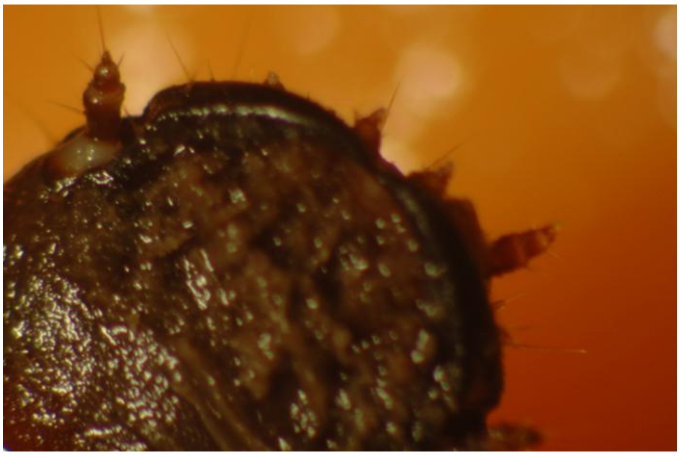
FINAL REPORT

HAL Project VG05037

(May 2010)

Improving the management of sweetpotato soil insect pests



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HAL project No. VG05037

Improving the management of sweetpotato soil insect pests

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Purpose of report:

Report on studies on a broad range of management strategies for the major sweetpotato pests:- Sweetpotato weevil (*Cylas formicarius*), Root-knot nematode (*Meloidogyne* spp.) and both True and False Wireworm (Elateridae and Tenebrionidae families).

Funding Sources:

Horticulture Australia Ltd
Agri-Science Queensland, a service of the Department of Employment, Economic Development and Innovation

Queensland Government

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Date of Report: 30 May 2010

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Contents

Media summary

Key components of the project

The work program included:

- assessing the efficacy of insecticides for the control of wireworm, root-knot nematode and sweetpotato weevil in the sweetpotato cropping system
- identifying new ‘soft options’ which have the potential to contribute to sweetpotato IPM systems
- conducting an insect pest and control practices survey of the sweetpotato industry
- developing and testing improved IPM strategies, which included pheromone technology.

Industry significance of the project

The Australian sweetpotato growers group (ASPG), a group that represents over 80% of Australia’s production, identified soil insect pest management as the industry’s number one research priority. Sweetpotato soil insects pose the greatest risk factor for market failure in the rapidly expanding sweetpotato supply chain. These major pests include wireworms, root-knot nematodes and sweetpotato weevil. Growers are continually reporting increased incidences of major soil insect damage.

At the onset of this project (VG05037) the only reliable means of controlling soil insect pests was through the application of multiple broad spectrum insecticides incorporated in the soil prior to planting and foliar applied during crop development. Insecticides were often applied as an insurance cover when possibly the wrong insecticide was being used or it was not needed at all.

Key outcomes

The R&D work program has demonstrated the activity of five insecticides on wireworm, one nematicide on root-knot nematode and one insecticide on sweetpotato weevil. These are bifenthrin, chlorpyrifos, phorate, fipronil and thiamethoxam against wireworm. Minor use permits for bifenthrin (APVMA PER9722, Expiry 30 Sept. 2013) and chlorpyrifos (PER5851, Exp. 12 Feb 2012) for soil incorporation prior to planting against wireworm in sweetpotato were successfully pursued on behalf of the sweetpotato industry.

A more effective means of delivering smaller amounts of fipronil through drip irrigation against wireworm has been demonstrated and should be further pursued on behalf of the sweetpotato industry. Oxamyl was demonstrated as an effective alternative to fenamiphos against root-knot nematode and the minor use permit for the use of oxamyl (PER10762, Exp. 31 March 2012) was successfully pursued on behalf of the sweetpotato industry. Thiamethoxam applied to the soil prior to planting is effective for the control of sweetpotato weevil. This new insecticide would appear to have low impact on beneficial arthropods and potentially has a very good ‘IPM fit’.

The use of pheromone technology as an important tool in the management of sweetpotato weevil populations was successfully demonstrated on a grower’s property. Pheromone technology for the management of sweetpotato weevil should continue to be pursued on behalf of the sweetpotato industry. The grower survey found an increase in the use of sweetpotato weevil pheromone technology from 6% of growers surveyed in the Bundaberg region in 2006 to 80% in 2010. As a result of this project (VG05037) the grower survey also showed that while there was no report of growers having root-knot nematode counts done before planting in 2006, now in 2010 30% of growers surveyed were obtaining nematode counts on blocks prior to planting.

The grower survey also identified a significant decrease in insecticides soil incorporated prior to planting used at the onset of this project (VG05037) compared to the present time. The reduction in insecticide use has been mostly from the group 'organophosphates'. While this is seen as a good result the survey also identified the subsequent over-dependence of bifenthrin used both soil incorporated prior to planting and foliar applied in the sweetpotato cropping system to control both wireworm and sweetpotato weevil. A range of alternative chemistry must be pursued on behalf of the sweetpotato industry in order to manage the inherent risk of resistance developing.

Technical summary

Nature of the problem

The Australian sweetpotato growers group (ASPG), a group that represents over 80% of Australia's production, identified soil insect pest management as the industry's number one research priority. Sweetpotato soil insects pose the greatest risk factor for market failure in the rapidly expanding sweetpotato supply chain. These major pests include wireworms, root-knot nematodes and sweetpotato weevil. Growers are continually reporting increased incidences of major soil insect damage. At the onset of this project (VG05037) the only reliable means of controlling soil insect pests was through the application of multiple broad spectrum insecticides incorporated in the soil prior to planting and foliar applied during crop development. Insecticides were often applied as an insurance cover when possibly the wrong insecticide was being used or it was not needed at all.

Description of the science undertaken

The work program included:

- reviewing the scientific literature
- assessing the efficacy of insecticides for the control of wireworm, root-knot nematode and sweetpotato weevil in the sweetpotato cropping system
- identifying new 'soft options' which have the potential to contribute to sweetpotato IPM systems
- conducting an insect pest and control practices survey of the sweetpotato industry
- developing and testing improved IPM strategies, which included pheromone technology.

Major research findings and recommendations

Wireworm

- Bifenthrin consistently provided the longest duration of crop protection when soil incorporated prior to planting.
- Soil incorporated insecticides are only working to repel wireworm out of the root zone. This is a major concern as sweetpotato has a crop development period greater than 140 days.
- A significantly reduced rate of fipronil applied once through the trickle irrigation system was effective at controlling wireworm. It was able to provide a significantly high level of protection against wireworm injury. The label registered rate of 250 mL of fipronil soil incorporated prior to planting for wireworm in sweetpotato is not effective. For effective control fipronil was required to be applied at 1 L/ha soil incorporated prior to planting.
- Thiamethoxam soil incorporated prior to planting was not effective at preventing wireworm feeding injury in sweetpotato out to commercial harvest but did show activity to 100 days after planting in the Bundaberg trial.
- Even the presence of low numbers of wireworms in experimental plots detected using a sweetpotato baiting technique prior to planting resulted in

unacceptable levels of wireworm feeding injury to sweetpotato at commercial harvest when no insecticide was used.

Sweetpotato weevil

- Male sweetpotato weevil pheromone technology is a successful tool that locates areas of high weevil populations. Once hot spots are identified it is then possible to reduce large populations of sweetpotato weevil across major sweetpotato production areas.
- There is strong evidence that thiamethoxam, from the neonicitinoid chemical group, has systemic activity against sweetpotato weevil in the variety Beauregard out to 160 days after planting.
- Commercially available strains of Becker Underwood Pty Ltd entopathogenic fungus *Metarhizium anisopliae* are not effective as a biological insecticide in the field against sweetpotato weevil.
- Sweetpotato varieties with high tolerance levels against sweetpotato weevil have been successfully imported from the USA and are ready for field testing in spring 2010.

Root-knot nematode

- Low root-knot nematode soil counts prior to planting result in economic losses due to root-knot nematode infestation at commercial harvest (139 days after planting).
- Nematicides are required in the sweetpotato production system due to Beauregard's high susceptibility to root-knot nematodes.
- Oxamyl applied via trickle irrigation was effective at preventing root-knot nematode infestation to Beauregard in comparison to untreated controls and fenamiphos treatment.

