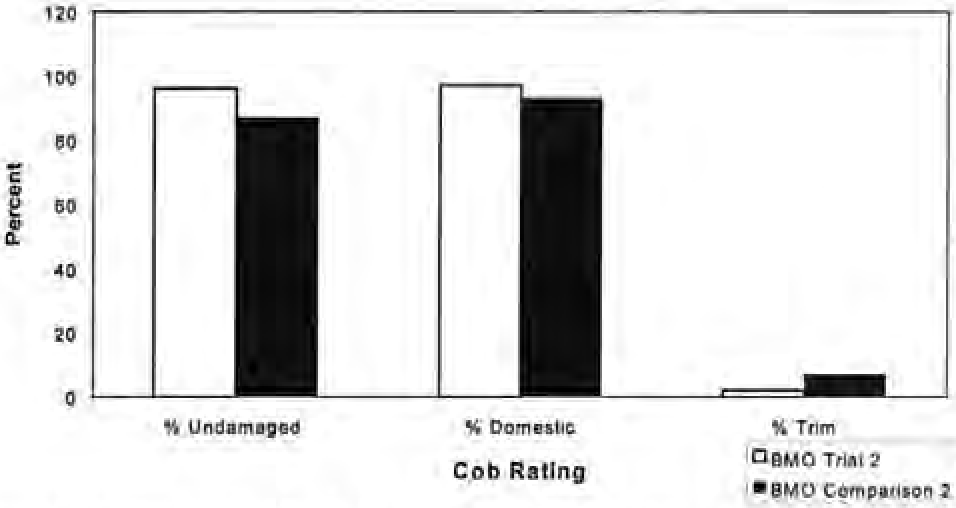

Figure 1. Comparison of cob damage for Best Management Trial 2 and Standard Practice

Discussion

Best Management Options including Success® and its incorporation into a Best Management Strategy on a commercial scale was evaluated under the most extreme season yet experienced in Victoria with respect to pressure from corn earworm.

Although the original aim of comparing BMO using Success® with standard grower practice did not eventuate due to the extensive use of Success® as an off-label application. We were able to look at effects of release of *Trichogramma*, pre-silking applications of Gemstar® (which was applied by some growers when available), and timing of spray applications based on crop scouting information.

The ability of *Trichogramma* releases to provide some additional control was demonstrated and the overall performance of the BMO plantings, notwithstanding the application problems in the first trial, was better than the standard grower practice.

However the unprecedented pressure experienced this recent season and control failures using Success® during the middle of summer with high pest pressure and high temperatures highlights the limitation of a seven day spray interval and the lack of options for alternative pesticides. It also highlights that although good parasitism levels were achieved at times when pest pressure was extreme the benefit may be limited.

Technology Transfer

More detailed information and results are available in the following reports:

Growers and industry representatives were exposed to BMO research through newsletters, media releases and by conducting farm walks and field days. Also the results of these trials were published in,
Milestone Report 6 - Insect Pest Management in Sweet corn (HRDC Project VG 97036)

Proceedings of Workshops No 2 (1999) & 3 (2000) of Insect Pest Management of sweet corn (HRDC Project VG 97036) 1998 and 1999.

Grower Information Night – 11/2000

Recommendations

These results indicate that reliance on a single new chemical is not adequate and that a package of control methods is more effective. The need for pre-silking sprays should be based on pest pressure.

The trials and seasonal results, in which Success®, a new chemical, was used extensively for the first time, highlighted the necessity for another chemical option and the limitations of the 7-day spray intervals under high pest pressure and hot conditions. It also highlighted the need to consider pest pressure and application rate of Success® with higher rates being necessary under extreme pressure.

Acknowledgments

The project team would like to thank the following for their assistance and participation in the project: Aventis, Dow Agrochemicals, E. E.. Muir & Sons, Bon Accord, Growco, N Cox, Whitbourne Farms.

11. Evaluation of Insecticides

Further details of work programs associated with **Evaluation of Insecticides** have been reported in :-

- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 26-28; 40-44 & 48-50.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 106 –111 & 123-127.
- Proceedings of Workshop No 3, June 2000, (Bowen, Qld) – pp 72-75.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 15-19.

Evaluation of Insecticides (cont.)

R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle, DNRE, Vic.

Introduction

A field trial was conducted to evaluate the effectiveness of three new 'softer' pesticides for *H. armigera* control in sweet corn. The trial was carried out in the Lindenow valley in East Gippsland in Victoria during season 2000/01. These are new chemical groups to which corn earworm has not yet developed major resistance problems. Currently only one new pesticide, Success®, is registered and this on its own can not provide an effective pest management strategy.

Proclaim® (Emamectin), Secure® (Chlorfenapyr) and Avatar® (Indoxacarb) are three new insecticides available for a range of caterpillar pests including heliothis in other crops but not in Sweet corn. Alternating chemicals will be essential in developing an integrated management strategy for heliothis control. This trial aimed to evaluate the potential for use of these chemicals in sweet corn for corn earworm control.

Materials and Methods

A block of Sweet corn (var. Golden Sweet) was selected in a commercial crop and six treatments were applied including a control with no pesticides, in a complete randomised design with four replicates.

Five chemicals ,Success® (Spinosad) at 800 mL/ha, Dominex®(α- cypermethrin) at 400 mL/ha, Secure® (Chlorfenapyr) at 400 g/ha, Proclaim®(Emamectin) at 300g/ha, Avatar® Indoxacarb at 250g/ha and a control without spraying were included in the study.

Pesticides were sprayed using a power operated knapsack sprayer with four flat-fan nozzles commencing at 50% silking. Four sprays were applied at weekly intervals to each treatment. The cob damage index was developed using a range of scores from 0 to 5 where 0 is allocated for non damaged cobs and 4 for the top damage and for the base damage.

Marketability was assessed according to the damaged caused by grubs to the tips and the cobs with a damage over of 6 cm and cobs damaged at the base or sides were assessed as unmarketable.

Results

The plots sprayed with Success®, Proclaim® and Avatar® had the lowest cob damage of 36%. Though slightly higher Secure® also had a significantly lower cob damage (52.4%) compared to the control where 85% of cobs had damaged. However Secure® was not significantly different from Dominex® which had 62.7%. (Table 1).

Table 1. Mean cob damage levels and Marketability of cobs as Percentages.

Treatments	No Sprays	Spray Interval (days)	Mean damage% *		Mean Marketable% *		
			Nil damage	Cob damage	Marketable whole	Trimmed	Unmarket able
Control	Nil	-	15.0	85.0 a	15 a	68.3 a	16.25 a
Success®	4	7	64.2	35.8 c	65.9 c	32.5 b	1.65 c
Dominex®	4	7	38.3	61.7 b	38.3 b	52.5 a	9.13 b
Secure®	4	7	47.6	52.4 bc	48.1 c	48.6 a	3.3 bc
Proclaim®	4	7	63.6	36.0 c	63.6 c	36.1 b	0.0
Avatar®	4	7	64.1	35.9 c	64.1 c	35.9 b	0.0
LSD				20.6	20.5	20.8	6.5

(* Column means followed by the same letters are not significantly different at $P \leq 0.05$)

The damage index was significantly lower for Avatar® (1.42) Proclaim® (1.51) and Success® (1.50). Compared with those three chemicals Secure® (2.07) was similar to the index of Dominex®(2.38) and significantly higher than the other three but lower than the control (2.95).

Discussion

In this study Avatar® and Proclaim® were similar in effectiveness to Success® and this agreed with the results of the previous studies for Avatar® (Scholz. B. and Latimer K., 1999). These findings indicate that Avatar® and Proclaim® are useful chemicals for application to sweet corn crops. Further investigations are needed on the impact on beneficial insects.

Though Secure® also produced some successful control of heliothis in comparison with untreated plots, it was not significantly different from Dominex®.

Technology Transfer

Outcome of this trial was discussed at the sweet corn annual conference and it was published in the conference proceedings (Refer: Proceedings of the workshop No 4, 30th April - 3rd May 2001)

Recommendation
Since we cannot rely only on Success®, alternative pesticides are needed for successful heliothis management programs before long. Therefore strategies have to be developed for registration of other options such as Avatar® and Proclaim®, timing for their use and effects on beneficial insects etc.

It is essential to develop appropriate strategies for use of these chemicals for resistance control.

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Lavinia Zirnsak , Sheeree Bambrook, Ross Galati, Bill Bulmer, Ross Ingram and Roger Woodward.

Dow Agro Sciences, Cynamid Agriculture, Syngenta, DuPont and Aventis

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Scholz B. and Latimar, K (1999) The effects of two new insecticides on *Trichogramma* in sweet corn, 107 pp, Proceedings of the Second National Workshop, Bathurst, NSW, May 1999.

12. Insecticide Resistance Management

Further details of **Insecticide Resistance Management** work programs have also been reported in :-

- Proceedings of Workshop No 1, May 1998, (Gatton, Qld) – pp 35 and 40-44.
- Proceedings of Workshop No 2, May 1999, (Bathurst, NSW) – pp 6 –11.
- Proceedings of Workshop No 4, April/May 2001, (East Gippsland, Vic) – pp 38-48.

Insecticide Resistance Management (cont.)

Compiled by John Duff, Gatton DPI, with contributions from Project Team Members.

A report on the techniques useful in managing insecticide resistance, including the protection of currently available narrow spectrum and biological insecticides in the Australian sweet corn industry.

[Copies of this report will be distributed to all stakeholders]

Introduction

Over the past four (4) plus years of a national "Insect Pest Management in Sweet Corn" project, the sweet corn industry has undergone a major change in respect to insect pest management and in particular Heliothis management. The traditional reliance on broad spectrum insecticides has been unsustainable due mainly to resistance issues with these products. The Insect Pest Management in Sweet Corn project has investigated alternative control options which can deliver equivalent control and in some instances improved control of Heliothis and a subsequent reduction in damage to the sweet corn cob. Since the beginning of this project, three (3) new products have either been registered for use or had permits issued for use in sweet corn against Heliothis. However there have been concerns raised as to the long term usefulness of these products in this industry due to potential overuse and subsequent resistance issues which could arise. The likelihood of additional new products, of which there are potentially four (4), being registered for use in sweet corn, would also be questioned if the development of widespread resistance is to occur. This would greatly depend on whether the industry can be seen as being responsible users of currently registered products in such a way that Heliothis developing resistance from the sweet corn industry is minimised. As a consequence a resistance management strategy was discussed at the 2001 sweet corn industry workshop to address this issue and to demonstrate that the sweet corn industry is committed to the long term use of these products through responsible use of integrated pest management options.

An Insecticide Resistance Management Strategy (IRMS) is a management option, which is designed to minimise the likelihood of a particular insect pest (eg. *Helicoverpa armigera*) from developing resistance to particular insecticides or groups of insecticides. Such an IRMS should encompass as wide a range of control options as possible without solely relying on a chemical rotation program as has been the traditional means of targeting resistance. Those management options that could form an IRMS are as follows (adapted from Ashby *et al.* 1998.):

1. Regular crop monitoring to ensure that the minimum number of sprays are applied/targeted at the insect growth stage which is most susceptible for that insecticide. Newly hatched Heliothis are the most susceptible stage when growing sweet corn.
2. Use of alternative control options to help reduce the selection pressure on the insecticides. This is all encompassing and includes the wide range of cultural control options and the use of biological control options such as inundative releases of beneficial insects.
3. Rotation of insecticides from different chemical groups depending on the mode of action each has on killing the insect pest being targeted. This will slow down the process of selection for resistance.
4. Correct application according to the label directions, such as the appropriate rates and application methods. Lower rates may increase partially resistant individuals surviving and poor coverage would reduce the effect the insecticide has on the pest.

The success of this strategy in sweet corn will depend on the following factors:

1. The number of alternative insecticides and groups of insecticides which are effective and registered for control the insect (in this case Heliothis) in sweet corn.
2. The range of other effective pest management options available to growers in each region.
3. The proportion of the pest population exposed to the insecticide(s). When the majority of the pest population within a region is exposed to the insecticide then selection for resistance to that insecticide is high.
4. Insect biological factors, such as duration of the life cycle and mobility of the pest.
5. The degree of risk of resistance development (mode of action) to the registered insecticides.
6. The cohesion and the level of expertise in the industry and its advisers and the industries willingness to adhere to the strategy. This is always a difficult ask, as growers are concerned with producing a clean pest free crop that can be sold at a profit.

Cultural Management Options

These control options involve the use of crop management techniques that target the fundamentals of growing of the crop and how this can be manipulated to assist in reducing the impact that insect pest, diseases or weeds may have on the development of the crop or individual plant. These generally involve inputs from the grower and may include such things as :- cultivation to reduce over-wintering pupae or other soil pests and weed seedlings; selecting the correct crop and variety for your area; planting at times of the year when particular pests are not active or of low impact to the crop grown. Other techniques may result in making the crop/plant less palatable, less attractive or better able to withstand damage from the pest.

Site preparation and hygiene
Thorough land preparation is essential, particularly to allow for the complete break down of crop residue and any green manure crop. Cultivation will also reduce the number of over wintering *Helicoverpa* pupae, thereby reducing spring populations of Heliothis, a process known as pupae busting. Poor farm hygiene will result in losses from pests and diseases and is one of the simplest and most often overlooked methods of pest management.
Destroy old crop residues, reject cobs, weeds and volunteer plants that are a reservoir for pests and diseases.

Cultivar selection
Cultivar choice depends on a range of quality characteristics and market acceptability. Good husk cover protection is a desirable attribute to protect cobs from weather and harvesting damage as well as providing some protection from insect attack. Emphasis has generally been on cultivar tolerance to insect damage since anecdotal evidence has suggested that there are differences between Australian sweet corn cultivars in their susceptibility to Heliothis damage. Field observations have shown that cultivars such as H5 and Florida Staysweet are more resistant to attack from Heliothis than cultivars such as Goldensweet. This resistance mechanism is thought to be through a reduction of the movement of larvae through the silk channel and consequently reduce the likelihood of the larvae reaching the kernels and causing damage. However any external cob damage or significant damage to the silks will still render the cobs unmarketable as whole fresh cobs particularly for export markets are sought. The development of good quality temperate and tropical cultivars with this attribute is a desirable plant breeding objective and remains a challenge for breeding programs.

Crop monitoring
Pest management involves making pest control decisions based on sound knowledge of the pests and beneficial insects in the crop. Much of this knowledge is gained through crop monitoring. Crop monitoring is a process whereby a grower or consultant will enter a crop and look for the presence of pests and beneficial insects, diseases, weeds or nutritional disorders. Such an exercise is carried out on a regular basis throughout the crop life, particularly when the crop is at a vulnerable stage in its development, such as silking. Regular crop monitoring and good record keeping are the cornerstones of successful pest management.

Advantages of crop monitoring include:
- Detecting the build-up of insect and mite pests well before economic damage occurs.
- Ensuring correct decisions on whether control measures are necessary.
- Optimising the timing of spraying or other control measures.
- Selecting the most appropriate control measure.
- Finding out how successful the control measure has been.
- Identifying problem cultivars and areas within crops.

Disadvantages of crop monitoring include:

- Effective crop monitoring takes time and so is an added expense in IPM.

Record keeping

- Each week's records can be compared to see whether pests are becoming more or less abundant.
- The records will show whether a previous spray application had the desired effect.
- Long-term records will reveal whether some areas of a farm or field consistently harbour more insects; for example, along edges. They will also indicate the times when pest pressure is greatest.
- Observations of beneficial insects will be useful in determining whether a spray is required or whether another control measure would be more appropriate.
- Keeping records may confirm suspicions that a particular cultivar always hosts a lot of pests or that stressed plants are more attractive to the pests. At times of high pest pressure it may be possible to avoid growing the more susceptible cultivars.
- They provide documented evidence of what was sprayed and when.

Use of pheromone traps in monitoring

- Pheromone traps are not a control measure but provide additional information about Heliothis pressure.
- Pheromone trapping systems for Heliothis indicate the flight activities of adult male moths and when to start looking in the crop for eggs and young caterpillars. Pheromone traps could therefore be used as an early warning system only and indicate when to carry out more intensive monitoring.
- Take care to distinguish Heliothis moths from other moths that might also be caught (common armyworm moths, *Mythimna spp*, are sometimes caught in the traps).
- Pheromone lures are species specific and can be used for trapping either *Helicoverpa armigera* or *H. punctigera*. Only *H. armigera* is a significant pest of sweet corn.
- The male is attracted to the synthetic lure, which imitates the female's sex pheromone.
- Traps should be located at the edge of sweet corn fields.
- Traps should be checked as often as possible, at least weekly and on the same day of the week and cleared at the time of checking. Pest strips can be used to kill moths when they enter the trap, as they may otherwise escape. **During critical periods (silking and when temperatures are high), traps need to be monitored at least 2 -3 times a week.**

Records of the average number of moths per day can show peaks of activity. Remember these are catches of male moths and do not necessarily reflect female moth egg laying.

In the USA, the Scentry® Heliothis net trap is used widely to monitor *Helicoverpa zea*. These large tent traps are far more effective for collecting moths than the green funnel traps or Multipher traps. These American traps have been used in Victoria and have been more consistent than green funnel traps. Unfortunately, they are more expensive and difficult to service.

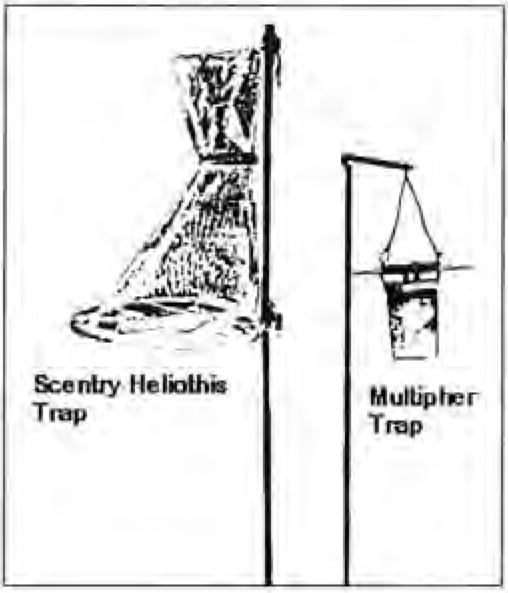


Figure 1.
Two commonly used pheromone traps. The Scentry Heliothis trap and the Multipher or Green Funnel Trap.

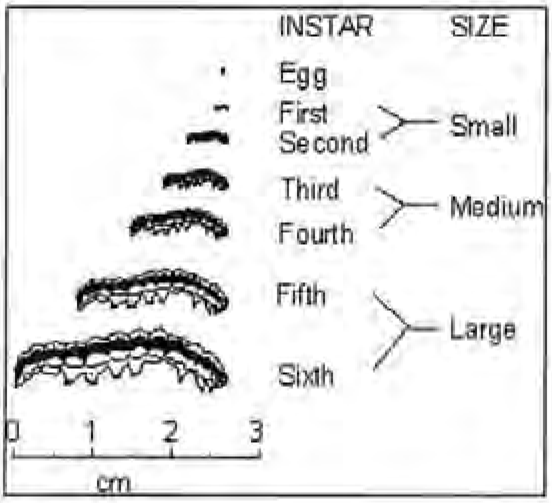


Figure 2.
Heliothis larval sizes.
Diagram provided by Dr G. McDonald, Ag Victoria, Rutherglen

Guidelines for making insect pest management decisions
The aim of insect monitoring in sweet corn is to provide information about insect pest populations and to determine if a management option needs to be implemented.
A range of factors to be considered :-

1. Correct insect identification.
2. Accurate data collection on insect life stage and where it is on the plant.
3. Weather at time of monitoring and insecticide application.
4. Beneficial organisms, eg. parasitoids, predators and diseases.
5. Insecticides used previously.
6. Production system. eg processing vs. fresh market.