Recommendations for future R&D

- Change the label registered application method for the use of fipronil to control wireworm in sweetpotato from the ineffective method of soil incorporation prior to planting to the effective method of application through the drip irrigation at strategic times in the crop’s development should be pursued on behalf of the Australian sweetpotato industry. This application strategy should be pursued for future chemical registrations/permits for wireworm control.
- Additional investigations are required to determine the efficacy of thiamethoxam applied through the drip irrigation system against sweetpotato weevil in the sweetpotato cropping system. Subsequent studies need to be undertaken then to determine the impact on the control of secondary sap sucking pests in the sweetpotato cropping system and beneficial arthropods associated with the biological control of these sap sucking pests.
- Appropriate guidelines for managing insecticide and nematicide resistance in sweetpotato pests should be developed as products are being put under maximum working pressure 12 months of the year due to ideal conditions in major sweetpotato growing regions for the continuous and rapid cycles of wireworm, sweetpotato weevil and root-knot nematode pests.

- Investigate ways to better manage sweetpotato crop residues post harvest as current break crops are not successfully out-competing sweetpotato volunteer regrowth. The regrowth is a major contributing factor to the success of pest cycles in the production regions.

Chapter 1: Literature review of soil borne pests of sweetpotatoes

Summary

Wireworm (species in the families Elateridae and Tenebrionidae): True (F. Elateridae) and false (F. Tenebrionidae) wireworm larvae are extremely mobile in the soil environment. Larvae will move up and down the soil profile in response to changes in soil moisture and temperature. The adult beetles of both the true (click beetles) and false wireworms emerge during spring or early summer and are capable of flying to seek suitable egg laying sites. They lay their eggs on the soil surface or just below. The eggs and newly hatched larvae are susceptible to extremes in soil moisture and temperature. True wireworm and false wireworm beetles can be monitored using black light traps, sticky traps or pitfall traps, where as the larval populations can be estimated in paddocks using various food baiting techniques such as grain, corn, oats, cut pieces of potato or cut piece of sweetpotato placed below the soil surface.

Actively growing crops that provide substantial ground cover and are irrigated during the late spring and summer months provide the ideal habitat for egg laying adults and developing wireworm larvae. Foliar application of chlorpyrifos or bifenthrin to sweetpotato blocks may be effective at controlling immigrating populations of adult beetles and newly hatched larvae near the soil surface. Soil incorporated insecticides applied prior to planting are more effective at repelling the larvae then actually causing death.

Sweetpotato weevil (*Cylas formicarius*): The entire lifecycle of sweetpotato weevil is undertaken on the host plant, with the lifecycle being completed in approximately 33 days under warm climatic conditions. Left over sweetpotato storage roots lying on the soil surface are an ideal food source for dramatically increasing populations. Bifenthrin and chlorpyrifos foliar applied to sweetpotato blocks effectively control adult sweetpotato weevil, but not larvae. Insecticides which can be taken up and transported through the sweetpotato plant are presumably effective for killing larvae in the vine. Research on the efficacy of entomopathogenic nematodes and fungi in America and Japan has shown they are able to control adult and larval populations. Grower uptake is limited as many factors such as shelf life, storage temperature, application methods and soil moisture combine to affect the efficacy of such entomopathogenic pathogens.

Japan has reported successful eradication of sweetpotato weevil using a technique that continually releases large populations of sterile male weevils into problem areas and monitors the populations with pheromone traps. Pheromone traps have also been developed that include small balls of blue diatomaceous earth impregnated with insecticides or entomopathogenic fungi. These balls stimulate increased contact from male sweetpotato weevil so ensuring contact between the weevils and the control agents.

Resistant cultivars: Communication with staff at the US Department of Agriculture indicates the possibility of obtaining sweetpotato varieties that have high levels of

resistance to soil insect pests, including sweetpotato weevil and wireworm. These varieties have similar agronomic characteristics to Beauregard.

Soil applied insecticides: The efficacy of soil incorporated insecticides is compromised when applied to hot and dry soil environmental conditions. Under such conditions wireworm larvae are likely to be deep in the soil profile, out of the zone in which the insecticide is active. The active life of the applied insecticide will also be compromised as high temperatures increase the rate of volatilisation. The active life of soil incorporated insecticides can also be significantly reduced as a result of soil pH and soil micro-organisms.

Introduction

The Australian Sweetpotato Growers (ASPG), a group that represents over 80% of Australia's production, has identified soil insect pest management as the industry's number one research priority. Sweetpotato soil insects pose the greatest risk factor for market failure in the rapidly expanding sweetpotato supply chain. Growers are continually reporting increased incidences of major soil insect damage. Currently the only reliable means of controlling soil insect pests is through the application of insecticides incorporated in the soil prior to planting and foliar applied during crop development. Insecticides are often applied as an insurance cover when possibly the wrong insecticide is being used or it is not needed at all.

An integrated pest management (IPM) strategy is to be developed that will enable growers to better manage sweetpotato soil insect pests, while decreasing their dependence on insecticides. The first stage in developing this insect pest strategy has involved surveying 20 growers on the east coast of Australia and undertaking two facilitated sweetpotato grower sessions at Bundaberg, QLD and Cudgen, NSW. This process set the scope for this literature review document.

The review has a strong focus on the insect pests, true wireworm and false wireworm, true wireworm being a global pest of many agricultural crops. Extensive research has been undertaken on these pests in Europe and U.S.A. for potato. Research has also been undertaken on true wireworm in the U.S.A. for sweetpotato production. Two out of the 667 species of true wireworm present in Australia have been studied extensively, *Hapatesus hirtus* in potato and *Agrypnus variabilis* in sugarcane. The earliest literature reviewed on true wireworm was published in 1934. False wireworm is a major soil insect pest of germinating summer and winter grain crops from central Queensland to northern NSW. Extensive biology and ecology studies have been undertaken for three of the major false wireworm pest species in Australia. The published scientific literature on these species was extensively reviewed in 1993, with little research being published on this pest since. It is unclear from the literature whether true wireworm species or false wireworm species cause the most damage to sweetpotato in Australian production systems. Both the true and false wireworm species can be found in commercially grown sweetpotato blocks causing damage to the storage roots.

Sweetpotato weevil has also been reviewed in this document, which includes a major research project that has developed strategies to control sweetpotato weevil on the east coast of Australia over four years, concluding in June 2001. This document also briefly reviews the sweetpotato pests, cane grub (beetles in the family Scarabaeidae), African black beetle (*Heteronychus arator*), whitefringed weevil (*Naupactus leucoloma*) and nematodes.

Wireworms

Introduction

Shotgun is the name used by Australian sweetpotato growers for the random scattering of small holes found on sweetpotato storage roots caused by wireworm feeding. Even though these holes may be quite shallow, as few as four holes can make a sweetpotato unmarketable.

In Australia, wireworms belong to the Coleoptera families Tenebrionidae and Elateridae. Soil insect pests in the family Tenebrionidae are *Gonocephalum* spp. and *Pterohelaeus* spp., commonly known as false wireworms (Image 1.01). Soil insect pests in the family Elateridae include *Agrypnus* spp., *Conoderus* spp., *Heteroderes* spp., *Dicteniophorus* spp. and *Hapatesus* spp. Elateridae are commonly referred to as click beetles[1] or true wireworms[2] (Image 1.02).

Image 1.01: False wireworm adult beetle and larvae found in sweetpotato crop

Image 1.02: True wireworm adult beetle and larvae found in sweetpotato crop

There is no published literature from Australia to suggest one family, genus or species of wireworm is causing more damage to sweetpotato than any other, as many fields can contain more than one species. Larvae of both the false and true wireworms have been observed in sweetpotato fields exhibiting high levels of damage at Rockhampton in central Queensland, Bundaberg in south eastern Queensland and Cudgen, northern New South Wales.

According to Calder (1996) the most important recorded pest species of agronomic significance in Australia from the Elateridae family (true wireworm or click beetle family) belong to the genera *Agrypynus, Conoderus, Heteroderes, Arachnodima* and *Hapatesus*.

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[1] The term click beetle is often used to refer to the adult form of true wireworm i.e. from the Elateridae family

[2] The term wireworm is often used as a substitute for larvae from the family Elateridae

True wireworms (Family Elateridae)

The potato wireworm *Hapatesus hirtus* causes considerable economic damage to the potato industry in Victoria (Horne and Horne 1991). Sugarcane wireworm, *Agrypnus variabilis* and other wireworm species from the *Heteroderes* genus cause considerable economic damage to sugarcane as they feed on the eyes and young shoots of germinating cane setts (Agnew 1997). Wireworm from the *Conoderus* genus are more commonly found in cane fields in southern Queensland than *A. variabilis* or *Heteroderes* spp. (Samson and Calder 2003). *Heteroderes* spp. have been identified as damaging sweetpotato in Cudgen, northern NSW (Rochecouste 2003). Wireworm species of the *Conoderus* genus are the major wireworm pest of sweetpotato in south eastern United States (Chalfant and Seal 1991), while in neighbouring potato fields the species *Melantus cummunis* is the most destructive true wireworm, with *Conderus* spp. having minimal effect on potato crops (Jansson and Seal 1994). True wireworm species from the *Agriotes* genus are also major potato soil insect pests in the northern hemisphere.

False wireworms (Family Tenebrionidae)

False wireworms are the most prevalent and widespread of the soil-dwelling insect pests that attack a wide range of establishing summer and winter crops in Queensland and northern New South Wales (Roberston1993).

True wireworm (Coleoptera: Elateridae)

The majority of Australia's sweetpotato are produced around Bundaberg in southeast Queensland and Cudgen in northern New South Wales, and both areas also produce sugarcane. There have been a limited number of studies on true wireworm in Australia. The sugarcane industry has undertaken in-depth studies of true wireworm in QLD (Samson and Calder 2003, McDougall 1934). True wireworm are a major economic pest of sugarcane in southeast QLD, boring holes into the germinating setts or ratooning stubble, or into the growing point of young shoots (Samson and Calder 2003). Samson and Calder (2003) sampled and identified five named and 21 unnamed species from five genera of true wireworm in established cane fields in north, central and southern Queensland, and New South Wales. The most abundant species identified in this study belonged to the genera: *Agrypnus, Conoderus and Heteroderes*. Sugarcane fields commonly border sweetpotato fields and are used in rotation with sweetpotato production.

Ecology and biology

The biology of most of the 667 Australian true wireworm species is totally unknown (Calder 1996). In-depth studies on species of agronomic importance in Australia include *A. variabilis* by McDougall (1934) and *H. hirtus* by Horne and Horne (1991).

Lifecycle

The lifecycle of true wireworms varies greatly between species, taking one year with four larval instars for sugarcane wireworm, *A. variabilis,* to complete its cycle (Agnew 1997) and approximately four years, with 10 larval instars for the potato wireworm, *H. hirtus* (Horne and Horne 1991). True wireworm adults emerge during October/November under Australian conditions (Agnew 1997; Horne and Horne 1991) at which time the females begin laying eggs on or just below the soil surface.

Eggs are usually laid in areas protected by grass and weeds to minimise the risk of desiccation (drying out). Eggs hatch in about eight days depending on temperature and soil moisture. Larval development will vary considerably between species and individual sites (Parker and Howard 2001). The time taken for larvae to reach the point where they can pupate is highly variable; factors that impact on pupation include species, food quality, soil moisture, and soil temperature. During spring larvae burrow deeper into the soil (10 to 30 cm below the soil surface) and hollow out small pupation cells (Parker and Howard 2001), where the pupal stage lasts about two weeks. The completion of the majority of the life cycle occurs underground with limited periods of activity above the ground making this a formidable pest to study and control. Table 1.01 is a summary of true wireworm lifecycle.

Table 1.01. Summary of true wireworm lifecycle (derived from Agnew (1997), Horne and Horne (1991) and Parker and Howard (2001)).

Developmental stage	**Month**	**Time for stage completion**
Adults emerge	Oct/Nov	Beetles migrate if habitat is not suitable. Female beetles require food (green leaf material) before they begin ovipositing.
Eggs laid	Nov/Dec	Eggs laid in batches. Approximately ten to fifteen eggs laid per batch. Eggs take eight days to hatch. Once larvae have emerged they are generally restricted to the top 5 cm of the soil profile and are relatively immobile.
Larval instars	Varies according to species	Ten months and four instars for larvae to fully develop (*A. variabilis*, SE QLD). Four years and ten instars for larvae to fully develop (*H. hirtus*, Victoria).
Pupation	Sept/Oct	Once larvae mature they will hollow out small soil cells to pupate within. This stage generally takes about two weeks.

Response to soil moisture and temperature

High soil temperature and/or low soil moisture in the upper layers of the soil will drive larvae down in the soil profile (Parker and Howard 2001). Ideal soil moisture varies between true wireworm species, however it is generally accepted that dry soil causes the larvae to desiccate and often results in death, which is a major driver for the larvae to follow the moisture in the soil profile.

Saturated soils result in reduced movement/activity and sometimes death (Parker and Howard 2001). Field flooding has even been investigated by Van Herk and Vernon (2006) as a control strategy for true wireworm, *Agriotes obscurus* and *Agriotes lineatus* in British Columbia, while McDougall (1934) found that *A. variabilis* required saturated soils for the successful completion of its lifecycle in central Queensland.

In a study undertaken by Jansson and Seal (1994) on Irish potato in Southern Florida, it was shown that the drier the soil, the greater the incidence of true wireworm

(*Melantus cummunis*) feeding. Larvae of *M. cummunis* will seek moisture from a food source, such as potatoes, to avoid desiccation.

High temperatures increase wireworm activity, while low temperatures induce dormancy (Parker and Howard 2001).

Adult flight

Knowledge of true wireworm flight ecology is limited, but it is generally believed that if adults emerge and adequate host plants are not present they will fly to suitable egg laying sites (Boiteau *et al.* 2000). During monitoring of African black beetles (*Heteronychus arator*) in spring of 2002 large numbers of click beetles were collected at various times in a black light trap placed at Atkinson Dam, Lockyer Valley, QLD (J. Duff, pers. comm. 2006). These click beetles were not identified into genus. Boiteau *et al.* (2000) studied the vertical and temporal distribution of true wireworm in flight above an agricultural landscape in Canada. The study concluded that flight occurs for many species of true wireworm but at low frequencies for most.

Larval movement

Larvae have the ability to move up and down the profile in response to moisture and temperature (Parker and Howard 2001). They will also move to a food source using carbon dioxide gradients in the soil (Chalfant and Seal 1991), as larvae are attracted to a carbon dioxide source which is produced by germinating seeds, respiring roots and decaying organic matter.

Chaton *et al.* (2003) studied the behaviour of larval *Agriotes* spp. and suggest that food is found by chance and that carbon dioxide is not an attractant for the larvae. Chaton *et al.* (2003) argue that wireworm lack any efficient receptors to elicit a response to the food source and suggests that it is more likely that high larval moving speeds may allow them to explore quickly and extensively the upper soil layer, finding seeds and seedlings at random.

Distribution

World-wide there are 398 genera of true wireworm (Jansson and Seal 1994). The genera and to some extent the species have been quantified in some countries:

- United States: 73 genera and 885 species (Jansson and Seal 1994)
- United Kingdom: 60 species (Parker and Howard 2001)
- Australia: 70 genera and 667 species (Calder 1996)

Although there are a large number of genera and species only a small proportion are damaging to commercial crops, generally feeding on the roots, while the majority feed on a range of material such as rotting plant material and larvae of other beetles. Distribution data for true wireworm in Australia is limited mainly to sugar cane production areas.

True wireworms in sweetpotato (*Ipomoea batatas* (L.) Lam)

The only sweetpotato research that has clearly identified a range of true wireworm species and performed experiments to gain a better understanding of the species and their impact was conducted in Southern Florida and Georgia (U.S.A) by (Chalfant *et al.* 1990). The species identified were *Conoderus rudis*, *C. amplicollis*, *C. falli* and *C. scissus.*

True wireworms in potato (*Solanum tuberosum*)

There are a number of studies carried out to examine the effects of true wireworm in potato crops. These include:

- *H. hirtus* – Australia (Horne and Horne 1991)
- *M. communis, Ctenicera pruinina, Limonius canus , Limonius californicus , Melantus depressus, Limonius dubitans, Limonius subaurates, Hemicrepidus memnonius, Agriotes mancus, Hypnoides abbreviatus, Conoderus lividus and Conoderus vespertinus* - USA (Kuhar *et al.* 2003)
- *Agriotes sputator, A. lineatus* and *A. obscurus* – England (Jansson and Seal 1994)
- *A. lineatus, A. obscurus, Limonius agonus* – Canada (Jansson and Seal 1994)

True wireworms in sugar cane (*Saccharum officinarum*)

Sugar cane is the only crop in or near Australia's sweetpotato production areas where there is documented research regarding the effect of and identification of true wireworm. A number of species have been found to be involved with commercial damage to sugar cane including (Samson and Calder 2003):
A. variabilis, Agrypnus assus, Conoderus subflavus, Heteroderes cairnsensis, Hapatesus bubanus.