Biological Control Options

Biological means borne from a natural environment. Biological control options include organisms that can be found in nature that attack other organisms, such as insect pests. They do this by either consuming them directly as a food supply in order to complete their life cycle, as might be found with insects, or using them as a substrate on which to grow and proliferate such as fungi, bacteria and viruses will do, killing the host in the process. Some are more efficient at managing particular insect pests than others and as a result research has sought to develop those organisms that can be used in agricultural systems and can be readily reared under controlled conditions and released into the cropping system to help in the management of one or more pests.

Beneficial Insects

Not all insects found within a crop are pests. The large proportion of insect fauna is made up of non-insect pests with beneficial insects and mites part of this biodiversity. At least 28 species of insects have been identified as having some degree of beneficial activity against the known insect pests found in sweet corn crops in Australia. It is likely that there are a large number of yet unrecognised beneficials having some degree of impact on the insect pest populations. Those that have been identified to date are included in the table below. Their potential as biological control agents, based on field observations, is also provided.

Table 1. Commonly found beneficial insects in sweet corn crops.

PREDATORS/PARASITOIDS	COMMON NAME	POTENTIAL[A]
Diptera (Flies)		
Several species	Tachinids	*
Trichopoda giacomellii	Green vegetable bug parasitoid	*
Coleoptera (Beetles):		
Anthicus sp.	Brown Anthicid Beetle	*
Chauliognathus pulchellus	Green Soldier Beetle	*
Coccinella transversalis	Transverse Ladybird	**
Coelophora inaequalis	Variable Ladybird	*
Dicranolaius bellulus	Red and Blue Beetle	*
Diomus notescens	Two Spotted Ladybird	**
Harmonia octomaculata	Three Banded Ladybird	**
Harmonia conformis	Spotted Ladybird	*
Micraspis frenata	Striped Ladybird	**
Hemiptera (bugs):		
Campylomma liebknechti	Apple Dimpling Bug	**
Deraeocoris signatus	Brown Smudge Bug	**
Geocoris lubra	Bigeyed Bug	*
Nabis kinbergii	Damsel Bug	*
Orius sp.	Pirate Bug	***
Tytthus chinensis	Black Mirid	***
Hymenoptera (wasps and ants):		
Iridomyrmex sp.	Black Ant	***
Pheidole megacephala	Coastal Brown Ant	*
Cotesia spp.	Armyworm larval parasitoid	***
Microplitis demolitor	Heliothis larval parasitoid	**
Telenomus spp.	Parasitoid of Heliothis eggs	**
Trichogramma spp.	Parasitoid of Heliothis eggs	***
Various genera	Aphid parasitoids	*
Various genera	Larval parasitic wasps	*
Neuroptera (lacewings):		
Mallada sp.	Green Lacewing	*
Micromus tasmaniae	Brown Lacewing	*
Orthoptera (grasshoppers, crickets, locusts):		
Pteronemobius sp.	Pygmy Cricket	*

[A] * minor, ** moderate, *** high.

The advent of Integrated Pest Management (IPM), has seen the role of beneficial insects being studied in a wide range of cropping systems with information gained from one cropping system being adapted in some form by another cropping system. This work is particularly important in the area of insecticide use and the impact that insecticides have on beneficial insects. When using insecticides one must also consider successive applications of particular insecticides and the types of beneficial insects present in the crop. A one off spray of a particularly broad spectrum insecticide such as methomyl or a synthetic pyrethroid, may reduce populations of the *Trichogramma* egg parasitoids slightly by directly killing those the spray comes into direct contact with. Heliothis eggs that have been parasitised will still harbour and yield *Trichogramma*, allowing the population to bounce back after a short period of time. The difficulty arises where successive applications kill even those parasitoids that have emerged after the initial application. This will reduce the impact that beneficials (parasitoids and predators) would naturally have on pest populations. The tables below indicate the toxicity of the insecticides currently registered for use in sweet corn, to Trichogramma and a range of predators. Indoxacarb (which is not registered for use in sweet corn) is included for comparison. Where, and when possible, adopt practices that conserve both parasitoids and predators by using insecticides that have minimal impact on beneficials, so that their action can complement the mortality caused by the insecticide.

Table 2. The effects of insecticides on Trichogramma.

Effect of Insecticide	Name of Insecticide
Safe – No widespread mortality reported	Bacillus thuringiensis (Dipel®) Heliothis virus (GemStar®) Indoxacarb (Avatar®)
Moderately Disruptive	Endosulfan (Thiodan®) Spinosyn (Success®)
Highly Toxic!	Carbamates eg. methomyl (Lannate®) Synthetic pyrethroids eg. deltamethrin (Decis®)

Table 3. The effects of insecticides on predators.

Effect of Insecticide	Name of Insecticide
Safe – No widespread mortality reported	Bacillus thuringiensis (Dipel®) Heliothis virus (GemStar®) Indoxacarb (Avatar®) Spinosyn (Success®)
Moderately Disruptive	Endosulfan (Thiodan®)
Highly Toxic!	Carbamates eg. methomyl (Lannate®) Synthetic pyrethroids eg. deltamethrin (Decis®)

Guideline for the introduction of mass reared *Trichogramma pretiosum* has been proposed for the **Lockyer Valley**, Qld, which may also be useful in other districts where egg parasitism is typically high. The guidelines divide the growing season into three periods, each with key characteristics as follows:

1. Winter to Late October - natural enemies are low coming out of winter and acceptable control following a large egg lay may be difficult. Options available include introductions of mass reared *T. pretiosum* into early plantings combined with use of Gemstar® and /or B.t.

2. Late October to Mid December - egg parasitism is typically 50-70% at tasselling, and other natural enemies are increasing. In combination with Bt and/or Gemstar®, control is likely to be adequate.

3. Mid December onward – *T. pretiosum* has increased to very high levels throughout the district and egg parasitism a week before tasselling is typically over 90% even under heavy egg pressure. Later crops may not require any insecticide intervention, but the secondary pests yellow peach moth, sorghum head caterpillar and thrips may require late applications of appropriate insecticides.

Inundative release studies of *T. pretiosum* at 180 capsules per ha under conditions of moderate to high egg pressure enables rapid establishment of *Trichogramma* and significantly reduces the numbers of larvae emerging to cause damage to the cobs. Best results can be expected with pre-tassel releases of *Trichogramma,* allowing numbers to build up before silking.

Predators tend to be more generalist feeders than parasitoids, e.g. spiders may readily feed on ladybird beetles, bees, or Heliothis moths. Consequently it is difficult to determine the numbers of predators necessary to manage various populations of Heliothis. A report by Richard Llewellyn suggests that 3 or more of the main predators per plant, can make a significant contribution to Heliothis control. During crop monitoring, if high numbers of white eggs, but few brown eggs and larvae are found, then it is likely that predation is having an impact on the Heliothis population. If there are high numbers of white eggs this could result in high numbers of brown eggs in 1-2 days time. If not, then predators have most likely reduced the numbers of eggs. Don't be alarmed by the presence of white eggs alone because they may be acting as a food source for foraging predators.

Enhancing beneficial insects
Crop monitoring is essential to help reduce unnecessary insecticide usage.
Use an appropriate registered insecticide to control the pest. i.e. one that has a limited direct impact on beneficials (eg. Bt or NPV)
Inundative releases of beneficials such as *Trichogramma* have shown to have a positive impact on Heliothis populations.

Pesticide Application Techniques for use in Sweet Corn

Pesticide application is a key component of IPM.

The Basics of Application
Insecticides used to control insect pests in sweet corn have different modes of action. A sound knowledge of the mode of action for a particular product will help in understanding the application requirements.
Contact insecticides kill insects by direct contact at the time of application or after application, by contact by the insect with the spray residue on the plant surface. Other products that have a stomach poison action need to be eaten by the pest which must consume a lethal dose of the pesticide for it to be effective. The dosage required may relate to the size of the larvae. Larger larvae generally require higher doses than smaller larvae. After application, pesticides will persist for varying periods of time on the plant before breaking down.

The target will vary depending on the plant growth stage and this can change from leaves, to tassels, to silks or even the actual pest. Ultimately the aim of growing sweet corn is to produce cobs with minimal larval damage and cobs free from live larvae. Once larvae entrench themselves in the tips of cobs they are impossible to control. Therefore it is important to control larvae early when they are exposed on the silks. Other growth stages such as seedling emergence, the vegetative growth stage and tassel emergence may be equally important in certain production regions.

There are several issues which influence spray distribution and uniformity:

1. Application equipment.
2. Crop canopy.
3. Silk position.

If the **application equipment** used to spray the crop is not delivering a uniform dose across the paddock then overdosing some sections and under-dosing others will occur. Blocked nozzles, worn nozzles or even subtle changes in travel speed are factors that will contribute to variable application across the paddock.

The **crop canopy** has a large influence on spray penetration and spray distribution on the plant. The distribution on the plant is very difficult to manipulate when spraying over the top with a boom. The deposit is greatest in the top part of the canopy and reduces rapidly down the canopy. Unfortunately the cob is a long way down in the canopy and a large proportion of the spray volume will be filtered out by the leaves above the cob.

Some sweet corn varieties have large flag leaves surrounding the cobs, others produce more tillers. There is also significant variation in canopy height amongst sweet corn varieties. All these factors will have an impact on the spray efficiency especially when there is additional foliage sheltering the silk or a greater distance for droplets to travel before they reach the silk.

The total spray recovered on **silks** has been measured, but the distribution of spray deposits on individual silks has not. Visual inspection of fluorescent tracer deposits has shown that the undersides of silks receive limited spray deposits. Depending on where egg lays occur on the silk, emerging larvae may easily escape contact with pesticide deposits.

Know Your Equipment
The most expensive sprayer will perform poorly if used inappropriately. Regular calibration of equipment is important, (measuring individual nozzle outputs, replacing worn nozzles and calculating the sprayer output). A range of nozzle types are available and each have specific optimal operating requirements including pressure, spacing and height. Controlled droplet application (CDA) equipment and sprayers using the air-shear principle for generating droplets have specific operating parameters to work efficiently.

Aircraft and a range of ground based spraying equipment are used in sweet corn production areas in Australia. Some of the equipment evaluated to date, include aircraft, ground sprayers with over the top booms and droppers, and ground based air assisted sprayers.

Even though equipment plays a significant role in the effectiveness of coverage, particularly on the silks, the interaction between the plant canopy and application equipment is also important. Unfortunately if the silks are critical targets, only small proportions (approximately 0.5%) of spray released from over the top will actually find its way to the silk. Leaves filter out a large proportion of the spray applied from overhead.

There is still some scope for improvement in application techniques with both aerial and ground based spray equipment. Although aircraft are heavily scrutinised they will continue to be an important tool for sweet corn growers. The volumes applied by aircraft for sweet corn (40 to 60 L/ha) are much higher than application volumes in broad acre cropping systems such as cotton.

In some areas the swath width flown by aircraft for sweet corn are up to 30% less than what they would be in other crops.

Currently many sweet corn growers and contract spray operators use high clearance sprayers fitted with short droppers. Comprehensive trials have been conducted using different length droppers set up to specifically target the silks, compared with a conventional boom spraying over the top. Sprayers equipped with long droppers have provided up to 4 times the spray recovery on the silks, while short droppers have produced 2.5-3 times more droplets on silks compared with the over the top conventional boom sprayer. Droppers do have problems if the crop is lodging or rows are not particularly straight and leaves brush past nozzles preventing spray droplets from reaching the silks. Of those operators using droppers there is a large variance in the water volumes applied per hectare. Contractors generally tend to apply much lower volumes (200 to 500L/ha) than growers using their own spray equipment (200 to 1300 L/ha). Further work is required to determine if this variation in water volume is important in pest management and to determine optimum nozzle configuration for droppers.

Air-assisted sprayers are used by some growers can provide considerable benefits including spray drift management and spray penetration. Further testing is however required with air-assisted sprayers to determine if there are significant differences in the spray deposit for the different settings (air velocity and angle) which can improve the effectiveness of this equipment.

Aircraft

Aircraft are extensively used in many sweet corn production areas in Eastern Australia. There is considerable debate as to the effectiveness of aircraft compared with ground based sprayers. The discussion should revolve around "over the top spraying" (ground and aircraft) versus "directed spraying" (boom + droppers). Table 4 lists several important factors that

should be considered when comparing various equipment types. Using this comparison, aircraft application scores well because it receives the greatest number of ticks in most categories. When interpreting Table 4, a grower or operator who ranks achieving good spray penetration as very important, would be seeking equipment capable of directing spray onto the target zone to improve pest control.

Table 4. Advantages of different types of equipment.

	Standard Boom	Air-assisted Boom	Boom + Droppers	Aircraft
Penetration		✓✓✓	✓✓✓✓	
Timing (work rate)				✓✓✓✓
All weather access				✓✓✓✓
Crop Lodging	✓✓✓✓	✓✓✓✓		✓✓✓✓
Crop Height	✓	✓		✓✓✓✓
Labour Input				✓✓✓

The application volumes used by aircraft when spraying sweet corn range from 40 to 60L/ha. These volumes are very high compared with conventional volumes applied by aircraft when low volume spraying (20 to 30 L/ha) or ultra low volume (ULV) spraying, (2 to 5 L/ha) in cropping systems such as cotton are used.

The types of nozzles used to deliver this volume are either CP nozzles or the Micronair AU5000. The CP nozzle is a hydraulic nozzle that gives the operator a great deal of flexibility. This nozzle has multiple orifice sizes (that can be used to alter flow rate) and a selection of three angles on a deflector plate (that are used to alter droplet size).

The Micronair AU5000 falls into the category of controlled droplet application (CDA) equipment. It consists of a cage that can be made to spin at a range of speeds by altering the pitch on three blades. Faster rotational speeds produce smaller droplets and slower speeds larger droplets.

There have been many recent advances in the technology associated with precision application of pesticides with aircraft. Global position systems (GPS) have enabled aircraft to apply pesticides to fields with a pre-selected swath with a variability of less than 1m. With GPS technology, aerial operators can also store flight paths allowing them to produce print outs of a spray job showing every swath flown.

The main areas where the performance of aircraft can be improved are: (1) improving the uniformity of a single deposit pattern (2) flying an appropriate swath width (3) maintaining a consistent swath across the field, and (4) selecting nozzles that produce an appropriate droplet size range.

An example of the spray **deposit pattern** from a single pass of an aircraft is shown in Figure 3. The ideal swath width is much less than 40m as the pattern tapers off at both ends. The appropriate swath for this aircraft can be determined by taking the single pattern and theoretically overlapping the deposit data using a computer. A range of swath distances are selected, and the swath width that gives a low coefficient of variation (approximately 30%) is regarded as the most appropriate to use, to produce uniform coverage. For this aircraft set up and this deposit pattern, the ideal swath width is 12m.

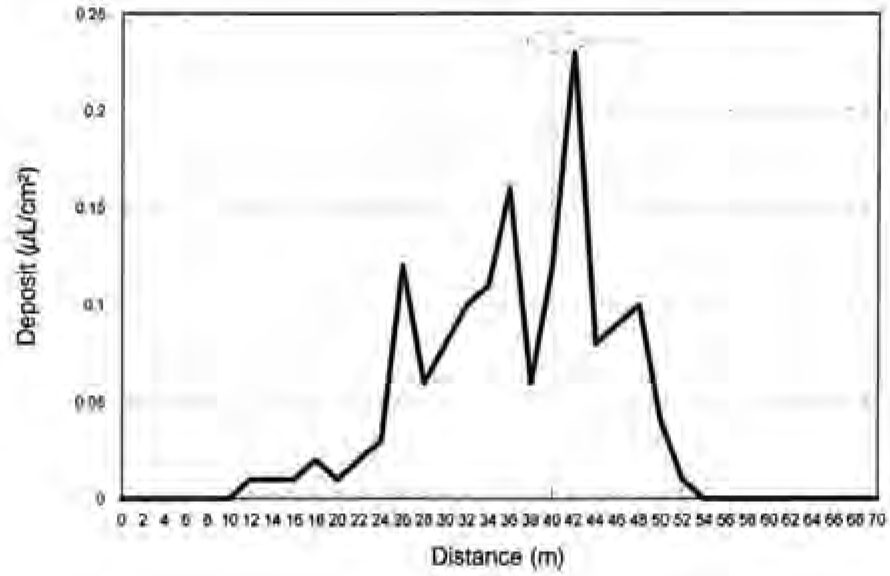


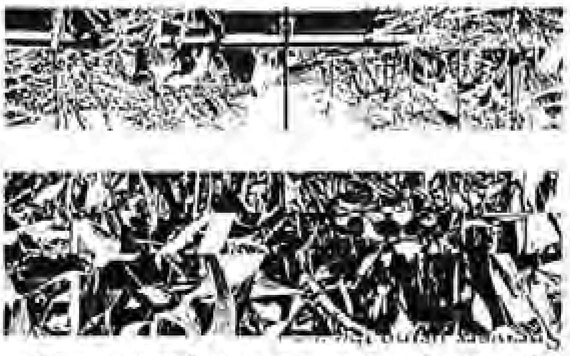
Figure 3. Deposit pattern of flat plates from a single pass of an aircraft (Cessna Ag Truck). The vertical line shows the aircraft flight pass.

Ground Based Sprayers

vi) Figure 4. Over the top booms with hydraulic nozzles or air-shear outlets,

vii) Figure 5. Over the top booms with hydraulic nozzles and air-assistance,

viii) Figure 6. Over the top booms with hydraulic nozzles plus droppers



Hydraulic pressure is used to produce droplets from nozzles such as flat fans and hollow cones. Sprayers using the air-shear principle produce droplets by using high velocity air (> 200 km/hr) to shatter the spray liquid into droplets.

Air-assisted sprayers offer many advantages compared with conventional spray booms. An axial flow fan, usually hydraulically powered, produces an air flow which is then ducted through an air bag along the boom. Along the bottom of the air bag this air is released as an air curtain. The air curtain produced by these sprayers assists in the reduction of drift and improves spray penetration into the crop canopy. The air curtain also produces turbulence within the crop which can result in improved coverage on the undersides of leaves and hard-to-get-to targets such as the silks on cobs. The direction of the air curtain can be altered on some sprayers, from straight down through to forward or backward in relation to the direction of travel. This enables spraying to be undertaken in less than optimum conditions when a strong wind may otherwise cause large spray losses. Even under ideal spraying conditions, spray penetration and coverage may also be improved in parts of some crops by having the air curtain directed forwards or backwards.

Spray application outcomes

Many commonly used pesticide application techniques have been evaluated for their efficiency in targeting insecticides to silks or artificial targets placed near silks. Using fluorescent tracers, spray deposits on silks have been collected for a range of equipment types. Some of the techniques tested have produced significant improvements over conventional application methods. Even though the equipment used is important when applying insecticides to sweet corn, the sweet corn canopy has a large influence on the spray penetration and spray distribution on the plant. The distribution on the plant is difficult to manipulate when spraying over the top with a boom. The following conclusions can be drawn for the spray application equipment used on sweet corn.

- Calibration is very important. Spray penetration and uniformity of spray deposition across a paddock may be improved with aircraft by using reduced swaths. Ensuring a precise swath width is flown across a paddock is also critical. This can be achieved by using track guidance (global positioning systems GPS) or by placing markers in the field so pilots know where to fly each pass.