A study by Samson and Calder (2003) using soil baiting during 1995 – 1996 in 35 cane fields in Bundaberg and 25 cane fields in the Mackay region found that *Agrypnus* spp. tended to be more abundant around Mackay and *Conderus* spp. were dominant in the Bundaberg area.

Food source and habitat

Calder (1996) states that since the natural habitat of the larval stage of numerous true wireworm species is either grassland or pasture it is not surprising that some are also agricultural pests. Blackshaw and Vernon (2006) state that non farmed areas are an integral part of cropping habitats and that understanding the dynamics of movement between different habitats is an essential prerequisite to good management practices.

Wireworms are able to feed on both living and decomposing organic matter. McDougall (1934) states that larvae of *A. variabilis* are able to complete full larval development on detritus material attained by simply ingesting soil. Some true wireworm pest species are omnivorous and can predate other true wireworm larvae, scarab larvae[3], cerambycid larvae[4] and termites (Calder 1996). Larvae are even known to feed on cane grub pupae (K. Chandler pers. comm. 2006).

The ability of pest species to feed on alternative food sources when crops are not available has not been studied any further in Australia but what is known suggests that common cover crops such as forage sorghum, while not ideal food sources, may provide enough plant roots to at least sustain a crop damaging population.

Identification

Australian identification keys are for adult beetles, no keys allow identification from the larvae stage. In Georgia and southern Florida, in the U.S. Seal *et al.* (1992a)

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[3] Scarab larvae include whitegrubs, peanut scarab or the black sunflower scarab
[4] Cerambycid larvae include longicorn beetles larvae (Witchety grubs)

developed keys to identify the wireworm species affecting sweetpotato from the larvae stage.

Identification of Australian wireworms is difficult, due to a lack of taxonomists able or willing to work with this group of insects (I. Kay pers. comm. 2006).

The literature reviewed suggests that individual species have very specific ecological and biological characteristics and specific crop preferences. It is important to identify at least some adults associated with damage to sweetpotato crops to the species level to help narrow down the number of species causing significant economic damage in this crop.

Main points

- ***Conoderus* spp. were the most commonly found larvae in Bundaberg sugar cane fields during 1995 and 1996.**
- **The predominant wireworm species found in southern U.S sweetpotato crops is *Conoderus*.**
- **Adult movement mainly occurs in October/November.**
- **Egg laying occurs in Nov/Dec and grass/crop/weed cover is preferred.**
- **True wireworm are dependant on soil moisture and actively follow the moisture profile to avoid drying out and death.**
- **True wireworm can use a range of crops and decomposing plant matter as alternative food sources and some will predate other true wireworm and insect larvae.**

Control

Sweetpotato growers in Australia apply preventative soil insecticides at planting because the economic consequences of wireworm damage are great and there is currently no strategy that can accurately predict fields at risk. Currently the only insecticide registered for soil incorporation on sweetpotato in Australia is phorate.[5]

Insecticides registered for soil incorporation at planting to control true wireworm in other Australian crops include:

- phorate (cotton, sugarcane, potato, sweetpotato)

[5] Commonly sold as Thimet® and Umet®

- chlorpyrifos [6](cotton, sugarcane, potato, sorghum, tobacco, canola and maize)
- granulated chlorpyrifos[7] (sugarcane)
- bifenthrin[8] (cotton & sugarcane)
- fipronil [9](potato & sugarcane).

Chlorpyrifos and bifenthrin are both registered for foliar application in sweetpotato to control sweetpotato weevil. It is possible that these chemicals may also be providing some control of migrating click beetles.

Wireworm feeding damage to sweetpotato can occur at any stage in the 90 to 150 day growing period. The combination of long growing periods and the short residual effect of current insecticides require many sweetpotato growers to apply a second, third or fourth application of insecticide to ensure existing and immigrating populations are controlled.

Insecticides applied pre-planting and during crop development are currently the only reliable means of controlling wireworm. Current industry practice includes incorporating a soil insecticide at planting and then, starting at approximately 30 days after planting (DAP), undertaking a regular foliar application of chlorpyrifos or bifenthrin. When undertaking a foliar application during the crop's development growers tend to use chlorpyrifos when rain is imminent. If conditions are hot and dry the preferred option is bifenthrin.

Effectiveness of soil incorporated insecticides

The efficacy of soil incorporated insecticides is dependent on larvae being present in the application zone. The application zone is typically created by a rotary hoe which results in the insecticide being mixed in the top 100 to 200mm of soil. If the larvae are below this zone the treatment will only be effective for as long as the insecticide applied remains active providing a barrier to larvae moving up through the profile.

Chlorpyrifos: Suppression of damage from *Heteroderes* spp. has been demonstrated by pre-plant soil incorporation of an emulsifiable concentrate (EC)[10] chlorpyrifos formulation in northern NSW (Rochecouste 2003). Effective control was recorded at 65 days after planting (DAP), however by commercial harvest (142 DAP) 98% of the crop was unmarketable due to wireworm damage. A granular chlorpyrifos formulation commonly marketed as Suscon® Green produced similar results as the EC formulation.

Wireworm damage from the species *H. hirtus* was significantly reduced (from 28.6% to 1%) by an EC chlorpyrifos formulation applied to potatoes in Victoria (Horne and Horne 1991). In the same experiment granular chlorpyrifos (Suscon® Blue) and tefluthrin produced no reduction in damage compared to the untreated plots of potato. In the report by Kuhar *et al.* (2003) 45 insecticide trials conducted over 20 years in 12 states of the U.S. for 14 different species were summarized and found chlorpyrifos

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[6] Commonly sold as Lorsban™ ,an EC formulation
[7] Commonly sold as Suscon® Blue and Suscon® Green
[8] Commonly sold as Talstar®
[9] Commonly sold as Regent®
[10] EC is a term used to distinguish the form the insecticide is used and has been used in this text to clearly differentiate between the liquid and granular form of a given insecticide.

soil incorporated at planting was the most effective and consistent method for controlling wireworm.

Phorate: Wireworm damage from *Heteroderes* spp. has been reduced using a pre-plant soil incorporation of granular phorate in northern NSW (Rochecouste 2003). Effective control was recorded 65 DAP, however by 142 DAP 90% of the crop was unmarketable (Rochecouste 2003). Kuhar *et al.* (2003) found that phorate soil incorporated at planting consistently provided 60% protection from wireworm in potato.

Bifenthrin: Wireworm damage from *Heteroderes* spp. has been reduced using a pre-plant soil incorporation of an EC formulation of bifenthrin in northern NSW (Rochecouste 2003). Effective control was recorded at 65 DAP, and at 142 DAP 45% of the crop was marketable in comparison to the untreated plots where 0% was marketable. Kuhar *et al.* (2003) found that bifenthrin soil incorporated at planting consistently provided only 40 to 50 % protection from wireworm in potato.

Rochecouste (2003) also tested terbufos (Counter®), fipronil (Regent®) and imidacloprid (Confidor®) using a pre-plant soil incorporation but found none of them to be effective in controlling wireworms at 60 DAP or at harvest (142 DAP). Kuhar *et al.* (2003) stated that fipronil and imidacloprid incorporated into the soil at planting provided approximately 50% control of potato damaging wireworms in the U.S.A.

Mid-season applications

Due to inadequate control provided by insecticides incorporated prior to planting, further applications by pressurised spray equipment are required during the crop's development.

The effectiveness of these applications is dependent on the presence of adult beetles during the spray operation and/or the presence of newly hatched larvae in the top few centimetres of the soil at or just after spray application.

Insecticide trials for the control of wireworm for sweetpotato production in northern NSW by Rochecouste (2003) concluded that methods that may allow a secondary application of an organophosphate product (i.e. phorate or chlorpyrifos) need to be developed. Incorporation of organophosphate insecticides into the soil at planting was found to provide adequate protection up to 60 days after planting only. Broadcasting phorate over the developing sweetpotato crop at 60 days after planting was not effective (Rochecouste 2003). Under field conditions in western Australia the half life of chlorpyrifos was found to be 81 days, with only a fraction of the chemical remaining in the soil at 148 days after application (Kookana *et al.* 1995).