- Boom sprayers fitted with droppers have the ability to direct more spray onto silks compared with conventional over the top boom sprayers and aircraft.

  (1) Dropper length

  No recommendations can be made on the length of droppers required, as length will vary depending on crop height and distance from the cob to the tassel. Some spray operators are using short droppers (50cm), with the nozzle placed above the top cob but directed downwards towards the cob. Longer droppers are more likely to become tangled and break off in crops that lodge. Short droppers will still give 2.5-3 times more droplets on the silks.

  (2) The number of nozzles required on each dropper

  Four nozzles are likely to give better spray deposition than two nozzles, especially if leaves are constantly brushing up against nozzles and preventing droplets from reaching the target.

  (3) Nozzle types on droppers

  Most of nozzles used on sprayers with droppers employed to spray commercial sweet corn crops are wide-angle flat fans. The reason for using flat fan with a spray angle of 110^0 is the width of the spray pattern at a set distance (i.e. 50cm) is wider than most conventional hollow cone nozzles that have typical angles of 70^0.

  (4) Application Volumes

  A wide range of application volumes are used when applying insecticides to sweet corn (200 L/ha to 800 L/ha). Increasing volumes will not necessarily increase spray deposit on the silks especially if the silks are drenched and run-off occurs. High rates would be appropriate with heavy pest pressures such as high numbers of eggs on silks.

(5) Ground speed of spray rigs
Ideal ground speed to give the best possible coverage on the silks would be between 6 and 8 km/hr. Excessive ground speed will reduce the deposits found on silks and hence the level of control of the pests being targeted.

Insecticide Control Options

Insecticides are categorised as either non-systemic or systemic, and act as stomach poisons, contact poisons or fumigants, whereas fungicides act as either protectants or eradicant/curative products. Newer and more environmentally friendly insecticides are beginning to make some inroads into pest management and are technically termed biopesticides. These include such products as *Bacillus thuringiensis*, and *Nuclear Polyhedrosis Virus* (NPV) or Gemstar®. The spinosad, Success® could also be placed with this group as it is a derived toxin from a soil micro-organism.

- **Non-systemic** pesticides are not absorbed by the plant and are only effective where they are applied.
- **Systemic** pesticides are those that are translocated in the plant.
- **Translaminar** pesticides or semi-systemic pesticides can move from one side of the sprayed leaf to the other where the pest may be protected from direct spray contact, as with mites thrips and aphids.
- **Stomach poisons** need to be ingested by the insect for them to be effective. This may involve the insect chewing part of the plant with the pesticide on it, as with *Bacillus thuringiensis*, or by the insect sucking sap from the plant tissues, for example dimethoate (a systemic insecticide) for aphid control.
- **Contact** pesticides need to come into direct contact with the pest, or the pest come into contact with the pesticide, for example walking over the plant part that has been sprayed. This is the case with synthetic pyrethroids.
- **Fumigants** are best known for their soil disinfestation properties for both insects and soil-borne diseases.
- **Protectant** pesticides, for example a fungicide, prevents the fungal spores from germinating and producing a disease. They need to be applied to the entire plant surface before the arrival of the disease.
- **Eradicant or curative** fungicides destroy the plant disease after it has penetrated the host plant, by systemically moving into the plant tissue. Coverage is not as critical as with protectants, but good coverage will give better control.

Pesticides can further be divided into a number of groupings, such as inorganics; synthetically derived organic molecules; and biologicals or botanicals.

Table 5. The main chemical groups

Inorganics	Common synthetics	Biologicals	Others
Sulphur	Organochlorines (OC's)	Rotenone	Petroleum spray oils
Copper compounds	Organophosphates (OP's)	Pyrethrum	Vegetable spray oils
Arsenic compounds	Carbamates	Azadirachtin	Insecticidal soaps
Sodium hypochlorite	Pyrethroids (SP's)	*Bacillus thuringiensis (Bt)*	
	Insect Growth Regulators (IGRs)	Insect viruses -NPV	

Spectrum of activity

This relates to the range of pests controlled by the particular pesticide.

Broad spectrum insecticides control a wide range of insect pests and do not discriminate between beneficial insects and the insect pest being targeted. Synthetic pyrethroids and many organophosphates such as dimethoate and chlorpyrifos are good examples of this.

Narrow spectrum insecticides control a specific group of insects, and include such products as *Bacillus thuringiensis* for lepidopteran pests. Some of the newer products such a spinosad and indoxicarb, although developed to control lepidopteran pest also have some activity on other pests, and are relatively safe to a range of beneficial insects important in sweet corn IPM.

Residual/persistence in the crop/environment

Residual and persistent are two terms that can mean the same thing but are quite different in reality.

Persistence refers to how long pesticides remain in the environment. For some it's only a few days, for example insect viruses and *Bacillus thuringiensis*, for others it may be much longer, for example copper based fungicides and organochlorine insecticides. Although they persist, they do not necessarily have a direct effect upon the pest initially targeted. This persistence is directly related to how the pesticides are broken down into by-products by micro-organisms, enzymes, heat, moisture, ultra-violet light or cultivation.

Residual relates to how long the pesticide is still active or useful in controlling the targeted pest, whether that be a weed, disease or insect. Insecticides generally have a short effective residual life on the pests being targeted, Bt's and viruses need to be reapplied after only a few days.

Using biological insecticides – biopesticides

Bacillus thuringiensis (Bt)

Bacillus thuringiensis is a biological insecticide used to control Heliothis larvae (corn earworm) in sweet corn as well as a wide range of other Lepidopteran pests in both sweet corn and other vegetable crops. Bt products are applied as a spray and need to be ingested by the larvae. The bacterium is then activated by the alkaline nature of the larva gut producing a toxin which causes a rupturing of the gut wall and a cessation of feeding almost straight away. Table 6 shows some of the advantages and disadvantages of using *B. thuringiensis* products.

Table 6. Advantages and disadvantages of Bt sprays

Advantages	Disadvantages
Only affects caterpillars, does not harm beneficials	May take some days before the larva is killed, though it will stop feeding well before that
Reduces the risk of resistance developing to other chemical controls	Short persistence, they are deactivated by sunlight
Soft on beneficial insects so is useful in IPM programs	More expensive than conventional insecticides

Nuclear Polyhedrosis Virus (NPV) or Gemstar®

This is an insect specific insecticide developed specifically for Heliothis in a number of broad acre and vegetable crops. As with Bt, NPV needs to be consumed by the larva in order for it to be effective. If the application is well timed, the damage that larvae do before they die is minimal. Smaller larvae are more susceptible than older and larger larvae. It is likely that the large larvae will not be controlled by this biopesticide. As this product is rapidly degraded by sunlight, late afternoon applications will help prolong the effectiveness of the product on the plant. This product is also exceptionally safe to both the environment and the worker and as it is specific to Heliothis, beneficial insects are not affected by it, making it an ideal control option for an IPM program in sweet corn.

Spinosad- Success®

This product is based on naturally produced metabolites of the living organism *Saccharopolyspora spinosa*, a soil micro-organism. These metabolites are produced under aerobic fermentation conditions. Application results in a quick knockdown of most lepidopteran pests including Heliothis, some beetles and a number of thrips species by affecting their nervous system. Spinosad is effective as both a contact and a stomach poison with feeding ceasing almost immediately with complete mortality within 3 or more days. Although spinosad is broken down by UV light in 2-3 days, its movement into the leaf produces a greater residual of the product. Spinosad has a relatively low toxicity to most beneficial insects with very little effect on beneficials once it dries. All of the above points make spinosads useful in any IPM program.

Records keeping

There are several advantages in keeping accurate records of all pesticides applied.

- Requirements may change in the future and growers who are currently keeping records will find it easier to comply with any new legislation concerning pesticide use.
- Records are useful for fine-tuning pest management practices, identifying problems and protecting growers against concerns with pesticide residues or spray drift.
- Growers who are implementing quality assurance systems already need to keep track of pest management decisions and practices.

Insecticide Rotation Program

Resistance in one or more pesticides is an ongoing problem for a number of cropping systems. Insects, diseases and weeds can all develop resistance to pesticides. In sweet corn, heliothis has developed resistance to a wide range of organophosphates, synthetic pyrethroids and carbamates over the past 20 or more years. As a result chemical companies there is a need to develop and promote Insecticide Resistance Management Strategies (IRMS), either for a particular crop, or a growing region. This has the benefit of safe guarding the effectiveness of insecticides.

Since the advent of heliothis resistance to insecticides, researchers, growers and chemical companies have been developing strategies for a wide range of cropping systems and more recently cropping regions. Insecticide resistance management strategies have been based on the principle of rotating products among chemical groups for different times of the year. The implementation of time periods or windows during the year, when certain products are restricted from use, can help to reduce the build up of resistance to new products as they become available for use.

It must be stressed that such a system is only part of the over all management of the pest, and should be used in conjunction with other integrated pest management options.

An Insecticide Rotation Program for the major sweet corn producing regions of Australia is proposed below and is appropriate as at July 2002 incorporating feedback from those interested parties.

<table>
<tr><th>Region</th><th>January</th><th>February</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th><th>October</th><th>November</th><th>December</th></tr>
<tr><td>North QLD</td><td colspan="2">No crop</td><td colspan="3">NPV
B.t.
carbamates
SP's
endosulfan</td><td colspan="2">spinosad
NPV
B.t.
carbamates
SP's,
endosulfan</td><td colspan="3">NPV
B.t.
carbamates
SP's</td><td colspan="2">No crop</td></tr>
<tr><td>South QLD</td><td>spinosad
NPV
B.t.
carbamates
SP's,
endosulfan</td><td colspan="4">NPV
B.t.
carbamates
SP's</td><td colspan="3">No crop</td><td colspan="2">spinosad
NPV
B.t.
endosulfan</td><td colspan="2">NPV
B.t.
carbamates
SP's
endosulfan</td></tr>
<tr><td>NSW/VIC</td><td colspan="2">spinosad
NPV
B.t.
carbamates
SP's
endosulfan</td><td colspan="2">NPV
B.t.
carbamates
SP's</td><td colspan="5">No crop</td><td colspan="3">NPV
B.t.
carbamates
SP's,
endosulfan</td></tr>
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carbamates
SP's,
endosulfan</td><td colspan="7">No crop</td><td colspan="2">spinosad
NPV
B.t.
carbamates
SP's</td></tr>
<tr><td>Region</td><td>January</td><td>February</td><td>March</td><td>April</td><td>May</td><td>June</td><td>July</td><td>August</td><td>September</td><td>October</td><td>November</td><td>December</td></tr>
</table>

This will change as new products become available and new pests become an issue.

Points that need to be considered when following this rotation strategy are:

1. Labels of new products place a limit on the number of applications to be used on any one crop or planting. If further insecticide intervention is required on one planting, insecticides from different chemical groups within the same window should be used.
2. Those products listed in the above strategy are in order of preference to help in the build-up of beneficial insects within the sweet corn crop.
3. The softer option products should be used before other products which have a greater impact on beneficial insects.
4. It is important to monitor crops regularly, so that the most susceptible stage of the pest is always targeted and to enable the correct product to be used.
5. Do not use mixtures of insecticides for controlling Heliothis particularly when they are from
   the same chemical group.
6. Use of the biological insecticides, Bt and NPV, in the early stages of crop development is encouraged. This will assist in the build-up of beneficial insects.

Resistance Monitoring
Heliothis has developed resistance to a wide range of commonly used insecticides such as carbamates, organophosphates and synthetic pyrethroids. As new products become available for the control of Heliothis in different crops, including sweet corn, data is being collected on resistance levels of local populations of Heliothis. This will help track levels of resistance of these local populations over time and allow grower groups and chemical companies to develop management strategies to minimise resistance problems to the limited range of new products.

This resistance testing is carried out through a central testing facility at Tamworth with resistance results to a number of new and old insecticides posted on Cotton Australia's web site for those who are interested in viewing this information.

Best Management Options

A Best Management Option for growing sweet corn in your area is the implementation of one or more Integrated Pest Management tools currently available for the control of Heliothis.

Some typical BMO's for sweet corn may be as follows:

North Queensland – Gemstar® applications pre-tasselling in conjunction with *Trichogramma* inundative releases
Gemstar® at silking has shown variable results and so needs further work
to fully evaluate this growth stage, but Success® may also be useful.

Case study 1.
A Comparison of Heliothis Management Strategies during Vegetative Growth in Winter-Grown Sweet Corn in Bowen, May-July 2000

A comparison of three strategies to control Heliothis during the vegetative growth stage was conducted in commercial plantings of sweet corn in Bowen during May to July 2000 by *Bowen Crop Monitoring Services Pty Ltd.*

Standard practice (SP) - Gemstar® sprays (3 @ 0.5L/ha) applied at peak egg hatch.
BMO 1 - Standard practice + 2 releases of *Trichogramma pretiosum* (120,000 wasps/ha)
BMO 2 - More frequent sprays of Gemstar® (6 sprays @ 0.5L/ha)

Numbers of Heliothis eggs and larvae and levels of parasitism were recorded from emergence to tasselling. Number and size of Heliothis larvae at tasselling was recorded. All treatments were sprayed according to standard practice during silking. A final damage estimate for all treatments was made just prior to harvest.

Low Heliothis egg lays were recorded throughout the vegetative growth stage (Figure 1). Because of the cool temperatures during this period, the average time for the eggs to hatch was 6-7 days.

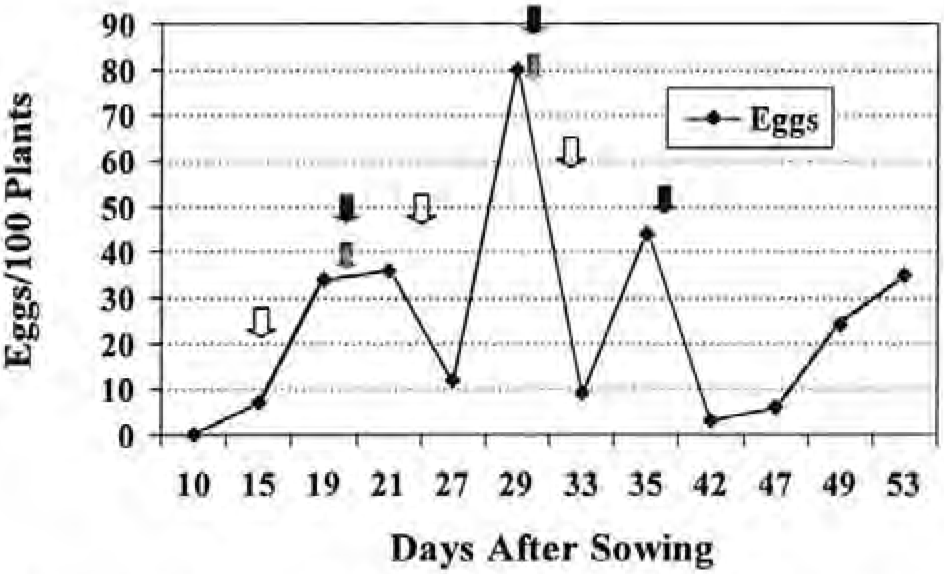

Figure 7. Numbers of *Helicoverpa armigera* eggs recorded pre-tasselling in winter-grown sweet corn, Bowen May/June 2000. (Black arrows indicate Gemstar® sprays; unfilled arrows indicate extra Gemstar® sprays (BMO2 treatment); grey arrows indicate releases of *T. pretiosum*).

Peak parasitism of 22.9% was recorded following the second release, but declined to almost nil for the remainder of the trial. There was little difference in larval numbers in tassels where *T. pretiosum* had been released compared to standard practice (Table 1). In contrast, increased applications of Gemstar® halved the medium and large larvae and total number of larvae in tassels (Table 1). Larvae infected with the fungal pathogen, *Nomuraea rileyi,* were widespread throughout all blocks and made a significant contribution to larval control in all treatments.

Table 7. Number and size of larvae in each treatment at tasselling, Bowen, June 2000.

Treatment	No. Larvae/ 100 Tassels				
	VS	S	M	L	Total
Standard Practice	3	10	10	16	49
BMO 1 – Gemstar® (3) + T. pretiosum	8	11	12	13	44
BMO 2 – Gemstar® (6)	4	8	7	5	24

Table 8. Final cob damage levels at harvest, Bowen, July 2000.

Treatment	Damage at Harvest (%)			
	Cobs with Larvae	Silk/Tip Damage	Kernel Damage	Total
Standard Practice	9	7	3	19%
BMO 1	8	6	3	17%
BMO 2	9	2	1	12%

Final damage levels in Standard Practice and BMO 1 were similar, however there was reduced silk, tip and kernel damage in the BMO treatment as a result of the reduced activity of large larvae at tasselling.

These results indicate that investigations of more frequent applications of Gemstar® at current and reduced rates is justified. The fungal pathogen, *Nomuraea rileyi*, may be worth investigating as a potential applied biocontrol agent in vegetative sweet corn.

The practical significance of this work as a BMO for Heliothis management during vegetative growth during winter in North Queensland are that:

- More frequent sprays of Gemstar® at lower rates may provide better levels of control than current practice without substantially increasing the cost of control for growers.
- There was no evidence of any value in releases of *Trichogramma pretiosum* during vegetative growth in winter, possibly due to the cold conditions. Earlier work has indicated different results. See Proceedings of Workshop No. 3.
- Despite much lower egg lays during the cooler winter months, intensive monitoring and correct timing of sprays pre-tasselling is just as critical as it is when activity is high during the warmer periods of autumn and spring.
- The fungus *Nomuraea rileyi* may have commercial potential as an applied pathogen in vegetative sweet corn.

South Queensland - Early inundative release of *Trichogramma* recommended in spring to supplement local populations. Gemstar® and/or Bt pre-tasselling if required.
Applications of Gemstar®, Success® or even methomyl during silking. Methomyl or a synthetic pyrethroid late silking to clean up secondary pests.

<u>Case study 2.</u>
Spring populations of Heliothis prove to be the most difficult to manage over the sweet corn season in the Lockyer Valley, South East Queensland. Traditionally the spring is a time of high Heliothis pressure and an insufficient level of parasites or predators for successful Heliothis management. Based on previous trials on timing (Nolan and Shields, 2000), pesticide applications and products, this trial tested different products and timing to manage a spring Heliothis population.

Two commercial plantings in the Lockyer Valley Queensland were used for the trials but only one will be covered here. More detailed information has been published in the "Proceedings of Workshop 4".
Farm 1 Commercial crop of Golden Sweet. The crop was treated with Gemstar® pre-silking and *Trichogramma* were released during the vegetative stage.

The crop was monitored twice per week during silking and then once a week after silking until harvest, recording Heliothis and other significant pests present.

Eggs were collected before any treatments were applied during silking and reared in the laboratory to assess egg parasitism. Ninety percent of the eggs were parasitised. Larvae were also collected and reared on artificial diet to assess the level of naturally occurring Nuclear Polyhedrosis Virus (NPV) present in the Heliothis population. Seventeen percent of Heliothis larvae collected were infected with the virus.

At harvest 40 cobs per plot were assessed for the presence of pests and the extent of damage to each cob. Growers considered between 20 and 30% damaged cobs an acceptable level of control for the local market. Control of minor pests such as thrips and a lower damage level was required for export market quality produce.

The planned pesticide treatments during silking were based on previous BMO/insecticide trials, with timing based on egg pressure as determined by monitoring.

Table 9. Planned pesticide treatments on Farm 1

Pesticide	Timing	Comment
Gemstar® (NPV) only 300ml/ha Gemstar® 300	Four applications @ 2,3,4 and 6 days from egg lay.	Last spray was not possible due to rain. Subsequent spray Day 14.
Success® (spinosad) only 600ml/ha Success® 600	Two applications @ 3 and 7 days from egg lay	Only day 3, too wet to apply second application. Subsequent spray Day 14.
Grower practice: Success® & Gemstar® as required. 800ml/ha *(Success® 800)*	Two-four applications depending on the pressure in the first 10 days of silking	The grower's timing was also interrupted by rain. The result being the timing for this treatment was the same as the Success® treatment, except for rate. No Gemstar applied.
Fastac®/Marlin® (alpha-cypermethrin/methomyl) 400ml/2L/ha: Fastac®/Marlin®	Applications every 2 days from egg lay.	Spraying was interrupted due to rain so only applied on Day 2 and 4 and then Day 14
Unsprayed	Receive no pesticide applications	

Grower's practice, of Success® at 800ml/ha, had the lowest proportion of damaged cobs at 11% chewed cobs (Figure 2). The Gemstar® 300 and Success® 600 treated plants showed the next acceptable level of damage at 16% and 17% respectively. Although higher, they were not significantly different from the Grower's practice. Unsprayed plants had 22% damaged cobs while Marlin®/Fastac® treated plants had close to an unacceptable level of damage at 28%.

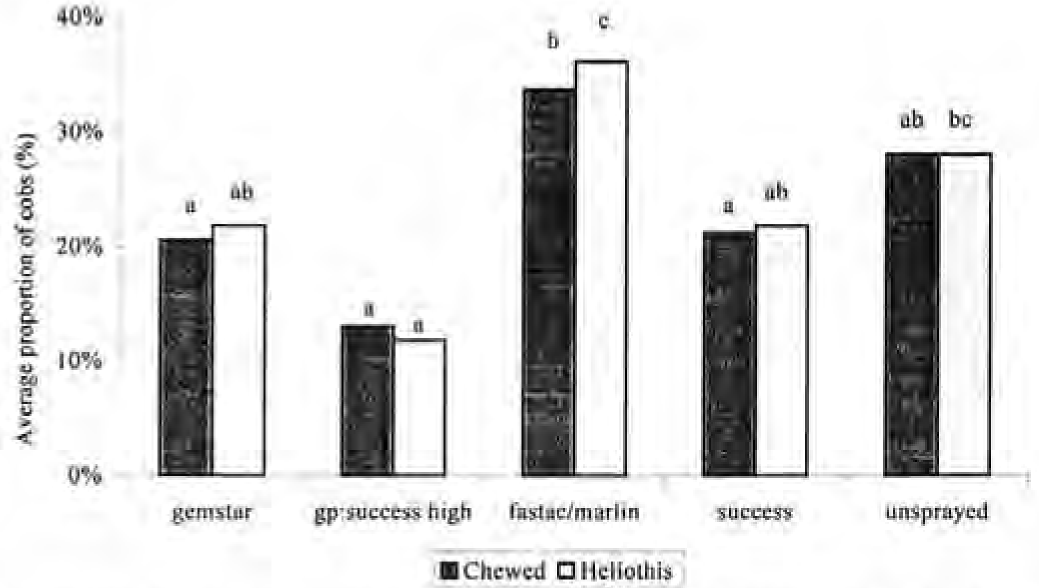

Figure 8. Harvest assessment from a commercial planting, December, 2000. Values with the same letter, within each category, are not significantly different.

The Grower's practice of 2 applications of Success® at 800ml/ha, at Day 3 and 14 after 80% of the crop was in silk achieved the best control of Heliothis and thrips. Gemstar® and Success® at 600ml/ha achieved similar Heliothis control however thrips were not as well controlled. These results were achieved at Heliothis pressure of an average of up to 2 eggs per plant.

Case study 3.
Best Management Options – Victoria, Sweet Corn Season 1999/2000 and conducted by R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle

These trials were established using commercial crops and compared with other commercial crops, which were treated according to standard practice within the district for the season. The aim of this evaluation was to test a "best bet" strategy (BMO) for *Helicoverpa* control and compare it with standard practice. The standard practice for commercial crops within the district for the 99/00 season was to apply Success® at the first sign of silking. Three applications about 7 days apart were made. An aphicide or clean up spray applied as a 4th spray or an aphicide applied with the final Success® application as required. Later in the

season when pest pressure was extreme and control poor, intervals between spray applications were reduced.
In the best management option trials, the following strategy was applied:

Management Option	Timing
Trichogramma release	tassel emergence
Pre-tasselling spray – Gemstar®	50% tassel emergence
Gemstar®	4 days after pre-tasselling spray
Trichogramma release	7 days after first release
Success®	Silking (<10% silking)
Success®	Need or timing determined by pest pressure
Synthetic pyrethroid or Success®	Need or timing determined by pest pressure
Synthetic pyrethroid or Success®	Need or timing determined by pest pressure
Synthetic pyrethroid or methomyl	Need or timing determined by pest pressure

The trial being reported on here was planted in late December with first silks being evident in late February when pest pressure had peaked at unprecedented levels.

Trichogramma activity was monitored by sampling eggs from the crop and the crop was scouted up to twice weekly, from silking to harvest, to assess egg numbers and determine necessity for spray applications. The BMO crop was compared with a crop using standard grower practice at a similar stage of development.

At harvest, a sample of cobs from each crop was assessed for feeding damage. The cobs were rated as:

- undamaged and marketable whole (suitable for export)
- slightly damaged at the silk tip or only slight damage to cob (suitable for domestic market)
- marketable as a trimmed cob (topped and tailed) (suitable for domestic market)

The level of damage for trimmed cobs was rated from 1-3 with 1 = 0-2 cm of tip damage, 2= 2-4 cm of tip damage and 3= 4-6 cm of tip damage.

Numbers of larvae were sampled up until 19 days after spray applications, but there were no significant differences observed between treatments. At harvest, cobs were assessed for damage, but there was no significant difference between treatments for cobs damaged by larvae. Cobs were sampled at harvest for evaluation of feeding damage by sampling every 10th row and down the row taking a cob every 20 metres.

Trichogramma were released on the 18th of February and 7 days later at 60 capsules for the 1.6 ha. The level of parasitism increased from five days after the first release until 14 days after the first release (Figure 10). Parasitism was at 18% at release and was above 70% of eggs sampled two weeks later. In the grower comparison parasitism increased similarly, but was at around 4% at the release date and at 19% two weeks later (Figure 11). Egg pressure was high at the point of *Trichogramma* release at 1.2 eggs/plant, but by silking was back to normal levels for this time of the year at 0.3 eggs/plant.

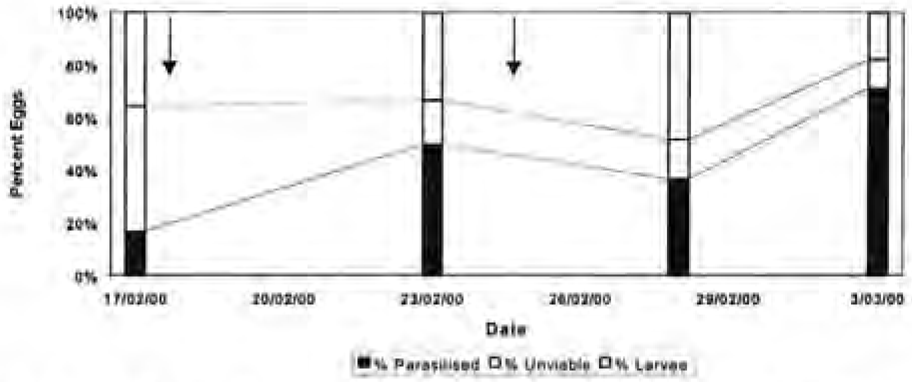

Figure 9. Percentage of parasitised *Helicoverpa* eggs – Best Management Option Trial 2

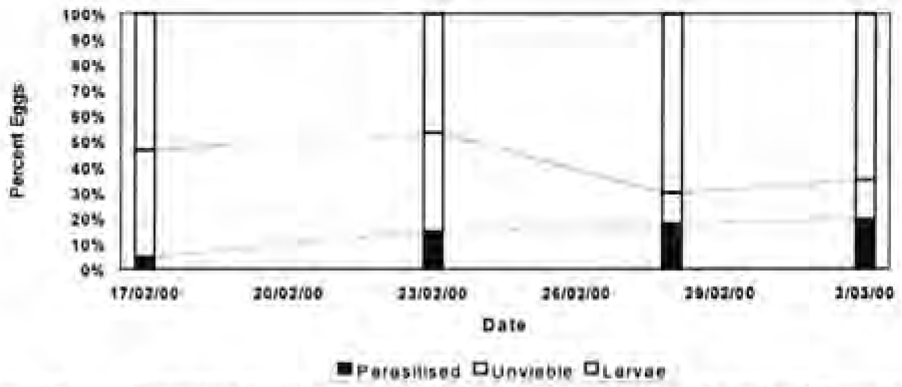

Figure 10. Percentage of parasitised *Helicoverpa* eggs – Standard Practice, Trial 2

Since these were not replicated trials, the two trials were compared for their fit in a normal distribution within the 95% confidence limits. There were significant differences between the Best Management Option and the grower comparison within the 95% confidence limits. The BMO planting had 95% undamaged cobs while the grower comparison had 87% undamaged cobs (estimate for p(1)-p(2) 0.0859 P=0.005) (Figure 13).

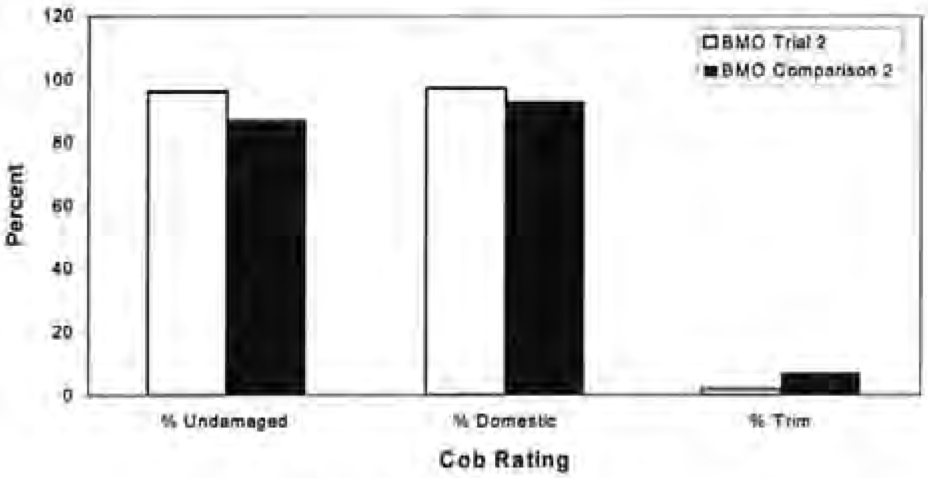

Figure 11. Comparison of cob damage for Best Management Trial 2 and Standard Practice

In this trial, the BMO planting received close to the ideal spray applications and intervals with five days between the first and second applications of Success® (this interval was reduced slightly based on the hot conditions, rapid hatching of eggs and experience earlier in the season). It would have been possible to extend the interval slightly (four days) between the second and third applications. The fourth Success® application was marginal in its application and although egg numbers were still high, numbers of larvae were negligible. The final application of Decis® and Lannate® was used as a clean up spray for aphids, but the spray interval was extended based on scouting with declining egg numbers, declining moth numbers and very few larvae. The grower comparison planting also received pesticide applications within a desirable time frame (7days apart) although there may have been some advantage in closing up the first applications due to the still high pest pressure at silking. However cob damage at harvest was still low although not as low as the BMO planting.

The original aim of comparing BMO using Success® with standard grower practice did not eventuate due to the extensive use of Success® as an off-label application. We were able to look at effects of release of *Trichogramma*, pre-silking applications of Gemstar® (which was applied by some growers when available), and timing of spray applications based on crop scouting information.

The ability of *Trichogramma* releases to provide some additional control was demonstrated and the overall performance of the BMO planting was better than the standard grower practice. However the unprecedented pressure experienced this recent season and control failures using Success® during the middle of summer with high pest pressure and high temperatures highlights the limitation of a seven day spray interval and the lack of options for alternative pesticides. It also highlights that although good parasitism levels were achieved at times when pest pressure was extreme the benefit may be limited. The trials and seasonal results, in which Success®, a new chemical, was used extensively for the first time, highlight the necessity for another chemical option and the limitations of the spray intervals under high pest pressure and hot conditions.

These case studies using Best Management Options indicate that reliance on a single control option may no longer be adequate and that a package of management options is more effective at delivering a cleaner product for the consumer. These include monitoring for both moth levels, and pests within your crop, but should also involve the release of parasitoids and the use of alternative biological pesticides pre-silking, as an alternate pesticide to help reduce numbers of larvae. The need for pre-silking sprays should be based on pest pressure and local knowledge as not all regions consider this necessary.

These are only a few examples of possible best management options for each region and should not be considered as a blue print for each area. The above typical BMO's which were trailed during the life of the project would be a starting point for any grower wishing to go down this path to a more sustainable growing future. These trials and more can be read in greater detail in numerous reports and workshop proceedings published as part of the IPM in Sweet Corn Project.

BMO programs clearly need to be developed further for local conditions, with the role of parasitism in these programs also varying from one district to the next as has been shown. Utilising parasitism in some instances is relatively easy as with processing sweet corn, where broad spectrum insecticides can be replaced with NPV (Gemstar®) and some tip damage is tolerable. In fresh market corn there are more factors to consider including the type and severity of damage, secondary pests etc. Nevertheless, in most fresh market areas gains have also been made simply by using NPV, aimed at egg hatch, up to tasselling. This gives more time for biocontrol agent and in particular parasitism, to increase and make a contribution to Heliothis management. Further, once a commitment is made to using a "soft" options approach, new ways are then developed for improving their activity. For example, a better understanding and more experience with NPV has led to experiments with application via sprinklers and post spray irrigation while some growers have already planted lucerne strips along roadways to encourage parasitoids.

Chemical insecticides are however still an important part of sweet corn production systems especially for fresh market growers. More work is required to better understand the impact of the various insecticides and whether or not there are benefits in spraying under different conditions. The work has shown that a single methomyl application reduces parasitism significantly but that recovery occurs within a week if the number of parasitised eggs per hectare is relatively high. (This however is not desirable if other control options exist.) Where parasitoid numbers are low or a second methomyl application is made within a week, recovery is much slower and is likely to reduce parasitism below useful levels. Spinosad (Success®) is less hazardous, but more work is required to observe the impact of repeated applications under various egg pressures and parasitism levels. Neem extracts and insect growth regulator type products appear relatively safe to Trichogrammatids and are likely to be important tools in the future.

Importantly, the findings from this project reinforce to industry and chemical manufacturers the need to develop products that are soft on non-target organisms and that such products are more likely to have a long useful life when there are good numbers of natural enemies present.

Any BMO program which utilises biological insecticides, selective chemical insecticides and natural enemies is likely to be more sustainable than broad spectrum focused programs - parasitised eggs produce no larvae to potentially develop resistance while predators clean up potentially resistant larva that survive a chemical application. This approach has important implications for resistance management and the sustainability of sweet corn pest management programs.

References and Further Reading

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Report: Milestone 4. April 1999. Commonly used pesticide application techniques have been tested for efficiency in targeting of insecticides to silks of sweet corn. Improved application techniques have been identified and promoted at farm walks and field days.

Report: Milestone 5. September 1999. Insect scouting protocols have been documented for each of the major sweet corn production regions in Australia.

Report: Milestone 6. April 2000. Best Management Options (BMO) have been compared with standard grower practice in each of the major regions in Eastern Australia.

Report: Milestone 7. May 2001. Cultivar evaluation trials to assess quality, yield and tolerance to pests and diseases.

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Proceedings of Workshop No. 2. 18-20 May 1999. Bathurst, NSW.

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Proceedings of Workshop No. 4. 30 April – 3 May 2001. East Gippsland, VIC.

Insecticide Resistance Management (cont.)

R Dimsey, P Ridland, Siva-Subramaniam and Brad Rundle, DNRE, Vic.

Introduction

Resistance levels to synthetic pyrethroids and to carbamates have been increasing steadily in Victorian populations of *H. armigera* in sweet corn. While caution must be used in extrapolating from laboratory assays to field performance, it is clear that Victorian growers have been experiencing increasing difficulty in controlling infestations of *H. armigera* when using the standard treatments of synthetic pyrethroids and carbamates.

Materials and methods

Helicoverpa larvae were collected from several sweet corn crops in Lindenow and Dalmore. The resulting pupae were then transported to Tamworth for testing by Dr Robin Gunning (NSW Agriculture) using diagnostic doses for fenvelerate, methomyl and thiodicarb.

Results

Survival percentage of Helicoverpa armigera larvae in laboratory bioassays to assess resistance status. Populations collected from sweet corn at Dalmore and Lindenow, Victoria.

Dalmore	1997	1998	1999	2000
fenvalerate	100	94	100	100
RF	15	20	22	39
fenv./PBO R%	-	13	17	60
methomyl	52	53	-	-
thiodicarb	-	59	-	83
% homozygotes	0	10	-	25

Lindenow	1997	1998	1999	2000
fenvalerate	75	100	100	100
RF	10	15	18	38
fenv./PBO R%	-	-	16	47
methomyl	50	-	53	-
thiodicarb	-	60	65	90
% homozygotes	0	0	23	0

(Fenv./PBO R% also treats the fenvalerate treated larvae with the synergist Piperonyl Butoxide)

Discussion

Testing of *Helicoverpa* from sweet corn crops in various parts of Australia has also shown that resistance to carbamates (methomyl and thiodicarb) is now widespread. Since 1997 high levels of resistance to fenvalerate have been observed at Lindenow and Dalmore. Between 1995 and

1999 the resistance factor was relatively low. In 2000 this changed significantly with the resistance factor nearly doubling while the PBO treatment only partially alleviated the effects of fenvalerate. This indicated that in season 1999-00 the larvae had an additional resistance mechanism (possibly nerve insensitivity).

The testing with carbamates has not been as detailed but a similar picture has emerged with survival to thiodicarb elevated in the 2000 tests. There has been an increase in percentage homozygotes in the populations tested in 1998 and 2000 in Dalmore and in 1999 (but not 2000) in Lindenow. This suggests that carbamate resistance is becoming more severe and that carbamates are less likely to provide adequate control in the field.

Technology Transfer
Further details are available in the following reports
Outcome of this work was published in
Milestone Report 2 - Insect Pest Management in Sweet corn (HRDC Project VG 97036)

Proceedings of Workshop No. 4, 30th April – 3rd of May 2001.

Grower Information Nights – 21/10/98
11/11/99
11/2000

Sweet corn Spray Program – Leaflet published in 1998,1999 and circulated to all growers.

Recommendation
A resistance management plan for new pesticides is essential in maintaining the effectiveness of these new pesticides and managing this pest.

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Proceedings of Workshop 2. 18-20 May 1999. Bathurst, NSW
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Proceedings of Workshop 4. 30 April – 3 May 2001. East Gippsland, VIC,

Milestones and Milestone Reports

Milestone No. 1. Oct 1997. Agreement of project milestones and signature of Research Agreement.