In Georgia, U.S.A. chlorpyrifos applied to a sweetpotato crop at planting and then re-applied through a linear move irrigation machine at a water rate of 63.5 kilolitres/ha or 6.35 mm/ha at 60 days after planting had significantly less wireworm damage to the crop than plots that were only treated at planting (Chalfant and Seal 1991). In a second experiment chlorpyrifos re-applied to a sweetpotato crop at 60 days after planting through the linear move irrigation machine at a water rate of 25.4 kilolitres/ha or 2.54 mm/ha had significantly more wireworm damage to the crop than plots applied at the 6.35 mm/ha water rate. Chalfant and Seal (1991) suggest that during hot dry conditions chlorpyrifos may need to be re-applied at water rates even greater then 6.35 mm/ha.

Chemical resistance

Jansson and Lecrone (1991) state that phorate resistance may be developing in certain *M. communis* populations in southern Florida.

Entomopathogenic nematodes

Georgis *et al.* (2006) states that true wireworm are not suitable targets of nematodes due to their lack of susceptibility, behaviour and/or biology. The ability of wireworm to readily move throughout the soil environment enables them to evade areas inhabited by the nematodes. Some Australian sweetpotato growers in the Cudgen district have trialled similar nematodes for wireworm in the 2005 season with limited success (E. Coleman pers. comm. 2006). Georgis *et al.* (2006) warn that certain entomopathogenic nematode product labels state wireworm as a target insect pest.

Entomopathogenic fungi

Kuhar *et al.* (2003) state that there may be potential to use entomopathogenic fungi such as *Beaveria bassiana* and *Metharizihum anisoplae*, since these organisms are active in the soil but to date there is no substantial efficacy data for true wireworm.

Insect predators

The common brown earwig (*Labidura truncata*) (Image 1.03) is listed as a predator of wireworm larvae and pupae (Wood *et al.* 2000). Adults are 24 mm long, brown and black with a flattened body and a pair of curved pincers at the end of the body. Nymphs resemble adults but are wingless. They are also said to attack moth larvae and other insect pupae. According to Wood *et al.* (2000) they are a nocturnal predator that attacks prey with its pincers. The common brown earwig is often seen in Australian sweetpotato fields hiding underneath leftover sweetpotatoes. Common brown earwigs have been observed in the laboratory feeding on wireworm larvae collected from sweetpotato fields in Bundaberg, Queensland.

Image 1.03: Common brown earwig feeding on wireworm larvae

There is no information available to verify the behaviour of these predators, therefore it is unknown whether they seek out wireworm within the soil environment or wait to attack wireworms as they come near to the soil surface. If predation occurs on or just below the soil surface they would be most effective at predating wireworm soon after eggs have hatched and during the first instar period when the larvae are relatively immobile. However they would also be highly susceptible to broad spectrum insecticides being used in the crop.

Cultivation

Ploughing a field three times, to a depth of 20 cm with a power tiller (rotary hoe) significantly reduces populations of *C. scissus* and *C. rudis* (Seal *et al.* 1992b). Before ploughing 1.75 wireworms were found per bait and only 0.2 wireworm per bait were found after ploughing. Seal *et al.* (1992b) suggest that ploughing brings the larvae and/or pupae to the surface of the soil to be exposed to predators, heat, low moisture and other stresses. Ploughing is only effective for reducing populations of wireworm species that do not move below the depth of soil ploughed (Seal *et al.* 1992b). Excessive power tilling of the soil however may be detrimental to soil structure.

Crop rotations/fallow

In the chapter, ‘Biology and management of wireworms on sweetpotato’, Chalfant and Seal (1991) state that wireworms attack a wide range of crops and weeds, but that the wireworm species that attack sweetpotato (*C. scissus*, *C. falli*, *C. amplicollis* and *C. rudis*) have different alternative crop preferences.

Seal *et al.* (1992b) found when comparing a peanut to sweetpotato rotation with a corn to sweetpotato rotation significant differences in the species populations occurred. Populations of *C. scissus* were significantly greater in a peanut to sweetpotato rotation then in a corn to sweetpotato rotation, where as populations of *C. rudis* and *C. amplicollis* were significantly greater in the corn to sweetpotato rotation than the peanut to sweetpotato rotation.

Seal *et al*. (1992b) also found that the abundance of *C. rudis* was significantly greater in sweetpotato crops which followed weedy fields than crops following a fallow field. Populations of *C. scissus*, *C. falli* and *C. amplicollis* did not differ following weedy or fallow fields.

Summer cover crops may provide excellent and attractive conditions for ovipositing wireworms and developing larvae (McDougall 1934; Chalfant and Seal 1991), therefore leading to damage in the subsequently planted sweetpotato crops.

In the review by Jansson and Seal (1994) they found that in Florida, (U.S.A) a summer cover crop of sorghum is very attractive to adult true wireworms. Jansson *et al.* (1991) compared the influence of different summer cover crop management strategies and the subsequent abundance and feeding damage to potato of *M. communis* in Florida potato growing regions. The strategies compared included:

- planting sorghum early summer
- planting sorghum late summer
- leaving the field fallow.

M. communis were more abundant in plots planted with the early sorghum crop than in those planted with the late sorghum crop in both 1987 and 1988. The percentage of potato crop loss from wireworm damage at harvest was significantly higher in plots planted with the early sorghum crop than in plots with the late planting of sorghum. Higher larval populations in the early sorghum planting would be due to the adult flight coinciding with the young actively growing sorghum crop and therefore a high egg lay occurring with an ideal habitat for the larvae to survive.

Manipulating soil moisture

McDougall (1934) states that improving the drainage of sugarcane fields will prevent damage from *A. variabilis* larvae, as smaller instars must have excessively wet soil environments for their survival.

Field flooding to control populations of *Agriotes obscurus* and *Agriotes lineatus* (van Herk and Vernon 2006) in British Columbia achieved 90% mortality in 8.6 days on Delta soils and 16.5 days in Agassiz soils only when mean monthly temperatures are approximately 20°C. During the cooler winter months fields would need to be flooded for greater then two months to achieve the same level of mortality.

Jansson and Seal (1994), state that *M. communis* feeding damage on potatoes increases as soil moisture levels decrease, as the true wireworm presumably seek moisture from the potato tubers to avoid desiccation. Using the sweetpotato as a source of moisture may explain why shotgun damage is reported by growers as being worse in dry seasons. Therefore the use of irrigation to maintain soil moisture levels at adequate levels to reduce this damage may be useful.

Main points

- **Wireworm populations may be avoided by planting sweetpotato after a less preferred crop.**
- **Fallow periods are the most successful rotation at reducing wireworm population.**
- **Sweetpotato following sweetpotato will increase wireworm populations.**
- **Wireworm damage in sweetpotato may be reduced by multiple ploughing.**
- **Weed free fields are less preferred by wireworms.**
- **Soil moisture regulates wireworm behaviour and their location in the soil profile.**
- **Organophosphate insecticides applied at planting provided adequate control for wireworm up to 65 DAP, but not for the full 140 DAP.**
- **Top up applications of insecticides during the crop can be an unreliable method of control.**
- **Dry weather increases damage due to insecticides being less effective and the wireworm using the sweetpotato as a moisture source.**

Insect pest monitoring

Insect pest monitoring is a vital part of an integrated management program. Monitoring enables control measures (insecticide application etc) to be targeted, maximising crop protection while minimising unnecessary and costly practices. Monitoring of wireworm can be undertaken for both the larval stage and adult stage.

Monitoring for larval populations takes place before planting to determine the potential for economic damage to a newly planted crop. Methods include collecting and sifting through soil samples or setting baits in the soil to collect and sift at a later date. Monitoring of adult populations occurs during the crop's growing season. This enables targeted insecticide spray applications to prevent females ovipositing within the crop as insecticides soil incorporated at planting are no longer active. Adults can be monitored using light traps or pheromone traps. This section will present an appraisal of world literature with regard to the various monitoring techniques.

Soil sampling vs setting baits

In the United States Seal *et al*. (1992a) trialled seven different seed baits and a soil sampling technique for wireworm (*Conoderus* spp.) in Georgia sweetpotato fields. Baits comprising a 30 mL corn-wheat mixture placed 5 to 10 cm under the ground in sweetpotato fields were most effective at attracting the wireworm species, *C. scissus*, *C. rudis*, *C. amplicollis*, and *C.falli*. Soil samples were not effective for finding wireworms.

In Australia Horne and Horne (1991) when sampling for *H. hirtus* in Victorian potato fields found that soil sampling did not adequately indicate potential damage to potato crops, while setting baits (potato seed pieces) provided more useful data in determining potential damage. One hundred soil samples were taken from a field known to have wireworm larvae, before planting to find only one wireworm larva. The subsequent harvested potato crop suffered approximately 30% damage at harvest.

Baits provided more useful data than soil sampling, with up to 30% of baits being attacked leading to the easy identification of areas that would have the highest chance of being damaged. This was confirmed with insecticide trials in the trial area, revealing harvested potatoes from control areas with 28.6% damage. Thirty five potato baits were placed 15 cm under the soil surface at two metre intervals along the length of a block. Baits were then collected five weeks later in winter, taken back to the lab and assessed for wireworm feeding injury. Horne *et al.* (2002) concluded that there are hundreds of other species of click beetles that can be found near potato crops, but these species did not damage potatoes and are not pests.

Learmonth (2004) undertook pre-crop monitoring in potatoes for wireworm larvae and then recorded subsequent damage at harvest in Queensland, New South Wales and Victoria. At Ravenshoe, Queensland, pre-crop monitoring during 2002 and 2003 recorded no wireworm larvae at the baits. All the crops subsequently planted sustained between 3% to 10% damage. In NSW three trial sites all recorded high numbers of wireworm, but no soil insecticide was applied, and at harvest no tuber damage was seen at two of the three sites and less than 2% at one of the sites. Baiting Victorian fields allowed larval population and distribution to be successfully mapped and hence insecticide treatments resulted in less than 2% damage to the potato crop.

Wireworm species were not identified in QLD and NSW, but in Victoria wireworm were identified as *H. hirtus*.

In the United Kingdom Parker (1996) also investigated the possible relationship between cereal bait catches of wireworms (*Agriotes* spp.) and subsequent damage to potato crops. He concluded that bait catches pre-planting cannot be used to predict the subsequent level of wireworm damage to potato crops, but that they were a more efficient means of assessing wireworm populations than taking soil cores for sifting.

Jansson and Seal (1994) successfully used rolled oat baits to develop economic thresholds for *M. communis* before planting fields to potato in southern Florida (U.S.A).

In Australia Samson and Calder (2003) conclude that a baiting method for true wireworm species in the genera *Agrypnus, Conoderus* and *Heteroderes* is unsuitable as a decision-support tool for insecticide application for the sugar cane industry. Rolled oats were used as baits to determine whether treatment was warranted for fields where new cane plantings would occur in the Mackay and Bundaberg regions. On farms with very high wireworm counts trials were undertaken to compare cane establishment treated or untreated with insecticide. No reduction to cane establishment occurred in plots not treated for wireworm compared to those that were treated. Conversely, cane blocks where baiting found no wireworm larvae resulted in the greatest reduction in crop establishment.

In conclusion, baiting would appear to be more effective than soil sampling. Factors which hinder the accuracy of monitoring larvae by baiting as part of a decision support tool for determining potential crop damage include:

- lack of knowledge on target species. Is there one or are there many?
- the patchy nature of wireworm distribution within a field
- the fact that wireworms tend to move away from their feeding site once they are fed (Seal *et al.* 1997)
- the depth at which the larvae are active in the soil environment
- soil temperature
- soil moisture
- soil type/friability
- availability of alternative food sources
- sampling errors involved with trying to estimate population sizes accurately.

Samson and Calder (2003) conclude that even if such technical aspects are overcome barriers to adoption include:

- economics: The number of baits which are needed cannot be justified while insecticide treatment is inexpensive.
- extension difficulties: Insecticide application is very simple and less time consuming than accurately baiting a field.
- risk: The consequences of a wrong decision to withhold insecticide could be severe.

There is strong evidence to suggest that soil sampling is not an adequate method for collecting true wireworm larvae. Baiting is the preferred method and studies have shown that larval counts found at baits can be used to then determine damage levels on subsequently planted crops. Not all baiting studies for true wireworm larvae have been useful in predicting damage to subsequently damaged crops.

The key difference in the literature between those that had success and those that did not is that those that did were baiting for a known species of true wireworm. Those that did not correlate catches to economic damage suggest that baiting for an unknown species of true wireworm is not effective for predicting future crop damage (Learmonth 2004;, Samson and Calder 2003; Parker 1996). Baiting for a known species of true wireworm can be successfully correlated to future damage levels (Horne and Horne 2001; Seal *et al.* 1992a; Seal *et al.* 1992b; Jansson and Seal 1994).

Currently it is unknown whether one species is responsible for the characteristic wireworm feeding holes occurring in the Australian sweetpotato industry or whether a range of wireworms from different families, genera or species is responsible.

Monitoring using traps

Monitoring of click beetles using light traps, sticky traps, pitfall traps or pheromone traps allows the targeted application of insecticides as a means of preventing ovipositing within a crop.

Light traps

Sugarcane wireworm, *A. variabilis*, adults are not attracted to white to yellowish light (McDougall 1934). This was assessed using acetylene light and white sheets in Queensland sugarcane growing areas at different times during the period from October to February 1931 to 1933. Species that were attracted to white/yellowish light method included (McDougall 1934):

- *Agrypnus assus*
- *Agrypnus humilis*
- *Agrypnus lateralis*
- *Heteroderes carinatus*
- *Heteroderes cairsensis*.

Black light traps were used to successfully monitor the seasonal abundance of click beetles, *C.rudis*, in sweetpotato fields of Georgia (U.S.A), during the sweetpotato production seasons of 1986 and 1987 (Seal and Chalfant 1994). Fluorescent ultraviolet-light traps attract *C. falli*, especially during the early part of warm, humid nights in south Carolina (U.S.A) (Day *et al.* 1971).

Wireworms have been collected in light traps in the Lockyer valley south east Queensland during September and October 2002 (J. Duff pers. comm. 2006). Wireworms have also been collected in black light traps in the Bundaberg region (CropTech pers. comm. 2006).

Emergence traps

Learmonth (2004) found that numerous wireworms were captured in emergence traps, (half a plastic drum placed over an area where a known population of larvae are dwelling), used for white grub adults in far north Queensland. These wireworms were thought to be the same species as the wireworm larvae causing the characteristic damage to potato tubers in the area, but this was not confirmed.

Pitfall traps
In a review of wireworm biology in the UK, it is stated that pitfall traps were successful in monitoring adult populations of *Melantus depressus* and *Melantus verberans* (Parker and Howard 2001).

Sticky traps
Parker and Howard (2001) state that yellow sticky traps placed at a height of 1.2 m or less were effective in catching flights of male beetles of *M. depressus* and *M. verberans* in north America, but not as effective as pitfall traps for females of the same species.

Pheromone traps
Blackshaw and Vernon (2006) successfully used pheromone traps to study the spatial distribution of wireworms, *Agriotes lineatus* and *Agriotes obscurus* within an agricultural landscape of British Columbia. The sex pheromone used to attract *A. lineatus* contained 160 mg of geranyl octanoate and geranyl butanoate in a 9:1 ratio, while *A. obscurus* was attracted using a 160 mg mixture of geranyl octanoate and geranyl hexanoate in a 1:1 ratio (Blackshaw and Vernon 2006).

Toth *et al*. (2002) compared baiting with different geranyl esters, geranyl butanoate, geranyl hexanoate and geranyl octanoate. Geranyl hexanoate captured large numbers of the wireworm *Agriotes rufipalpis* in Hungary, while in Italy it was successfully used to attract, *Agriotes sordidus.* In Hungary, geranyl butanoate attracted *A. sputator* and geranyl octanoate attracted *A. lineatus*.

Parker and Howard (2001) reported that pheromones used to monitor tufted apple budmoth (*Platynota idaeusalis*) in the U.S.A. also attracted *Melantus* spp., especially *M. depressus* and *M. similis*.

There appear to be no published data about the use of pheromone baiting for *Conoderus* spp..