Milestone No. 2. Report - April 1998. Documentation of the present pest management systems associated with sweet corn growing in the major regions of Eastern Australia; and the identification of Best Management Options (BMO) which will contribute towards an integrated approach to pest management.

Milestone No. 3. August 1998. All major stakeholders in the sweet corn industry have been identified and a mechanism for information exchange has been developed. (Confidential Report to HAL).

Milestone No. 4. Report - April 1999. Commonly used pesticide application techniques have been tested for efficiency in targeting of insecticides to silks of sweet corn. Improved application techniques have been identified and promoted at farm walks and field days.

Milestone No. 5. Report - September 1999. Insect scouting protocols have been documented for each of the major sweet corn production regions in Australia.

Milestone No. 6. Report - April 2000. Best Management Options (BMO) have been compared with standard grower practice in each of the major regions in Eastern Australia.

Milestone No. 7. Report - May 2001. Cultivar evaluation trials to assess quality, yield and tolerance to pests and diseases.

Milestone No. 8. Report - April 2001. The practicalities, commercial potential and reliability of techniques for mechanically sorting damaged and undamaged cobs in a sweet corn pack-house have been assessed.

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Appendices

I. Newsletters

The mechanism for the exchange of information among stakeholders between annual workshops involved mailing **"The Sweet Corn Ear" newsletter** to all stakeholders on the database.

Sixteen (16) Sweet Corn Ear Newsletters were published and distributed :-

April 1998; July 1998; December 1998; January 1999; March/April 1999 September 1999; March/April 2000; May 2000; August 2000; Sept/Oct 2000; December 2000; Feb 2001; April 2001; May 2001; June 2001 and March 2002

April 1998

July 1998

December 1998

January 1999

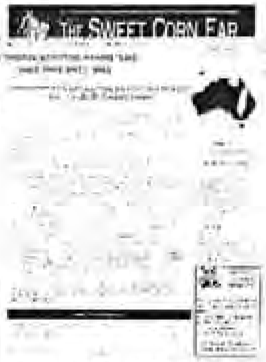
March / April 1999

September 1999

March April 2000

May 2000

August 2000



Sept./ Oct 2000

December 2000

Feb 2001

April 2001

May 2001

June 2001

March 2002

II. Papers, articles, rural media, posters, brochures, radio, TV etc

Some examples of media coverage of the Project activities and outcomes

:WS

5 million sought to ance gene research

GENE SHEARS

Managing pests in sweet corn

ANFIC

STARS OF THE FUTURE

ANFIC NURSERIES ARE:

ORCHARDING FOR THE FUTURE

Fruit & Vegetables December 1997

[redacted]

an irrigated 10ha paddock to butterfly pea in February 1998. This ... to butterfly pea. "To provide an economical seed source, we planted

there was a small proportion of cobs ... leaves and the top canopy blocked

DPI sweet corn project leader Peter Deuter, Gatton, said current ... impact or carry over of soil residues affecting following crops.

[redacted]

of the flooded coolibah river

application methods delivered 30 to

had limited use in the Lockyer

return to grain growing. ... content of Coulum's wheat and sorghum cropping operation had

researchers were looking for the best means to get pesticides to ... in an IPM system, she said.

Ms Gilbert said the only ... herbicides registered for use, weeds

[redacted]

performance in 2001 and half in 2003. Declining yields and protein

when to leave beneficial insects to

and nutrients and caused future difficulties by setting seed.

research started in 1998. ... of urea nitrogen treatments in 12 ... pea and grass pasture mix. The conventionally managed

and how effective beneficial insects were at minimising crop loss. ... damage levels in crops, those pesticides which managed them ... pests. Ms Walsh said researchers were studying secondary pest

DPI experimentalist Angelina Gilbert ... so long droppers could be quickly ... were difficult to use in a lodged crop

[redacted]

butterfly pea and 16ha of butterfly ... oded coolibah soils which had been continuously

simultaneously allowing beneficial ... use had allowed secondary pests to ... insecticides to manage heliothis, however, increased resistance ... corn growers, crop consultants, agribusiness representatives and

compared to over the top sprayer either with or without air assistance. Short droppers put two to three times as much spray on silks ... could be made for either short or long droppers and that in trials ... DPI Redlands Research Station engineer, Tom Franklin, who

[redacted]

resistance management strategies and more efficient water

PEST management, pesticide use,

which was very high, he said. Mr Battaglia said additional ... varied between 30 to 40 percent

[redacted]

New pest control

[redacted]

DPI REPORT

APRIL 13 2000 P/3

THE QUEENSLAND
Farmer and GRAZIER

Farm research and management update   Phone: (07) 4638 4633   FEBRUARY 1999

p19-22 Tractor buying guide

Heliothis restricts market prospect

Story GENEVIEVE McAULAY
Photo RODNEY GREEN

• Turn to p3

Entomology, Ross Wright and Ian Walker

Viridex

The breeding project has included QDPI staff

For any information on Viridex

Institute), finalised their modified hydraulic

and export markets."

project 'Insect Pest Management in Sweet Corn'. The project

application and timing of biological insecticides can increase

... to discuss the trial results

Farming in the Valleys

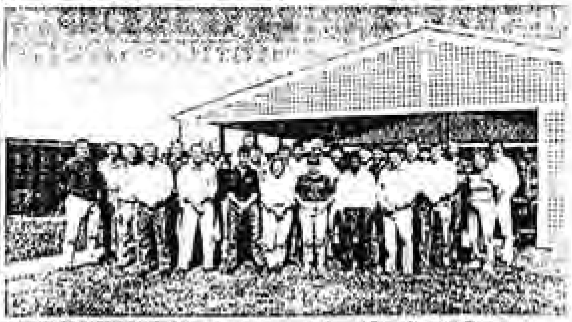
Warning on ergot

[illegible]

Workshop focuses on insect management

SWEET corn growers have held a workshop with researchers ... [illegible]

INSPECTING A CORN crop at Gatton Research Station ... [illegible]



WORKSHOP PARTICIPANTS TAKE a break during proceedings at Gatton Research Station

Initiatives welcomed

RURAL-BASED Queensland Senator ... [illegible]

Super wasps save sweet corn from pests

growers in the Lockyer Valley of south-east Queensland.

The corn earworm, or heliothis

The challenge of managing helio-

$220 million a year, including ... million for corn and maize.

"Heliothis causes most dam-

Heliothis is estimated to cost Australia's primary producers

caterpillar (*Helicoverpa armigera*), is a serious pest of maize and sweet corn.

age to corn from the time of silk-

caterpillars feed on those silks until they crawl or tunnel into the

Damaged cobs cannot be sold as fresh whole cobs, because con- ... increasing levels of damage as they feed and grow inside the cob. Seriously

before they move into the centre of the cob, where they are difficult to hit with insecticides."

To date, insecticides have been the most widespread, commercially used means of controlling heliothis

lems.

"Other control tactics must be

developed and integrated into exist- ing management strategies, and to

may need to be abandoned," Dr Scholz said.

Scientists from the Queensland

ment tactics which display promise for inclusion in integrated pest management (IPM) strategies in

sweet corn.

IPM involved using a number

age pests, without depending on a single tactic, according to Dr Scholz.

Two new tactics for sweet- corn IPM were investigated.

"One involved utilising parasitic

wasps that attack heliothis eggs, and the other was a viral pathogen

Chris Monsour inspects a corn plant in a virus trial.

Photograph: *Good Bug Book*.

... customers.

oking for solutions that provide

and quality of propagation

ary concern, and this is invariably

ng stock.

ell composed to provide

e growing media.

gration to provide a media that is

ictable medium.

y for a broad range of species in a ll volumes.

y to facilitate crop production.

plications.

manager, Phill McGrath; and product manager Sebastian Richards

III. Sweet Corn Agrilink

[The following is a copy of the three main pest management chapters of the National Sweet Corn Agrilink, to be published in late 2002. Copies of these chapters will be distributed to all stakeholders.]

a) An integrated approach to pest and disease management

Managing pests and diseases is probably the most difficult aspect of sweet corn growing. Serious pests and diseases will most likely be a problem at some stage in the life of the crop. These problems have the potential to reduce yield and quality and therefore profit. This section describes an integrated approach to pest and disease management which takes account of prevailing conditions and suggests more sustainable methods of sweet corn production.

Integrated Pest Management (IPM) – What is it?
Cultural and physical management practices
Crop monitoring
Biological management options
Chemical management options
Making a pest management decision

Integrated Pest Management (IPM) – What is it?

The current approach to crop protection is to manage crop pests with a range of management options so that the pests do not cause economic damage. Crop pests can be insects, mites, diseases, weeds or even animals (birds, mice, bats). An IPM strategy aims to reduce the pest population to a minimum using a range of tools and management options. IPM is also designed to maintain environmental sustainability and the economic viability of the production system.
An IPM program needs to be a part of the production system as a whole looking at the various components of the system and how they might be manipulated in order to reduce the pest population. As such, IPM could be considered as an integral component of Integrated Crop Management (ICM), looking at all aspects necessary to grow a crop. An integrated approach to pest management utilises a range of management options most suited to the crop, while at the same time reducing pests to acceptable levels. These control options could be a combination of cultural, physical, biological and chemical control measures to manage sweet corn pests and diseases.

Management options
Integrated Pest Management involves a combination of management options from the following lists.

Cultural and physical management practices

- Planning
- Site preparation
- Farm hygiene
- Crop hygiene

Crop monitoring

- What you will need when monitoring a crop

- How to monitor sweet corn
- Pest and disease monitoring – what to look for

Biological management options
- Protecting and promoting naturally occurring beneficials
- Introducing beneficial insects
- Using biological insecticides - biopesticides

Chemical management options
- Mode of action
- Spectrum of activity
- Residual and persistent activity of chemicals
- Toxicity to beneficial insects
- Selection and timing of sprays
- Application equipment
- Responsible use of pesticides
- Resistance management strategies

Cultural and physical management practices

Planning
Review the previous season. Review what happened last season and use this information to plan your actions for the current season. Think about:
- What did and didn't work;
- Weather conditions during the crop;
- Pest levels that occurred;
- Your market, for example export or local fresh market or processing;
- Available products, changes in registrations;
- Order beneficials, for example *Trichogramma*;
- Review your monitoring logs, spray thresholds used last season and crop damage.

Site selection. Select a site that either does not have a history of problems,. Remember that:
- losses caused by nematodes are unusual in sweet corn, but are more likely in sandy soils;
- frost and chilling damage are more likely in lower areas and where air flow is restricted.

Production methods. You may choose to grow your crop using drip, overhead or furrow irrigation. All of these methods can have an influence on pest and disease problems. Remember that:
- overhead irrigation can wash sprays off the plant;
- wind direction can influence disease spread but can also aid the dispersal of small parasitoids such as *Trichogramma*.

Production period. The time of year will influence what problems you have with your crop. Select a production period that will minimise pests and diseases. Remember that:
- foliage diseases are usually worse in warm, wet weather;
- heliothis are usually worse in warm weather;

- mites prefer warm, dry conditions.

Crop varieties. The variety you choose will be determined by your time of production and known or expected problems.

Site preparation
Thorough land preparation is essential, particularly to allow for the complete break-down of crop residue and any green manure crop. Good land preparation will also assist with plant establishment by reducing the risk of waterlogging and plant losses from damping-off and other soil borne diseases and pests. Cultivation will help in reducing the number of soil-borne insects including over wintering heliothis pupae, a process known as pupae busting.

Pupae busting. Mature heliothis larvae pupate in the soil and emerge as adults within two to three weeks. Heliothis also enter a stage of suspended development during the winter months, a process known as over-wintering. To control these pupae the soil should be cultivated to a depth of at least 5 to 10 cm with the appropriate equipment The pupae are either killed by direct physical damage or through disturbance of the emergence tunnel so the moth can't escape the ground.

Farm hygiene
Poor farm hygiene will result in losses from pests and diseases. Good farm hygiene is one of the simplest and most often overlooked methods of pest management. It results in fewer pests and diseases developing on and being spread around the farm. Good farm hygiene includes the following management practices.

Crop rotation. Sweet corn is a good rotational crop with potatoes because the higher organic matter incorporated into the soil generally gives cleaner potatoes. Most other vegetable crops can also be grown after sweet corn.

Cover cropping. Cover crops improve the soil's structure and its water and nutrient holding capacity.

Crop hygiene
Destroy old crops and their residues, weeds and volunteer (self set) plants that are a reservoir of pests and diseases. Plough in crops as soon as harvesting is completed, it could help reduce local area build-up of heliothis where sequential plantings are made besides each other.

Removal of reject cobs. Remove and destroy reject cobs that can be a source of disease infections such as boil smut. Heliothis infested cobs should also be destroyed by burying them to prevent larvae from pupating and developing into adults.

Good hygiene. Apply a high standard of hygiene and quarantine in the field and the packing shed. This should be part of your Quality Assurance system.

Crop monitoring
Monitoring sweet corn for pests and diseases is the first step in the crop protection cycle. Without monitoring you have no evidence of what pest management strategies need to be carried out or how well your current pest management strategies are working.
We recommend you use a competent crop consultant to monitor your crops. If you do not hire a professional crop consultant we suggest that you get some training from a crop

consultant or your local departmental officer. There are a few procedures to follow in doing your own monitoring. Inspections should continue from emergence until harvest, and ideally start before planting to check for soil pests that may prevent uniform establishment. The intensity of monitoring will vary with the crop stage, pest pressures expected and weather conditions.

What you will need when monitoring a crop

1. A note book or record sheets.
2. A 10 power hand lens. Most optometrists stock these or you can order them through an entomological supply agent.
3. Plastic freezer bags to keep samples of unknown diseases for identification, as well as containers for collecting unidentified insects.
4. Pheromone traps contain a lure that attracts male heliothis moths. They can be a useful tool to detect large increases in moth numbers over time. They are not a replacement for crop monitoring. It is not necessary to immediately identify all the problems you find, but the more you can identify the better.
5. Sweet Corn Insect Pests and their Natural Enemies pocket book by Richard Llewellyn.

1. Set aside enough time to check a block carefully.
2. Know what you are looking for in general terms before going into the block.
3. Check each area or block regularly, twice a week during the seedling stage, once a week during the vegetative phase and twice a week during the tasselling and silking stages of the crop.
4. Check a good cross section of the block—pests can often be in patches or at one end or side of a block. Walk in a V, W or X-shaped pattern through the crop, starting at a different place each time you inspect the crop.
5. Before tasselling look at the whole plant. From the start of tasselling, concentrate on the tassels and then the silks when they appear until they brown off when intensive monitoring is no longer required.
From the brown silk stage until harvest monitor for aphids, particularly if cobs are destined for the export market. See 'Pest and disease monitoring' below for details.
6. Write down what you find on a monitoring sheet or in a diary.
7. Simple tables and graphs of data help define patterns, and maps help identify local problems and pest movement.

Don't worry about not seeing a particular problem—you will.
Choose plants at random, being careful not to specifically target unhealthy plants while monitoring. If a plant doesn't look healthy and you don't know why, put it in a plastic bag and have the problem identified. Extension staff, local crop consultants, or chemical resellers may be able to help with these identifications. A small 10 power hand lens assists with viewing small insects. Soon you will be skilled at identifying the range of pests, beneficials and diseases on your farm.

Pest and disease monitoring – what to look for

The following procedure is one of several that can be used for pest and disease monitoring, as indicated in 'How to monitor a crop'.

1. Check overall appearance of the plants, paying attention to variations in colour and vigour. Closely inspect bleached and speckled leaves or yellowing patches for mite infestation, heavy disease infection or waterlogging of the soil.
2. Look for wilted or yellowing plants, particularly seedlings, and examine these for symptoms of disease or physical damage caused by soil insects.

3. Thoroughly examine a minimum of 20 to 30 plants per planting. In very large plantings you may need to sample several parts of the planting. The more plants you look at the more accurate will be your assessment of what is happening within the crop.
A systematic sample may involve selecting a number of randomly spaced sites within the crop and assessing four to six plants at each site. The number of sites sampled will depend on the area of production and the time available for monitoring.
4. Carefully note and record the following information:

- The number and maturity of heliothis eggs on the leaves and stems, particularly the top third of the plant, tassels and/or silks and wrapper leaves of the cob. White eggs are newly laid, brown eggs will hatch in about one day, and shiny black eggs have been parasitised by a minute wasp, *Trichogramma*. Check egg parasitism by collecting at least 20 brown eggs, more if possible, and waiting to see whether a grub emerges in about a day, or if they turn black, which usually takes a number of days.
- The number of other secondary pests such as armyworm, sorghum head caterpillar and yellow peach moth.
- Presence of thrips, aphids, mites and dried fruit beetles.
- What type and how many beneficial insects are present.
- The presence of any diseases, for example boil smut, leaf rust, viruses and wallaby ear.
- Weed types and stages of growth, and if they are harbouring insect pests or diseases.
- Record all observations on the monitoring sheet

For major pests enter the number of pests found in the monitoring log. For minor pests such as aphids, thrips and mites an approximate number is sufficient.
For more details see *Insect Pest Management in Sweet Corn*, HAL Project VG 97036 Milestone Report 5, "*Insect Scouting Protocols*".

Sweet corn pest and disease monitoring log

Block: ______________________________ **Date:** ______________

Weather since last monitored: ______________________________

	Heliothis					Other pests eg aphids, armyworm, sorghum head caterpillar, thrips, yellow peach moth				Beneficial insects eg pirate bugs, ladybirds, lace wings, mirids, hover flies, predatory shield bugs				Others problems, eg diseases			Comments
Sample	White eggs	Brown eggs	Small larvae (less than 7 mm)	Medium larvae (7-23 mm)	Large larvae (more than 23 mm)					Black eggs				Turcicum leaf spot	Wallaby ear		
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
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22																	
23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	
Total																	
Average																	

Overall comments and recommendations

SAMPLE sweet corn pest and disease monitoring log

Block: A4, been silking for 3 days **Date:** 23/10

Weather since last monitored: Fine, may rain in next few days

	Heliothis					Other pests eg aphids, armyworm, sorghum head caterpillar, thrips, yellow peach moth				Beneficial insects eg pirate bugs, ladybirds, lace wings, mirids, hover flies, predatory shield bugs				Others problems, eg diseases			Comments
Sample	**White eggs**	**Brown eggs**	**Small larvae** (less than 4 mm)	**Medium larvae** (7-12 mm)	**Large larvae** (more than 12 mm)	**Armyworm**				**Black eggs**				**Turcicum leaf spot**	**Wallaby ear**		
1	1	-	-	-						1							
2	2	1	1														Aphids on lower leaves
3	0	0															
4	3	1															
5	2	2															
6	6	0								2							
7	0	0	3														
8	3	1															
9	2	0															
10	5	0															
11	0	1	2							1							
12	0	2															
13	1	0	1														
14	2	0															
15	4	0															
16	2	0															
17	3	1				1L											
18	2	1								1							
19	0	2															
20	0	1	1														
21	0	0															
22	1	0															
23	2	1								2							
24	4	1															
25	3	0															
26	2	0															
27	0	1															
28	1	0								1							
29	0	2															
30	3	3															
Total	53	21	8			1				8							
Average	1.8	0.7	0.3							0.3							

Overall comments and recommendations

Parasitism very low. Spray ASAP, before rain.