Main points

- **The adult beetle trapping methods using lights and pheromone traps appear to be species specific.**
- **Trapping methods need to target the species attacking sweetpotato in Australia.**
- **At least some of the damage occurring after 60DAP may be attributed to migrating wireworms laying eggs and developing new larvae.**
- **Baiting is a more effective than soil sampling as a monitoring technique.**
- **Soil sampling is not a reliable/economic monitoring technique.**

Resistant cultivars

No true wireworm resistance research has been conducted on sweetpotato in Australia, however some growers have observed some resistance to true wireworm in some white flesh varieties grown in Australia.

Image 1.04: 'Ruddy' on the left and 'Beauregard on the right.

Breeding programs in the United States have been working towards developing resistance for a range of soil insect pests. The cultivar 'Ruddy' has consumer and agronomic characteristics similar to that of Beauregard as well as having high resistance to the southern potato wireworm (*C. falli*) and the tobacco wireworm (*C. vespertinus*), grown under south Carolina (U.S.A) conditions. Bohac *et al.* (2002) describe 'Ruddy' as having attractive red skin and medium orange flesh colouring (Image 1.04). Storage root shape is uniform and per plant production is greater than Beauregard. 'Ruddy' is also resistant to cracking, a characteristic common with many red skinned varieties. Ruddy is not yet ready for release.

A number of cultivars have been nominated for wireworm resistance testing in Australia by Janice Bohac from US Department of Agriculture, and include Excel, Regal, Carolina Bunch and Patriot. These cultivars show high resistance to attack under U.S growing conditions. Finding a cultivar with desirable consumer, agronomic and insect resistant characteristics is a vital component to a successful integrated pest management approach to soil insect control in the Australian sweetpotato industry.

Main points

- **Some cultivars have higher levels of resistance to true wireworm than others.**
- **Gold flesh cultivars with higher levels of resistance than Beauregard are available from the U.S.A. for testing.**

False wireworm (Coleoptera: Tenebrionidae)

This section of the review is based on Roberston's (1993) review of false wireworm in reference to an integrated pest management program in central Queensland field crops. There is little international literature published on this group of pests. Australian entomologists Peter Allsopp (BSES[11]) and Les Robertson (SRDC[12]) are leaders in their knowledge of false wireworms. Their published work is often referenced in reviews on wireworm from around the world. False wireworm larvae are often found in damaged blocks of sweetpotato in Queensland and New South Wales, but it is not certain whether there are any distinguishable differences between true wireworm damage and false wireworm damage on storage roots. Table 1.02 is a summary of *Pterohelaeus alternatus* and *P. darlingensis* lifecycle.

Ecology and biology

Life cycle

Pterohelaeus alternatus and *P. darlingensis*.

Table 1.02. Summary of *Pterohelaeus alternatus* and *P. darlingensis* lifecycle (derived from Robertson (1993)).

Developmental stage	Month	Time for stage completion
Beetles emerge	Oct/Jan	Beetles migrate if habitat is not suitable. Female beetles require food (green leaf material) before they begin ovipositing.
Eggs laid	Nov/Feb	Oviposition starts about one month after emergence. Egg laying may continue for up to 20 weeks but is terminated by cool weather. Females are capable of laying 1,000 eggs or more. Once larvae have emerged they are generally restricted to the top 5 cm of the soil profile and are relatively immobile during the first instar stage.
Larval instars	Varies	Larvae develop through autumn, winter and spring. Cannot distinguish between larvae instars. Believed to have up to 11 instars.
Pupation	Sept/Oct	Rainfall triggers pupation. This stage generally takes about two weeks.

Gonocephalum macleayi

According to Robertson (1993) the life cycle of *G. macleayi* in central Queensland is similar to that of *P. alternatus*.

- Peak pupation and emergence follows rainfall in October – November.
- Fifteen mm of rainfall on dry soil is enough to trigger pupation.
- Adults and larvae aggregate under concentrations of crop residues or under weeds in fallow fields.

[11] Bureau of Sugar Experiment Stations
[12] Sugar Research and Development Corporation

Robertson (1993) suggests that false wireworms have adapted to exploit ephemeral habitats characterised by climatic fluctuations. Such adaptive characteristics include; ability to disperse, lay large numbers of eggs, achieve rapid population fluctuations to such densities that frequently exceed the carrying capacity of the habitat.

Dispersal

Adults are capable of flying for a relatively short period of one month after emergence. Wing muscles then break down (atrophy) and energy is diverted to reproductive effort once suitable habitat is found. Adults seek areas of actively growing crop in which to feed and lay their eggs, such as sorghum, sunflower or soybean.

Larvae are mobile in the soil environment, but are generally found in close association with plant roots. Larvae will move up and down the soil profile with temperature and moisture, generally inhabiting that boundary between the dry surface soil and a deeper moist layer (Robertson 1993).

Natural habitat and food source

Robertson (1993) suggests that false wireworm species live in native grasslands and grassy woodlands. He also suggested that they are adapted to feeding on tropical and sub-tropical grasses which grow over the wet summer period. Adult and larval false wireworms feed on decaying organic residues in the soil, as well as on living weeds and crops (Roberston, 1993).

Temperature and moisture requirements

Larvae are usually found at the boundary between the dry surface soil and a deeper moist layer and descend with drying of the soil (Robertson 1993). Robertson (1993) reports that *P. darlingensis* prefers soil moisture levels in the range 20 – 40%, in a clay soil with a permanent wilting point of 26%. Allsopp *et al.* (1980) concludes that when soil moisture content is not below the level that causes dehydration then temperature dictates movement.

Control

Insecticide efficacy work for false wireworm control has been widely undertaken for grain crops in central Queensland and northern New South Wales. Protection from feeding larvae is only required for the first 4 to 6 weeks, as the plant needs protection to establish an effective root zone (Robertson 1993). Once the bulk of the roots are established crops can then withstand false wireworm larval feeding. Robertson (1993) states that most insecticides whether banded in the furrow at planting or incorporated as a seed dressing actually only act as a repellent to false wireworm larvae. False wireworm adults can also cause major economic damage by feeding on emerging seedlings. In the central Queensland highland grain cropping areas baits are broadcast immediately after planting to control feeding adults.

Chaton *et al.* (2003) suggests that more work needs to be done to try and find a method that ensures larvae ingest the insecticide as this is the only reliable means for killing larvae. Currently, methods mainly depend on an insecticide being absorbed through the cuticle of the larvae while living in the soil environment or by repelling larvae away from an area. The dependence on such methods will fail when crops require long periods of protection which extends beyond the active life of the insecticide applied.

Seed treatment

Thiamethoxam - Thiamethoxam is registered as a seed dressing for false wireworm and true wireworm control in sorghum cropping in Australia (Cruiser® 600 FS). It is also registered as a spray application for controlling first instar larvae of African black beetle and larvae of billbugs in the turf industry as Meridian®. Thiamethoxam is a neonicotinoid similar to imidicloprid (Confidor®). It has systemic action and therefore it is very effective at controlling sap sucking insects also.

Soil incorporated insecticides

Fipronil- Fipronil is registered for potato at 250ml/ha soil incorporated pre–plant for various wireworm pests in all states. The sweetpotato industry has let their APVMA off-label registration slip for all wireworm control as it is perceived to have poor efficacy. Chaton *et al.* (2003) states that the efficacy of soil incorporated insecticides are generally based on the direct penetration of the active molecules through the larval sclerified cuticle or skin. Chaton *et al.* (2003) found the penetration through the cuticle of fipronil appeared to be negligible when tested against wireworm.

Chlorpyrifos – Robertson (1991) states that the in furrow registration rates for chlorpyrifos do not adequately protect seedlings from soil insect feeding damage.

Bifenthrin – Robertson (1991) found that the most effective in furrow treatment was achieved using the soil-active pyrethroids, tefluthrin and bifenthrin for killing larvae and preventing seedling damage.

Baiting adults

Baits consisting of cracked grain, sunflower oil and chlorpyrifos are broadcast immediately after planting to control feeding adult populations. Broadcasting bait was more effective then banding a bait trail on the soil surface through the paddock. If broadcasting is not possible Murray (1989) found that banding bait trails should be spaced no more then 2 m apart for effective control. Murray (1989) suggested that surface-active insects encounter bait particles by chance rather than by attraction over any appreciable distance.

Predators

Robertson (1993) lists predatory beetles, spiders, earwigs and birds as predators of false wireworms in Queensland, but states that no quantitative study on the effects of predation on the false wireworm populations has been undertaken.