Biological management options

Biological agents (beneficials) can be used to help manage some insect pests of sweet corn, however growers cannot depend entirely on natural or released beneficial insects, particularly for heliothis control. Beneficials affect the pest population and include parasitoids, predatory insects or arthropods (spiders and predatory mites), fungi, bacteria, viruses, nematodes and animals, for example birds. Nature provides many beneficials (spiders and wasps) in our fields. Some beneficial insects (*Trichogramma*, lacewings and predatory mites) are reared commercially and can be released into the crop. Others are available as sprays, for example *Bacillus thuringiensis* and the nuclear polyhedrosis virus (for example Gemstar®). more info Beneficials, this section
There is a cost to using beneficials, but using them can reduce the cost of chemical applications and avoid the risk of pests developing resistance to the chemicals traditionally used. However, because of the high level of chemical application that can be necessary in sweet corn production, it is difficult to base your pest management solely on beneficial insects. If possible avoid using pesticides which may kill the beneficials. Suppliers of predators and parasites will also provide a list of chemicals that will not affect them.

Protecting and promoting naturally occurring beneficials
Beneficial insects which help manage pests, may be parasitoids or predators. If you use biological sprays, beneficial insect numbers in your crop and on your farm will gradually increase. This is particularly important at the start of the season when beneficial numbers are low. If you rely solely on organophosphates, carbamates and synthetic pyrethroids, beneficial numbers will remain low throughout the season and never be able to assist with pest control. Parasitoids, for example *Trichogramma*, are usually more sensitive to pesticides than are predators. Safeguarding this free work force requires the strategic and limited use of synthetic insecticides.
Beneficial insects supplement their diet with nectar and/or pollen, so some weeds or flowering plants planted within a crop may be beneficial. Weeds act as refuges for beneficial insects as well as harbouring some crop pests, such as aphids, that can supplement predatory beetle and lacewing diets and the aphid parasitoid.

Introducing beneficial insects
Only a small number of predators and parasitoids are reared by commercial producers. This is due to a lack of demand by growers and the cost of producing them. The most widely used beneficial insect in the sweet corn industry is *Trichogramma*, a heliothis egg parasitoid. *Trichogramma* has been very useful late in the season but numbers are usually very low at the start of the sweet corn season. The introduction of *Trichogramma* early in the season to supplement the natural population may be effective, provided softer biological pesticides are used. If IPM principles are followed, beneficial insect numbers should build-up with each successive sweet corn planting. Successive plantings benefit from the previous ones as beneficial insects move from one planting to the next in search of their prey, the insect pests.

Using biological insecticides – biopesticides
Most biopesticides are specific to a small range of pests. Non-target insects may become more abundant if biopesticides are used.

Bacillus thuringiensis (Bt)

Bacillus thuringiensis is a bacterial biological insecticide used to control a wide range of caterpillar pests, including heliothis, in sweet corn and other vegetable crops. Bt products are applied as a spray and need to be eaten by the larvae. The bacterium is then activated by the larva's alkaline gut, producing a toxin which ruptures the gut wall causing the larva to stop feeding almost immediately.

Advantages and disadvantages of Bts

Advantages	Disadvantages
Only affects caterpillars, does not harm beneficials	May take some days before the larva is killed, though it will stop feeding well before that
Reduces the risk of resistance developing to other chemical controls	Short persistence, it is deactivated by sunlight
Soft on beneficial insects so is useful in IPM programs	

Nuclear Polyhedrosis Virus (NPV)

Nuclear polyhedrosis virus (for example Gemstar®) is an insect specific virus developed to control heliothis in a number of broadacre and vegetable crops. Like Bt, NPV must be consumed by the larva for it to be killed. If the application is well timed the damage larvae do before they die is minimal. Application using droppers enables the product to be targeted directly to the silks where it is most needed. Smaller larvae are more susceptible than older, larger larvae, that will probably not be controlled by NPV. Late afternoon applications help prolong its effectiveness as it is rapidly degraded by sunlight. This product is exceptionally safe to both the environment and the worker. As it is specific to heliothis, beneficial insects are not affected by it, making it an ideal management option for an IPM program in sweet corn.

Spinosad

Spinosad (for example Success®) is based on naturally produced metabolites of the soil micro-organism *Saccharopolyspora spinosa*. This product affects the insects nervous system producing a quick knockdown of most caterpillar pests, including heliothis, as well as some beetles and thrips.

Spinosad acts as both a contact and a stomach poison. Feeding ceases almost immediately and death occurs within three or more days, so take this into account when monitoring. Although spinosad is broken down in two to three days by UV light, its movement into the leaf results in the product having a longer residual effect. Spinosad has a relatively low toxicity to most beneficial insects, although it can adversely affect *Trichogramma* wasps, with very little effect once it is dry. All of the above points make it useful in any IPM program.

Chemical management options

Mode of action

Chemical control usually refers to synthetically derived pesticides, including any toxic product that provides an immediate or short term kill of the pest(s). Pesticides are categorised as either non-systemic or systemic in their mode of action. Insecticides act as stomach poisons, contact poisons or fumigants, whereas fungicides act as either protectants or eradicant/curative products.

- **Non-systemic** pesticides are not absorbed by the plant and are only effective where they are applied.

- **Systemic** pesticides are translocated throughout the plant to where they are needed, usually distant from the site where they were applied.
- **Translaminar** pesticides or semi-systemic pesticides can move from one side of the sprayed leaf to the other, where the pest may be protected from direct spray contact, as with mites and aphids.
- **Stomach poisons** need to be ingested by the insect for the pesticide to be effective. This may involve the insect chewing part of the plant with the pesticide on it, as with *Bacillus thuringiensis*, or by the insect sucking sap from the plant tissues, for example dimethoate, a systemic insecticide for aphid control.
- **Contact** pesticides need to come into direct contact with the pest, either by a direct hit, or by the pest walking over sprayed areas on the plant.
- **Fumigants** are used mostly for disinfesting soil of insects and soil-borne diseases.
- **Protectant** pesticides, for example a fungicide that prevents the fungal spores from germinating and producing the disease, need to be applied to the entire plant surface before the disease arrives.
- **Eradicant or curative** fungicides destroy the plant disease after it has penetrated the host plant, by systemically moving into the plant tissue. Coverage is not as critical as with protectants, but good coverage will give better control.

Chemicals can be divided into a number of groupings, the main groups are: inorganics; synthetically derived organic molecules; and biologicals or botanicals.

Spectrum of activity

Spectrum of activity relates to the range of pests controlled by the particular pesticide. We will discuss only insecticides and miticides.

Broad spectrum insecticides control a wide range of insect pests and do not discriminate between beneficial insects and the insect pest being targeted. Synthetic pyrethroids (for example permethrin) and many organophosphates (for example dimethoate and chlorpyrifos) are examples of broad spectrum insecticides.

Narrow spectrum insecticides control a small group of insects. Examples are *Bacillus thuringiensis* on caterpillar pests, or chemicals specific to mites or aphids as with dicofol and pirimicarb respectively. Although developed to control caterpillar pests, some of the newer products, for example spinosad, will also have some activity on other pests. They are also relatively safe to a range of beneficial insects, important in sweet corn IPM.

Residual and persistent activity of chemicals

Residual and persistent are two terms that can mean the same thing but are quite different when used to describe chemicals. Both the crop and the environment can be affected by the long term activity and persistence of chemicals.

Residual relates to how long the pesticide is still active or useful at controlling the targeted pest, whether that is a weed, disease or insect. Herbicides have the greatest residual effect in the soil and could determine the type of crop planted back into the area treated. High rates of atrazine may affect subsequent crops for up to two years, whereas metolachlor may be residual for only 10 weeks after the initial application. Insecticides generally have a short effective residual life on the targeted pests. Bts and viruses need to be reapplied after only a few days.

Persistent refers to how long pesticides remain in the environment. For some it's only a few days, for example insect viruses and *Bacillus thuringiensis*, for others it may be for several years, for example copper based fungicides and organochlorine insecticides. Although they persist, they do not necessarily have a direct effect on the targeted pest. Persistence is directly related to how the pesticides are broken down into harmless by-products by micro-organisms, enzymes, heat, moisture, ultra-violet light or cultivation.

Toxicity to beneficial insects

The implementation of IPM in sweet corn or other vegetable production systems has increased awareness of the effects that pesticides have on the beneficial insect populations within a crop. Beneficial insects are more susceptible than the insect pest to the wide range of pesticides used in horticulture.

Selection and timing of sprays

Monitoring your crops gives you information on pest numbers and enables you to time spraying both to prevent damage and for when pests are most susceptible. Caterpillars are easier to control when they are small and feeding on exposed positions on the plant than when they are large and hidden within the cobs.

It is illegal to use a pesticide against an insect or disease problem for which it is not registered. Read the label carefully, it contains useful information on how to use that pesticide most effectively.

Responsible use of pesticides

Use pesticides only when economically damaging numbers of pests are present and only apply pesticides registered for use in sweet corn. Always read the label before use, only apply the registered rates and observe the withholding period (WHP). The withholding period is the time between the last pesticide application and harvest.

If application rates are higher than those recommended on the label, or withholding periods are not observed, pesticide residues may exceed the maximum residue limit (MRL). Detection of residue levels above the MRL can lead to seizure of the produce and prosecution.

All chemicals are toxic to some degree, so follow safety instructions given on the label. Avoid spraying in hot, still weather or windy conditions when spray drift is likely. Always wear the recommended protective clothing as detailed on the product label.

Keep records

Commercial growers do not have to keep accurate records of all pesticides applied to their crop. However, there are several advantages in keeping such records.

- Records are useful for fine-tuning pest management practices, identifying problems and protecting growers against concerns with pesticide residues or spray drift.
- Growers implementing quality assurance systems may need to keep track of pest management decisions and practices.
- Requirements may change in the future and growers who are used to keeping records will find it easier to comply with any new legislation concerning pesticide use.

An example spray record sheet is provided and a partly completed sample spray record is shown.

Resistance management strategies

Resistance to one or more pesticides has been a problem for a long time. Insects, diseases and weeds can all develop resistance to particular pesticides, for example heliothis has developed resistance to a wide range of carbamates and synthetic pyrethroids over the past two decades. When a new pesticide becomes available there is a tendency to use it until it fails due to heliothis or other pests developing resistance to it. As a result chemical companies are keen on promoting resistance management strategies, either for a particular crop, or a growing region. This helps safeguard the effectiveness of their product for longer so that it will control heliothis or other pests for a number of years.

Resistance management strategies are based on the principle of rotating products between chemical groups. As new products become available, the implementation of time periods or windows during the year when restrictions on use of the product apply, can reduce the chance of the pest building up a resistance to the product.

Spray record

Business/Grower Name: .... **Crop / Variety:** .... **Year / Season:** ....

Date / time	Block / row	Crop stage / target	Product	Dilution rate	Application rate	Equipment used	Date safe to harvest / WHP	Comments (eg. weather)	Operator

To the best of my knowledge the information provided on this record is correct.

Name: .... **Signature:** .... **Date:** ....

SAMPLE spray record

Business/Grower Name: Bill Bloggs **Crop / Variety:** Sweet corn **Year / Season:** 2001

Date / time	Block / row	Crop stage / target	Product	Dilution rate	Application rate	Equipment used	Date safe to harvest / WHP	Comments (eg. weather)	Operator
23/9						Boom spray		Calibrated boom	B Bloggs
25/10	1	Tassels/heliothis	Gemstar	350 mL/ha	400 L water	Boom	N/A	Fine	B.B.
31/10						Boom/droppers		Calibrated boom with droppers	B.B.
1/11	1	Silks/heliothis	Success	400 mL/ha	450 L water	Boom/droppers	N/A	Cloudy	B.B.
5/11	1	Silks/heliothis	Methomyl	2 L/ha	450 L water	Boom/droppers	1	Fine	B.B.
10/11	1	Silks/heliothis	Success	600 mL/ha	450 L water	Boom/droppers	N/A	Cloudy	B.B.

To the best of my knowledge the information provided on this record is correct.

Name: .... **Signature:** .... **Date:** ....

Making a pest management decision

The first decision you must make is whether action, including pesticide application, is needed to avoid losses from pest damage. The management of pests in your crop depends on you making the right management action decisions. You should aim to:

- introduce parasites and predators (beneficial insects) if suitable ones are available;
- spray only when the pest level becomes economically damaging;
- spray at the stage in the pest life cycle when it is most susceptible;
- spray individual plantings and not the whole farm;
- target sprays on appropriate plant parts, for example the silks;
- use sprays that will be least damaging to beneficial insects.

Monitoring and action thresholds help you make these decisions. An action threshold is the critical level at which a decision is made. Below this threshold you maintain as many cultural practices as possible to reduce the pest's impact on your crop; above this threshold you start specific control measures targeted at the pest. Thresholds are based on the average number of pests found per plant.

$$\text{Average number of pests per plant} = \frac{\text{total number of pests recorded}}{\text{number of plants inspected}}$$

Thresholds for insect pests are generally based on pest numbers and stages of the life cycle found in the crop. They are intended to reflect the pest level that will cause economic damage. If pest pressure is high you may be over the threshold, if it is low you may not reach the threshold.

The threshold you set will also depend on the activity of beneficial insects and the risks involved in not controlling the pest. For example beneficial insects may build up rapidly with aphid populations and be more effective than chemicals.

Weekly sampling for heliothis egg parasitism will indicate levels present within the crop and guide you in your choice of insecticides. A high percentage of black eggs indicates high parasitism levels reducing the need to take action against the pest. Without sampling for egg parasitism, or predator activity, you have no idea of the levels of beneficial insects present in the crop. Any sign of insect activity would most likely result in insecticides being applied whether they are needed or not. This can result in more damage to your crop, because you are also killing off beneficial insects which aid in the control of a number of insect pests found in sweet corn. For more detailed results see *Insect Pest Management in Sweet Corn*, HAL Project VG 97036 Milestone Report 6, "*Best management Options*". Threshold levels for other pests are normally based on the history of the area, stage of development of the crop, weather conditions and other observations. Record all these in your monitoring log, as they can be used to judge when outbreaks may occur and what steps may be required to keep them in check.

Using threshold levels

Broad thresholds developed by experienced crop monitors and researchers based in the Lockyer Valley in Queensland are presented, as a guide only. No scientific research has established definite action threshold levels for sweet corn. With experience you may be able to refine these thresholds for your situation. Use these levels as a guide to when specific action should be taken. Higher pest levels may be able to be tolerated up to tasselling.

Low threshold figures should be used when the crop is at a sensitive stage to that pest, for example silking, or at the start of the season when beneficial insects numbers have not yet built up.

High threshold figures should be used when the crop can tolerate the pest, or when beneficial insect numbers are high, generally later in the season.
Medium threshold figures should be used at other times.
Reviewing the variations recorded in pest levels is another guide to making the decision to act. For example if the number of brown eggs is much lower than the level of white eggs recorded previously, it is likely that there is a moderate to high level of predation present within the crop.
An increase in pest activity may indicate the need for:

- checking spray application equipment;
- a different pest control strategy;
- a different pesticide selection;
- an additional pest control strategy;
- a shorter spray interval.

A decrease in pest activity may indicate the need for:

- a longer spray interval;
- a softer pesticide selection;
- reduced targeting of that pest.

Once you have decided what pests need to be targeted you are ready to decide what control actions to use. In addition to pesticides, incorporate into your pest management plan other pest management strategies such as field hygiene and quarantine, biological control, resistant varieties and crop rotation. Using a range of pest management options in an integrated approach is called Integrated Pest Management (IPM). IPM generally reduces the risk of crop loss because it uses a broad range of options rather than relying on a single control option. The following tables are based on crop monitoring experience in the Lockyer Valley. The following Tables are for the vegetative stage of the crop, from planting to tasselling, and the reproductive stage, tasselling to harvest, respectively.

A guide to pest levels from planting to tasselling

Pest	Part of plant to check*	Record	Pest threshold to use: High	Medium	Low
Insects and mites			Average number per plant		
Heliothis	Whole plant	No. of eggs	1–5	5–10	10+
		No. of larvae (vs/s)	1	2	3
Thrips	Whorl	Number	1–20	20–100	100+
Two-spotted mites	Lower leaves	Number	0–10	10–50	50 +
Aphids	Lower leaves	Nymphs + adults**	1–20	20–100	100 +
Leafhoppers	Whole plant	Nymphs + adults	No levels set, target young plants and control at first sign of wallaby ear		
Diseases					
Turcicum leaf spot	Leaves	Leaf area affected	No levels set		
Wallaby ear	Whole plant	Number of plants affected	Control leafhoppers at first sign of wallaby ear		

A guide to pest levels from tasselling to harvest

Pest	Part of plant to check*	Record	Pest threshold to use		
			High	Medium	Low
Insects and mites			Average number per plant		
Heliothis	Tassels, silks, wrapper leaves and adjacent stalk	No. of eggs	0–0.1	0.2	1–2
		No. of larvae (vs/s)	0–0.05	0.2	0.25 +
Thrips	Silks and wrapper leaves	Number	1–10	10–50	50+
Two-spotted mites	Leaves adjacent to cobs	Number	1–10	10–50	50 +
Aphids	Tassels, cobs and leaves adjacent to cobs	Nymphs + adults	As above for planting to tasselling or 2 tassels in 20 plants with aphids		
Diseases					
Turcicum leaf spot	Leaves	Leaf area affected	No levels set		

vs = very small, s = small; * monitor 20-30 plants per planting or paddock; **need to check for parasitism of aphids

Developed in association with Shane Gishford (Independent Crop Consultant Services) and Andrew Johanson (Mulgowie Farming)

b) Insect and mite pest management

Pest infestations are a major cause of reduced yield and quality in sweet corn. Monitoring for pests and managing them is critical to your success as a sweet corn grower. The main problem is heliothis. Other caterpillar pests such as armyworm, yellow peach moth and sorghum head caterpillar can also damage cobs. Pests such as aphids, mites, thrips, green vegetable bug, dried fruit beetle and soil borne insects can also be problems at different times of the growing season or in different districts.
A pocket guide *Sweet corn insect pests and their natural enemies – an IPM field guide – by Richard Llewellyn* is also a valuable reference for field identification

Heliothis
Armyworms
Aphids
Maize leafhopper
Maize plant hopper
Thrips
Mites
Cutworm
Sorghum head caterpillar
Yellow peach moth
Green vegetable bug
Dried fruit beetle
Redshouldered (*Monolepta*) leaf beetle
Soil borne insects

Heliothis
Heliothis grubs are the major insect pest of sweet corn. They are also known as corn earworm, budworm and tomato grub, and are most often the larvae of *Helicoverpa armigera* moths. Heliothis will be present throughout the year, though they are more prevalent in warmer months and less common in cold areas in winter. The moths can travel over long distances between and within regions.
Eggs are laid on all parts of the plant, but are most abundant in the crop during silking when they are generally laid singly on the silks. The dome shaped eggs are about 0.4 mm in diameter, with ribs down the sides. They are white when freshly laid. As eggs age they turn from white to cream then develop a brown ring, which is the caterpillar developing inside. If the eggs turn black instead of brown, they have been parasitised, the black colour is the parasitic wasp developing inside. Eggs take two to four days to hatch in warm weather or up to 10 days in cool conditions.
Caterpillars (larvae) go through six development stages. This takes about two to three weeks in summer, increasing to four to six weeks as conditions cool. Newly hatched caterpillars are less than 3 mm long and have a dark head and fine dark hairs along the body. Stripes appear on larger caterpillars whose colour varies from green to orange to brown. At the last development stage, caterpillars are 30 to 40 mm
When the caterpillar has grown and is fully fed it moves from the plant to the soil. The caterpillar digs into the soil, makes a pupal chamber and an emergence tunnel and then turns into a pupa. Under normal conditions the pupa will form an adult moth and emerge from the soil after at least

16 days. In early-mid autumn the heliothis pupa can enter a pupal resting stage known as over-wintering, or diapause. An over-wintering pupa stays in the soil in a state of suspended development for several months before emerging as a moth. Decreasing daylength (generally less than 12 hours) and low temperatures, less than about 23°C, trigger over-wintering. In south Queensland it usually begins in mid-March.

The percentage of the population that enters diapause increases with latitude from very low in north Queensland to very high, probably 100%, in southern production areas.

Over-wintering pupae resume development in response to increasing temperatures during late winter and early spring. Seasonal conditions determine the exact timing of moth emergence. Under normal conditions peak moth activity occurs during October. In a warm year, moth emergence will occur slightly earlier while in a cooler year emergence will be delayed. Factors affecting soil temperature also influence moth emergence times. For example plant cover, such as weeds, may lower soil temperature and delay moth emergence.

Heliothis caterpillars chew leaves or tunnel down the silk channel of the cob. In the cob they feed on the kernels, bigger grubs do more damage. The presence of caterpillars and damaged kernels make the cob unfit for fresh market (whole cob) sale. Damage can be removed by topping and tailing the cobs and marketing them in pre-packs.

Monitoring

Monitor crops frequently enough to make good management decisions. This should be at least once per week up until tasselling, then twice per week from tasselling to harvest. It is critical that you monitor your crop from the late vegetative stage.

During the vegetative stage check the leaves, whorl and stem. Once silking has commenced focus on the cob region, including the flag leaf, silks and some tassels. Monitor more frequently during the silking stage because once eggs have hatched the caterpillars quickly move into the cobs where management is difficult. Specific monitoring advice for each state is presented the Insect Pest Management in Sweet Corn, HAL project VG 97036 *Milestone Report 5, Insect Scouting Protocols*. Pheromone traps provide additional information about heliothis pressure by indicating the flight activities of adult male heliothis moths. The male is attracted to the synthetic lure which imitates the female's sex pheromone. Pheromone lures are species specific, so a trap with a *Helicoverpa armigera* pheromone should only catch *H. armigera* moths.

Pheromone traps cannot be used to determine when control measures are necessary, but do serve as an early warning system for migratory moths and indicate when to start checking the crop for eggs and young caterpillars. Inspect the traps every day or two and record the number of heliothis moths caught. The trap catch provides a picture of local pest pressures from field to field. Compare yearly catches to the previous season to indicate whether there is likely to be more or less pressure.

Monitoring for over-wintering pupae

The following information is from the DPI Crop Link leaflet, *Pupae busting*.

To monitor a field for over-wintering pupae, measure out a series of randomly selected one metre lengths of row and search for emergence tunnels. Carefully remove the top 2 to 3 cm of soil with a garden trowel and inspect for tunnels. Each emergence tunnel will appear as a small circular hole slightly larger in diameter than a pencil. When the tunnels are found, dig carefully down to about 10 cm to find the pupae.

Soil moisture will influence the success of pupal sampling; soil too wet or too dry makes accurate sampling difficult. Sometimes the chamber will only contain the remains of the pupa indicating that the moth has emerged; in others the intact pupa will still be present. The pupae will be 2 to 10 cm deep depending on the soil conditions when the caterpillars move to the ground to pupate. If the soil is moist they will tunnel down further to construct their pupal chamber and emergence tunnel. Caterpillars seek a site to pupate where the soil is soft or well-drained, such as close to the plant row. Consider pupae busting if more than one pupa per 10 m^2 is found.

Management of heliothis

Heliothis management will influence the management of many other pests. Biological control, chemical pesticides or a combination of these methods can keep heliothis below damaging levels. While biological agents may help in the management of heliothis, at certain times of the year pesticides are usually needed to attain a commercially acceptable standard of produce, especially for fresh market sale.

Many parasites and predators attack heliothis eggs and caterpillars. However they do not normally provide sufficient management where broad spectrum pesticides are used, or during unfavourable conditions for example Spring time in Queensland's Lockyer Valley is an example of this.

Good heliothis management has been achieved without using pesticides during silking in systems where:

- biological pesticides are used;
- in suitable environmental conditions;
- where parasites and predators have become established.

This scenario has been achieved by some growers in summer/autumn sweet corn crops in the Lockyer Valley.

Beneficial insects—*wasps*

Egg parasitoids, such as the *Trichogramma* and *Telenomus* wasps, occur naturally and can destroy many eggs. Parasitised eggs become black and shiny. *Trichogramma* sp. are also available commercially and can be released into crops as a natural 'insecticide' to increase the proportion of parasitised eggs. However this technology is still experimental, so growers should be cautious. Releases of these wasps are useful when heliothis pressure is low or before cobs are produced. Parasitic wasps are susceptible to most chemical insecticides. Follow the supplier's instructions and treat the wasps carefully, they are delicate insects.

Bacillus thuringiensis (Bts)

Bacillus thuringiensis (Bt) is the active ingredient of a range of biological pesticides. It is effective against heliothis and other caterpillar pests. Good coverage is essential as the caterpillars must feed to obtain a dose of Bt. Bts are most useful when heliothis pressure is low, or in the early stages of the crop. Aim applications at hatching eggs and young caterpillars.

Nuclear Polyhedrosis Virus (NPV)

The *Helicoverpa zea* nuclear polyhedrosis virus has been formulated into a commercial biopesticide. Some different strains of it can also occur naturally in the crop. NPV is very host specific to the heliothis larval stage. The caterpillars must eat the virus to become infected. Aim applications at hatching eggs and young caterpillars, much larger doses are required to kill large caterpillars. Depending on the temperature, caterpillars may take nearly a week to die and this should be taken into account when using NPV as caterpillars in cobs will damage the kernels before they die. Apply during the vegetative stage, vigilant monitoring is required for applications during silking.

Cultural

The following information is from the DPI Crop Link leaflet, *Pupae busting*.
Over-wintering pupae may be killed by cultivation with full soil disturbance. Cultivation to a depth of 5 to 10 cm with appropriate equipment either kills them by direct physical damage or through disruption of the emergence tunnel so the moth can't escape the ground. This process is known as pupae busting.

Broad spectrum pesticides

Broad spectrum insecticides not only kill *H. armigera* but are also active against other pests and beneficial insects. *H. armigera* has developed resistance to a range of the 'traditional' broad spectrum insecticides in several chemical groups, so these insecticides are no longer effective. Some insecticides only kill caterpillars while others kill eggs and caterpillars.
Good coverage is important. Most eggs are laid on silks, so take particular care to get good coverage of this part of the plant. Timing of sprays is important. Eggs and young caterpillars are much easier to kill than older caterpillars and do less damage.
Many of the older chemistry based pesticides kill the adult heliothis.

Armyworms

There are several species and they are difficult to separate and identify in the field. This is especially so when the caterpillars are small. Armyworm are sporadic pests and do not always cause economic damage. They include the common armyworm, *Mythimna convecta*, northern armyworm, *M. separata* and the day feeding armyworm, *Spodoptera exempta*.
Armyworm caterpillars can be confused with heliothis. Large caterpillars both have green and brown stripes, however large armyworm caterpillars appear smooth with less hairs than heliothis. The common armyworm caterpillar is brown with dashed black stripes along the back and two wide pale stripes along the sides. It hides by day and feeds at night. Caterpillars lodge in the whorl where they feed on the new leaves. Older caterpillars are voracious feeders, as the crop develops they will attack silks and developing ears.
Common armyworm and northern armyworm caterpillars hatch from eggs laid in crevices, for example under the sheathing at the base of leaves. Caterpillars undergo a series of moults before reaching full size. When mature, the armyworm caterpillars burrow into the soil to form pupae from which adult moths emerge. The moths are active at night. The life cycle can range from six weeks to several months depending on temperature.
Day feeding armyworm is important at times in northern Queensland where it occurs between late December and March. Outbreaks follow good rains after a drought period and appear to be more serious when the rains are late. Eggs are laid in clusters of a few to about 400 eggs by night flying moths. The clusters are covered with the fawn coloured hairs of the abdomen of the female and are normally found on the leaves of the young plants. Eggs hatch in about three days and the dark, striped caterpillars take about three weeks to mature. Leaves up to 450 mm from the ground are stripped. Damage to crops may not be noticed until the caterpillars are almost full-grown.

Monitoring

Common in vegetative stage of crop, particularly in the whorl and then the tassel as the crop matures. Some feed at night making it difficult to identify the cause of the leaf damage and to monitor. Damage may not be noticed until the grubs are fully grown, when they may be difficult to kill. Feeding on silks may affect kernel set.

Management

Armyworm are rarely in sufficient numbers to warrant management action. However as a caterpillar pest, their management is similar to heliothis. They are, however, more likely to be killed by older pesticide chemistries as armyworms do not have tolerance to pesticides.

Biological

Parasitic wasps and insect diseases (naturally occurring or via a commercial formulation) can play a significant role in armyworm management, often before the critical stage of the crop is reached. The caterpillars are subject to fungal and viral disease, however these normally become widespread only when large populations of caterpillars occur and they act too late to prevent serious damage by the pest. The virus which attacks these caterpillars is different from the commercially available NPV, which is specific to heliothis. However Bts, which are not species specific, will kill armyworms.

The parasitic wasps, *Cotesia* spp. can be significant in armyworm control if they are in a low insecticide use environment.

Broad spectrum pesticides

Be aware of the possible adverse side effects of broad spectrum pesticides. Spraying them in the early stages of the crop may delay the establishment, in the crop environment, of important beneficials such as *Trichogramma* wasps.

While there are no registrations for armyworms in sweet corn, they are normally kept in check by pesticides used for heliothis, except for NPV.

Aphids

The corn aphid *Rhopalosiphum maidis* is the most common aphid in sweet corn. Aphids spread Johnson grass mosaic virus.

Aphids can occur in sufficient numbers to damage plants by sucking sap causing wilting and leaf puckering. Their excretion or honeydew is sticky and hard to remove, and a black sooty mould grows on it, making cobs unattractive and unsaleable.

Monitoring

Monitor crops to ensure that aphids do not build up to levels that will cause economic damage. They first appear on the underside of lower leaves in the vegetative stage of the plant. Adults also fly into the whorl and spread through the top of the plant. Take action during this stage if there are high numbers. When aphids are in the cob wrapper leaves they are difficult to manage and it is usually too late. When monitoring, especially during the vegetative stage, assess the activity of beneficials that attack aphids such as ladybirds, lacewings or parasitic wasps.

Management of aphids

Effective management includes good farm hygiene, beneficial insects and insecticides.

Hygiene

Destroy old crops as soon as harvesting is completed and destroy weeds that host aphids.

Beneficials

Natural predators of aphids include ladybird (coccinellid) beetles and their larvae, and hover fly and lacewing larvae. Several species of parasitic wasps lay their eggs in aphids. A wasp larva develops within each aphid which dries and becomes swollen, tan/brown and mummified. An adult wasp emerges from the aphid mummy.

Beneficials can be effective in managing aphids, unless aphid numbers build up to high levels before the beneficials gain control. Minimise the use of broad spectrum pesticides to achieve the most effective biological control.

Pesticides

If necessary, spray to manage aphids with an appropriate insecticide. Aim for thorough coverage of the undersides of leaves.

Maize leafhopper

The maize leafhopper, *Cicadulina bimaculata*, feeds by sucking sap. In susceptible varieties the disorder wallaby ear occurs when heavy infestations, that is more than 15 leafhoppers per plant, inject a toxin into the plant while feeding. Significant damage is due to wallaby ear rather than direct feeding by the leafhopper.

Monitoring

Monitor crops carefully to ensure leafhopper numbers are not building up quickly.

Management of maize leafhopper

An IPM approach, including planting resistant varieties, farm hygiene and the use of pesticides when necessary, is the best way to manage maize leafhoppers.

Hygiene

If possible plant new crops well away, and upwind, from older infested crops. Destroy old crops immediately after harvesting.

Pesticides

If necessary spray with an appropriate chemical from the *Problem Solver Handy Guide*. When spraying it is important to get good coverage in the whorls of leaves.

Maize plant hopper

The maize plant hopper, *Peregrinus maidis*, feeds by sucking sap. It spreads the maize stripe virus.

Monitoring

Monitor crops carefully to ensure plant hopper numbers are not building up quickly.

Management of maize plant hopper

An IPM approach, including farm hygiene and the use of pesticides when necessary, is the best way to manage maize plant hoppers.

Hygiene

If possible plant new crops well away, and upwind, from older infested crops. Destroy old crops immediately after harvesting and destroy volunteer maize, sorghum and wild sorghum plants.

Pesticides

If necessary spray with an appropriate chemical from the *Problem Solver Handy Guide*. When spraying it is important to get good coverage in the leaf whorls.

Thrips

A common thrips, *Frankliniella williamsi*, and other species have been identified in sweet corn. They cause damage by rasping plant tissue in the whorl, under the leaf sheath or wrapper leaves or in the silks. They are rarely an economic problem through direct feeding, however damage to seedlings can be a problem. Thrips are a contaminant in cobs destined for the export market.

Monitoring

Thrips are present throughout the life of the crop, however their presence is most significant during cob development when they become contaminants. Monitoring the whorl prior to silk expression will provide an indicator to whether action is necessary.

Vigilant monitoring is important as it is highly likely thrips carried on the wind will reinfest the crop.

Management of thrips

Hygiene

Destroy old crops and weeds in and around the block.

Biological control

Predatory bugs, especially pirate bugs, *Orius* sp., can play a major role in managing thrips. However natural populations of these bugs do not decrease the population enough to reduce cob contamination so a combination of management options may be needed.

Pesticide

No narrow spectrum pesticides are registered in sweet corn for thrips management. Coverage and timing is extremely important, as this pest hides and can be difficult to reach. Target applications in the morning or afternoon, as thrips tend to withdraw into the leaf sheath and be least active in the middle of the day. If necessary apply an appropriate insecticide

Mites

Mites, also called spider mites, are usually more of a problem in warm dry conditions. Damage is usually caused by the twospotted mite *Tetranychus urticae*, that infests a wide range of plants. All active stages cause a yellow stippling of the upper surface of the leaf and a fine webbing underneath. They can be spread by wind, and carried on clothing, machinery, birds and insects. Mites also make some workers itchy.

Monitoring

Monitor for mites by looking for the yellow stippling on the upper surface of leaves and checking the under surface for mites with your hand lens. They will often be near the main rib.

Management of mites

Mites can be very difficult to manage in warm, dry conditions. Monitor the crop and take action as early as possible to prevent a major flare up of mites. Hygiene, predators and miticides (where registered) are all options that should be considered.

Hygiene

Clean up old crops immediately after harvest and remove weeds and volunteer hosts from around the crop.

Predators

Predatory mites can be purchased to manage spider mites, however many of the chemical pesticides used to manage other pests will also kill these predators. The companies supplying predatory mites will supply a list of chemicals that are least harmful to the predators. Releasing predators into the headlands around new plantings may help reduce mite numbers before they move into the crop. Some natural predators—adults and larvae of the ladybird *Stethorus* spp., lacewing larvae and predatory thrips—may also be present.

Miticides

Mites quickly develop resistance to some chemicals, particularly if the same miticide is used too regularly. Some chemicals, particularly pyrethroids, kill predators and can lead to a rapid build-up of mites. Good coverage of the underside of leaves is essential for the chemicals to be effective.

Cutworm

Several *Agrotis* species are minor sporadic pests during the establishment of the crop as they cut off young plants at or near ground level.

Monitoring
It is usually necessary to dig in the soil to find the cutworm caterpillars to determine the extent of the infestation. Inspecting the crop twice weekly in seedling and early vegetative stages will indicate whether there is a rapidly increasing proportion of crop damage that warrants management action.

Cultural
Remove weed growth for three to four weeks before planting the crop.

Sorghum head caterpillar

Cryptoblabes adoceta can chew leaves as well as be contaminants in the silk and wrapper leaves of cobs.

Monitoring
Early stages in the life cycle are difficult to see, start monitoring for this pest as silking begins. Look in the cob region, especially wrapper leaves and silks. More than one caterpillar may be found on an infested cob.

Sorghum head caterpillar is also a pest of field crops so neighbouring crops may be a source of infestation.

Management

Biological
When the biopesticide Bt is used against heliothis, it seems to provide some control of sorghum head caterpillar if coverage is good. There have been reports of *Trichogramma* parasitising the eggs. The parasitic wasp *Cotesia* sp. attacks the caterpillars, a white cocoon will be seen beside a dead grub in the cob wrapper leaves.

Broad spectrum pesticides
Applying pesticides can interfere with an integrated control strategy against heliothis. Before spraying, assess the economic significance of this pest compared with heliothis damage. If necessary apply an appropriate insecticide.

Yellow peach moth
Conogethes punctiferalis is a caterpillar pest in Queensland. Caterpillars tunnel into stems and the side of cobs and damage kernels. It tends to be a minor pest but can do economic damage through feeding.

Monitoring
It is difficult to find the eggs and young caterpillars of this pest but monitoring should target the silking period and continue until close to harvest. Caterpillars are often found in the cobs but are also found between the cob and the plant stem. Frass and webbing may be found around the entrance hole.

Management

Biological
The biopesticide Bt seems to work providing coverage is good enough to reach the pest. There have been reports of *Trichogramma* parasitising the eggs.

Tachinid fly parasitoid is an important natural enemy in some crops. Pesticides will disrupt natural enemy activity.

Broad spectrum pesticides
Applying pesticides at the critical crop stage where this pest is found may create heliothis damage which is usually more economically damaging. If necessary apply an appropriate insecticide.

Green vegetable bug
Green vegetable bugs (*Nezara viridula*) are a sporadic pest of sweet corn. They are more likely to be prevalent when alternative host crops such as soybeans are present in the vicinity.
Adults and nymphs will damage kernels by sucking the contents. The insertion point provides access for secondary disease infection. They usually appear late in the crop during cob formation.
Management
Management by pesticides is likely to upset a biological system in place for heliothis. Consider the pest management strategy for the whole crop before making any decision to spray. Weigh up the loss to green vegetable bug damage versus potential loss to heliothis if their management system is upset.
The parasites of green vegetable bug include two egg parasitoids, *Trissolans* sp. and *Trissolcus basalis*, and a parasite of the adult, *Trichopoda giacomellii*. These natural enemies have a more significant impact in managing green vegetable bug in sweet corn if the bugs are present early in the crops.

Dried fruit beetle
Dried fruit beetle, *Carpophilus* spp., are especially evident after pollen starts to shed. They are often found around the leaf sheaths where pollen settles and then in the silks and developing cob. If harvesting is delayed the beetles enter the cobs, damaging kernels and contaminating the cob.
Beetles are also attracted to fermenting cobs where caterpillars have damaged the cob.
Timely harvest usually avoids beetles being a problem as a contaminant. Management is not usually necessary.
Redshouldered (*Monolepta*) leaf beetle
Adult redshouldered leaf beetles, *Monolepta australis*, move into the crop in swarms from spring to autumn and eat the leaves. They also chew on emerging silks which may affect pollination.
If crops are monitored regularly, spot spraying of the swarms with an appropriate insecticide.

Soil borne insects
African black beetle
African black beetle, *Heteronychus arator*, eat emerging shoots or chew into the stems, 5 to 10 cm below ground level, eventually causing them to collapse and die. Infestations can arise from migration of adults from breeding areas in nearby pastures or as a result of planting into ill-prepared land, formerly covered with pasture.
The beetle is glossy black and about 16 mm long and sluggish in its movements. It spends most of its time on and in the soil. The larva, a typical white grub, grows to 12 mm, lives in the soil and feeds on grass roots.

Crickets
Crickets, including the black field cricket, *Teleogryllus commodus*, are minor and infrequent pests. Crickets feed at night and hide in the soil by day. They attack the newly planted seed and emerging seedlings by cutting off the tops and leaving them lying on the soil.
The field cricket is about 25 mm long and dark brown or black. Adults are winged and have strongly developed hind legs for jumping. Their presence is indicated by the noise the males make at night by rubbing their forewings.
Monitoring
Listen at dusk for cricket calls, they are often present in March.

Management
Keep soil sufficiently irrigated to prevent excessive cracking which gives crickets easier access to exposed roots.
Biological control agents including diseases, parasitoids, predatory birds and insects appear to have little effect.

Earwigs
Black field earwigs, *Nala lividipes* are minor and infrequent pests of sweet corn.
They usually feed on decaying stubble but also eat newly sown and germinating seed and the roots of crops. Feeding on prop roots may cause the plants to fall over as they grow. The damage is often first noticed when cultivating because the plants fall over as the equipment passes.
Monitoring
Take 300 mm X 300 mm soil samples down to the moist soil layer. The soil should be shaken onto a white sheet and if more than one earwig is found in 20 samples, take management action.
Management
Black field earwig is a pest mainly in areas with heavy, black soils. They prefer cultivated soils to zero till. Use press wheels at planting set at 2.4 kg per cm width. Prepare ground so that germination is as even and rapid as possible

Wireworms
Wireworms, *Agrypnus variabilis* are the juvenile stage of click beetles. The grubs are segmented, smooth, shiny and yellow to reddish brown. They grow up to 20 mm long and are active in the root zone of seedlings in warm conditions but in hot weather move deeper into the soil.
Grubs tunnel into germinating seeds, feed on small roots of seedlings and bore into the base of plants below the ground and can then burrow up into the stalks. Seedlings wilt and usually die or are stunted and deformed.
As with other soil borne pests they are usually a minor sporadic pest. However wireworm can be a more serious pest in ground following grass pastures and grains in lightly cultivated soil. Usually by the time the problem is identified the damage is done. In susceptible areas inspect the ground before planting the corn.
Management
Pre-planting treatment, treating seed and good soil preparation, can minimise the impact of this pest. They are difficult to manage once corn is planted.
Ants and ground beetles are natural enemies of wireworms.

White grubs
Another sporadic pest, white grubs are the juvenile stage of scarab beetles, such as the Christmas beetle and related species, that are commonly attracted to lights. Most of the troublesome species have a two-year life cycle. Eggs are laid in the soil in spring and early summer. By the following winter grubs have passed through two of the three stages and move downward through the soil sometimes to a depth of a couple of metres. During these stages they feed on soil organic matter . The maturing grubs prefer living plant tissue so they rise to the root zone where they can cause serious root damage, usually in the spring. Affected plants turn yellow, stop growing, wilt and die; they can easily be pulled out of the soil because no roots remain to anchor them.
The grubs are white with a brown head, C-shaped and have three pairs of well developed legs. When full-grown they are about 50 mm long. Following rains in October-November beetles

emerge from over-wintering pupae in the ground. After mating, the females are attracted to friable soil, with high levels of organic matter, where they lay their eggs.
Species include: *Anoplognathus porosus*, *Lepidiota* spp., *Rhopaea magnicornis*, *Antitrogus mussoni*, *Repsimus aeneus*.

Management

Thorough pre-plant cultivation exposes grubs to birds and mechanically injures them so they die. Pre-plant incorporation of an appropriate registered insecticide is another option for managing this pest.
White grubs are difficult to manage once the crop is planted. Occasionally fungal diseases exert some control.

c) Beneficials (natural enemies)

Not all the 'insects' we see in sweet corn are doing damage to your crop. Many are in fact beneficials, natural enemies of the real pests damaging your crop. It is important to be able to recognise 'friend and foe', and take the necessary action. This section will help you make that identification.

Introduction
Parasitoids
Predators
Enhancing effectiveness of beneficial insects
Parasitoids and predators in sweet corn

Introduction

Natural enemies or beneficial arthropods (insects, mites and spiders) help control pests in your crop. Avoiding the use of broad spectrum pesticides, using biological pesticides such as Bt or NPV and introducing natural enemies into the crop all increase natural enemy activity. Rarely do natural enemies alone achieve a standard of pest management sufficient to meet quality requirements for marketable produce. Therefore their role should be considered as part of an IPM system.

Natural enemies fall into two groups – parasitoids and predators.

Parasitoids

Parasitoids are organisms that parasitise and kill their hosts. Parasitoids tend to be very specific to their host, there are various wasp parasitoids that attack moth eggs, aphids or caterpillars. The wasps lay their eggs within or on the host pest at a critical life stage completing their entire development within that host by consuming it.

Egg parasitoids, such as *Trichogramma* spp. and *Telenomus* spp. may attack and develop in a range of moth eggs, typically turning the egg a silvery black. Parasitised caterpillars show few external signs of parasitism before dying. The parasitoid larvae can sometimes be seen if the parasitised caterpillar is carefully pulled apart. Larval parasitoids include *Heteropelma* and several other ichneumonid wasps, *Cotesia*, *Microplitis* and tachinid flies.

Aphids are often parasitised and are noticeable as bloated buff or brown shells commonly called 'mummies'. The aphid parasitoid, a small wasp, emerges through a circular hole in the abdomen of the aphid shell.

To determine the level of parasitoids in your crop you need to collect and rear the pests to observe if parasitoids will emerge from their host.

Only a limited number of parasitoids are mass reared by commercial producers. The most common is the egg parasitoid *Trichogramma pretiosum*, which has a wide host range.

Enhancing the cropping environment by providing nectar sources for parasitoids helps them live longer and lay more eggs. Reduce pesticide use as parasitoids are more sensitive to broad spectrum pesticides than many pests.

Predators

Predators feed directly on their prey, they include such insects as pollen beetles (red and blue beetle); lacewings; ladybirds; assassin bug; pirate bug; hover flies; predatory shield bugs and predatory mites. They attack such insects as aphids, thrips, moth eggs, and small, medium and large grubs. Not all predators are generalists (attack a wide range of insects). Predatory mites, such as *Persimilis*, specialise in eating plant feeding mites. Predators supplement their diet with nectar, pollen and fungi.

In most cases it is the larvae of these predators that are the main feeders and they tend to feed on the slower moving sap suckers including aphids, whiteflies and mites. Spiders are also common generalist predators. Wolf spiders are common soil predators, whereas the crab spiders, jumping spiders, orb weavers and many others are active predators in plant canopies. Table ?? shows the predator/prey relationships found in sweet corn.

Predator /prey relationship found in sweet corn

	Natural enemies									
	Parasitoids						***Predators***			
Pest	**Trichogramma**	**Telenomus**	**Microplitis**	**Heteropelma**	**Tachinid fly**	**Cotesia**	**Lacewings**	**Ladybirds**	**Predatory bugs**	**Spiders**
Heliothis eggs	✓	✓					✓	✓	✓	✓
Heliothis larvae			✓	✓	✓	✓	✓		✓	✓
Aphids							✓	✓	✓	✓
Thrips							✓		✓	✓

✓ indicates prey of natural enemy

Enhancing effectiveness of beneficial insects

The following actions will help increase the effectiveness of beneficial insects.

1. Monitor crops to help reduce unnecessary insecticide usage;
2. Use pesticides (insecticides, miticides and fungicides) only when necessary;
3. Use an appropriate pesticide to control the pest and limit its direct impact on beneficial insects (for example Bt sprays);
4. Provide an alternative food source for the adult parasitoids and predators (for example weeds or other flowering plants are a good source of nectar and pollen);
5. Make mass (inundative) releases of beneficial insects so they become effective more quickly.

Parasitoids and predators in sweet corn

Egg parasitoids

There are several species of egg parasitoids, the most common is *Trichogramma pretiosum*, and it is commercially reared. Depending on the season, other species such as *Trichogramma toidea* and *Telenomus* sp. also occur in sweet corn crops. They are all minute wasps rarely visible when monitoring crops, however the black parasitised eggs can be spotted easily. The egg parasitoids can have a significant impact on heliothis populations in the absence of synthetic pesticides. Their populations can be augmented by releases.

Microplitis

A parasitoid of heliothis and *Spodoptera. Microplitis* wasps are distinguishable by their brown pupae. They lay single eggs into young caterpillars. Their larva emerge, killing the caterpillar, and forming a brown pupa lightly attached to the dead grub.

Cotesia

These parasitic wasps lay eggs into larvae of armyworm, heliothis and sorghum head caterpillar. The larvae emerge to pupate, forming white bundles of pupae on the outside of the caterpillar. The dead caterpillar may still be attached to the pupae.

They are distinguishable from bugs by their transparent wings and smaller bodies, and are not seen as much as, for example, black mirids.

Tachinid flies

These parasitic flies are grey/black and slightly bigger than a house fly. They lay a white oval egg on or near caterpillars. The fly larva enters the caterpillar and attaches to the skin, leaving a breathing hole. The maggot grows inside the caterpillar, eventually killing it. It then forms a brown, oval pupal case from which the fly emerges. Tachinid flies are not usually very common.

Predatory beetles

Predatory beetles include ladybirds, and several species can be found in unsprayed sweet corn crops. The majority of them are red with a different number and shape of black spots. Their bodies are dome shaped with a hard wing covering. Their eggs and larvae are also prevalent especially when there are aphids present. Eggs are yellow, oval shaped and are laid upright on leaves, usually in a cluster. Larvae are black with coloured markings on the back. They also have three pairs of prominent legs.

Ladybirds are very effective predators of aphids but will also eat moth eggs and small larvae.

Predatory bugs

Pirate bug *(Orius)*

Pirate bugs are black and about 3 mm long. Their wings make a black and white cross pattern on their back. If thrips are present they are commonly seen where the leaves wrap around the stem or in the silks. The wingless nymphs are orange and black and they go through several stages before becoming adults. Pirate bug eggs are white, oblong and are laid embedded in the leaf, often near the sheath. Pirate bugs are common predators of thrips but also feed on moth eggs, aphids and small caterpillars.

Black mirids

Black mirids move faster than pirate bugs and are larger and thinner than them. They have long antenna and do not have the cross pattern on their back. Their prey includes moth eggs and soft bodied insects.

Big eyed bug

The big eye bug is about 4 mm long and is distinguishable by its large protruding black eyes. Its body is also black and squatter in shape than the pirate bug. Its prey includes aphids, mites, young caterpillars and moth eggs.

Damsel bug

The damsel bug is one of the larger predatory bugs, being up to 8 mm long. It is brown, long and thin, with large eyes and long antenna. Their prey includes soft bodied insects, moth eggs, small larvae and mites.

Lacewings

Brown and green lacewings are common in unsprayed sweet corn crops. Both adults and larvae are predatory, especially on aphids. The adult brown lacewing has brown wings, larvae are also brown and eggs are laid singly on leaves. Green lacewing adults have green wings and are slightly larger than brown lacewings. Their larvae carry debris on their back and their eggs are laid on stalks.

Spiders

Three types of spiders are commonly found in sweet corn crops – web spinners, foliage dwellers and soil dwellers. Their impact on pests has not been well documented however spiders represent up to a third of the predators recorded in sweet corn crops. They eat moth eggs, small caterpillars, aphids and thrips.

Predatory mites

Various predatory mites can occur naturally in unsprayed crops. *Phytoseiulus persimilis* is a predatory mite that can be bought commercially. Given the right environmental conditions it is a very effective predator of twospotted mite.

The mite is orange and the adult 1 mm long, larger than a twospotted mite. Their body is pear shaped, appears smooth and almost dome like. Another distinguishing feature is that predatory mites move faster than twospotted mites.

The efficacy of a range of beneficial insects and spiders

Common name	entific name ?? A MIX OF MES, Fam, Gen &sp ??	ıeficial rating*
Wasps and ants:	**nenoptera:**	++
ıa	hogrammatidae	++
	ımyrmex sp.	+
	roplitis demolitor	-
	ɜnomus spp.	
	niptera:	+
	'hus chinenis	++
	ıs sp.	++
ıg bug	**npylomma liebknechti**	
ɜe bug	aeocoris signatus	
	ıcoris lubra	
	bis kinbergii ?Nabis?	
ı:	**Araneae:**	+++
'oliage dwellers (eg. jumping spiders)	Salticidae	++++
;oil dwellers (eg. wolf spider)	Lycosidae	+++
Veb builders (eg. orb weaver)	Araneidae	++
;:	**Coleoptera:**	+++
.adybirds	Coccinellidae	+++
;arab beetle	Carabidae	++
₹ed and blue beetle	*Dicranolaius bellulus*	++
;reen soldier beetle	*Chauliognathus pulchellus*	+
ngs:	**Neuroptera:**	++
ɪrown lacewing	*Micromus tasmaniae* ??*Mallada* spp.	++
;reen lacewing	*Micromus tasmaniae Mallada* spp. ??	++
	Diptera:	++
'achinid flies	Tachinidae	++
ɪover flies	Syrphidae	+

of pest management in sweet corn = Low (+); Moderate (+++); High (+++++). Table shows the impact of foliar insecticides on the key beneficial groups. **Table ??.** Impact of foliar applied insecticides on the key beneficial groups

IV. Other Publications

A. Field Guide to Silk Length and Condition

By Brendan Nolan and Alison Shields, QDPI, Gatton Research Station.

[Copies of this document, in laminated form suitable for in-field use, was distributed to Workshop participants at Bowen in 2000.]

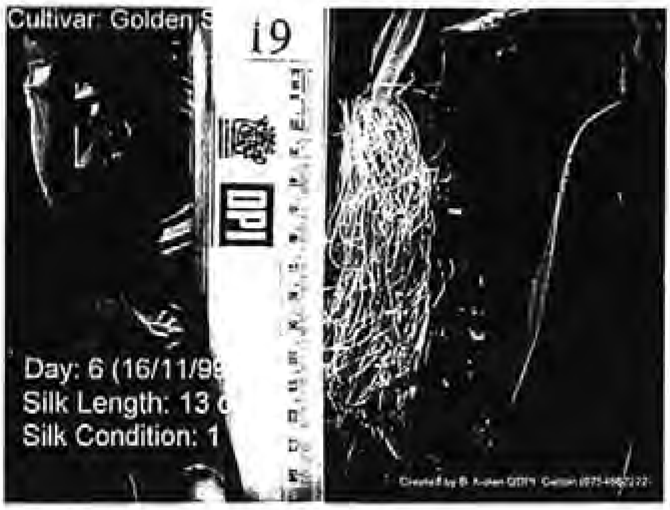

Cultivar: Golden Sweet
Plant
Number
19
Day: 1 (11/11/99)
Silk Length: 0 cm
Silk Condition: 0


Plant
Number
19
Day: 2 (12/11/99)
Silk Length: 0 cm
Silk Condition: 0


Cultivar: Golden Sweet
Plant
Number
19
Day: 3 (13/11/99)
Silk Length: 0 cm
Silk Condition: 0

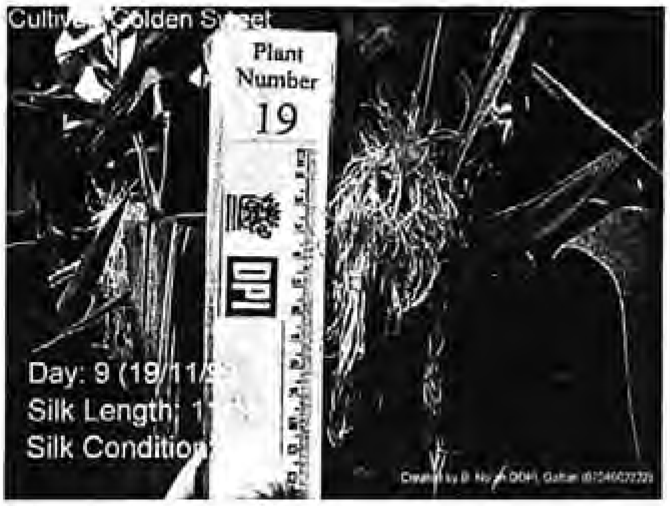

Cultivar:
19
Day: 4
Silk Length


Cultivar: Golden Sw
19
DPI
Day: 5 (15/11/99)
Silk Length: 13
Silk Condition: 1


Cultivar: Golden
19
DPI
Day: 6 (16/11/9
Silk Length: 13
Silk Condition: 1


Cultivar: Golden Sweet
19
(17/11/99)
Silk Length: 12 cm


Cultivar: Golden Swe
Number
19
DPI
Day: 8 (18/11/99)
Silk Length: 11 c
Silk Condition: 2


Cultivar: Golden Sweet
Plant
Number
19
DPI
Day: 9 (19/11/9
Silk Length:
Silk Condition


19
DPI
Day: 10 (20/11/99)
Silk Length: 10 cm
Silk Condition: 3

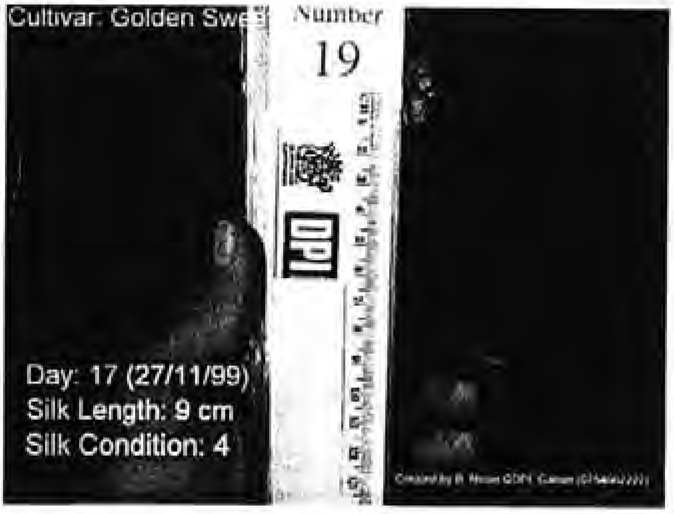

Number
19
DPI
Silk Condition: 3


Number
19
DPI
Day: 13 (23/11/99)
Silk Length: 10 cm
Silk Condition: 3


ultivar: Golden Sweet
19
DPI
Day: 14 (2 /11/99)
Silk Length: 10 c
Silk Condition: 4


Cultivar: Golde
Number
19
DPI
Day: 15 (25/1
Silk Length: 9
Silk Condition:


Cultivar: Golden Sweet
19
DPI
Silk Length: cm
Silk Conditio 4


Cultivar: Golden Swe
Number
19
DPI
Day: 17 (27/11/99)
Silk Length: 9 cm
Silk Condition: 4


ivar: Golden
Number
19
DPI
Day: 19 (29/11/
Silk Length: 9
Silk Condition:


Cultivar: Gold
19
DPI
Day: 20 (30/
Silk Length:
Silk Conditio


Cultivar: Golden S
19
DPI
Day: 21 (1/12/99
Silk Length: 8
Silk Condition:

B. Sweet Corn Insect Pests and their Natural Enemies – an IPM field guide.

By Richard Llewellyn

[This is a publication developed by Richard Llewellyn in a related project (VG97040) funded by HAL, with input from project team members in "Insect Pest Management in Sweet Corn" (VG97036)]

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