Entomopatgenic fungi

Robertson (1993) reports that the fungal pathogens *Metarhizium anisopliae* and *Beauveria bassiana* are important natural enemies of false wireworms in Queensland, and recorded *M. anisopliae* infection rates of up to 17% in *G. macleayi* larvae at 10 larvae/m^2, while *B. bassiana* was recorded at a maximum infection rate of 16% in a population of *G. macleayi* at 6 larvae/m^2 at a high stubble, no till site. The incidence of fungal diseases in false wireworms also tends to be higher in wet rather then dry winters (Robertson 1993). Drought may suppress fungal diseases of false wireworms.

Entomopathogenic nematodes

No mention of pathogenic nematodes infecting false wireworms could be found in the literature.

Cultivation

Cultivation in itself does not reduce false wireworm numbers, but cultivation to remove stubble may depress densities as it removes a food source, shelter and possible oviposition sites (Robertson 1993).

Crop rotation

Summer grown crops favour the development of false wireworm infestations (Robertson 1993). Out of 52 sorghum growing sites sampled for false wireworms in the central highlands, two-thirds were infested with adults or larvae. Soybean and sunflower showed similar infestation levels, whereas irrigated cotton did not show such high infestation rates. The frequent spraying of irrigated cotton with insecticides may have reduced the number of surface-active false wireworms before they had the chance to lay any eggs (Robertson 1993). Robertson (1993) suggests that more eggs are laid or survival rate of immature false wireworms is higher in actively growing crops than in a fallow field with crop residue. Adults seek areas of actively growing crop in which to feed and lay their eggs, larvae then are able to develop in the soil over the generally dry, cool period, feeding on organic matter in the soil. Robertson (1993) suggests that wheat crops may be less attractive to false wireworms, but this is most likely due to wheat being a winter growing crop. During spring and early summer active adult beetles would prefer the actively growing crops rather than wheat stubble.

Insect pest monitoring

Light traps

Peak flights of *P. alternatus* and *G. macleayi* were successfully monitored using black light traps from November to February in central Queensland (Robertson 1993).

Soil sampling

Robertson (1993) recommends that soil sampling with a spade to a depth of 15cm when soil is moist, as false wireworms are generally found close to the soil surface under moist soil conditions. It is recommended that 44 of such spade samples with no false wireworm are needed to assume safely that a damaging population does not exist. Conversely, as few as eight samples with a total of three false wireworms would indicate a population density that justifies treatment (Robertson 1993). Robertson (1993) also states that a population of two to four larvae per square meter can cause considerable economic damage to summer grain crops in central Queensland.

Soil baiting

Germinating crop seed placed at a shallow depth in moist soil to attract larvae is recommended as a larval monitoring tool (Robertson 1993).

Resistant cultivars

No literature could be found on sweetpotato resistance to false wireworm feeding.

Main points

- **Adult movement mainly occurs in October/November.**
- **Egg laying occurs from October and ceases with cool weather.**
- **Preferred egg laying sites have substantial grass/crop/weed cover.**
- **Larvae will move up and down the soil profile with temperature and moisture, generally inhabiting that boundary between the dry surface soil and the deeper moist layer.**
- **Adult and larval false wireworms feed on decaying organic residues in the soil, as well as on living weeds and crops.**
- **Dry conditions may suppress fungal diseases that attack false wireworms.**

Sweetpotato weevil (Coleoptera: Brentidae)

Introduction

Pinese (2001) reported that sweetpotato weevil (*Cylas formicarius*) was the most important constraint to the viable production of sweetpotato in Australia. Similarly, Waterhouse (1997) reports that sweetpotato weevil is the major pest constraint of sweetpotato production in PNG, and is ranked as their fifth most important invertebrate pest.

Cylas formicarius (Image 1.05) was first described from a specimen collected near Madras, India in 1978 and is widely distributed in India, the Pacific Islands, Australia and the Americas (Pinese 2001). In Australia, sweetpotato weevil was confined to the northern and eastern parts (Pinese 2001). According to Centro International De La Papa (CIP) there are three species of sweetpotato weevil, *Cylas formicarius, Cylas puncticollis* and *Cylas brunneus.*

Image 1.05: *Cylas formicarius*

Cylas formicarius (Asian species) is restricted to:

- Asia/Oceania
- southern United States of America
- Caribbean.

Cylas puncticollis and *Cylas brunneus* (African species) are restricted to sub – Saharan Africa.

This report will concern itself with the sweetpotato weevil, *Cylas formicarius*. Sweetpotato weevil larvae cause considerable damage to sweetpotato storage roots by tunnelling deep inside making the sweetpotato unmarketable. The weevil is also able to lay its eggs in the crowns or stems just above the soil surface. This is not considered as important as damage to the storage root, but it has been found that marketable yields decrease with increased attack to the crowns or stems (Pinese 2001). This damage interferes with the plant's ability to transfer water, nutrient and assimilates within the crown and from foliage to developing storage roots. The weevil spends its entire life-cycle on the host plant.

Ecology and biology

Sweetpotato is the preferred host for sweetpotato weevil and under ideal temperature conditions it has the ability to go through the entire lifecycle from eggs to adult in approximately 32 to 33 days (Pinese 2001; Sutherland 1984). This can result in enormous populations developing in a single sweetpotato cropping cycle. Table 1.03 is a summary of sweetpotato weevil lifecycle.

Life cycle

Table 1.03. Summary of sweetpotato weevil lifecycle (derived from Pinese (2001).

Developmental stage	Time for stage completion
Adults	Females begin laying eggs about a week after emerging and can continue for three or more months.
Eggs laid	Eight days to hatching
1st Larvae instar 2nd Larvae instar 3rd larvae instar	Total larvae period varies from 10 – 25 days
Pupation	Eight days for adults to emerge.

Eggs – The eggs are creamy white and measure about 0.6 mm x 0.4 mm. They are laid singly into holes chewed by the female in either the storage roots or the thicker vines.

Larvae – Eggs hatch after 4 to 7 days. The larvae are legless and feed inside the vines or storage root and feed for approximately 16 days before pupating.

Pupae – Pupation can occur in storage roots but mostly in the soil (Kumar 1992), with the adult emerging about 7 days later.

Adult – The adult sweetpotato weevil is about 6 mm long and 1.5 mm wide. When the adult emerges it remains inside the storage root or vine for approximately 5 days until its skin hardens and its colour darkens. The adults sometimes fly at dusk or in the early evening.

Temperature

Kumar (1992) reports that the duration of the lifecycle depends on weather conditions and takes between 28 and 49 days. Warm to hot temperatures increase the rate of life cycle completion for sweetpotato weevil. Pinese (2001) states that under such conditions the full cycle can be completed in as little as 33 days. Sutherland (1984) reports that in PNG the life cycle was completed in 32 days. Kandori *et al*. (2006) surveyed the cold tolerance of *C. formicarius*, finding females still actively ovipositing between 16 and 18°C. Below these temperatures ovipositing decreased significantly for the surveyed population of female sweetpotato weevil. This data supports Pinese's (2001) pheromone trapping survey results which found seasonal factors influenced weevil populations in sub-tropical Bundaberg, southeast Queensland, with no seasonal influence noted in tropical north Queensland. A distinct drop in adult weevil populations occurred during the autumn/winter months, then a peak in the spring/summer months at Bundaberg. In PNG the lifecycle is shorter in the warmer lowlands than the cooler highlands (Sutherland 1985).

Wet season/dry season

In PNG it is noted that the intensity of sweetpotato weevil infestation varies between the wet and dry seasons. According to Bourke (1985) the weevil caused economic damage in areas with a marked dry season or in unseasonably dry years. Sweetpotato weevil is a problem wherever the crop is grown and often worse during dry times. The weevil is reported to be most serious in areas with a marked dry season or in the drier parts of the highlands such as the Benabena and Henganofi areas of the Eastern Highlands Province. Moisture and rainfall has been shown to influence sweetpotato weevil incidence and damage level in PNG (Sutherland 1985; Powell *et al.* 2000). High levels of weevil incidence generally correspond with lower rainfall levels. Weevils fail to penetrate wet soils but can penetrate dry soils. Wijimeersch (2000) reported that at Keravat (PNG), with its well spread high rainfall, weevil damage is usually not a problem. Weevil damage was assessed during collection harvests in the dry season at Laloki (PNG), results however were inconsistent. Lutulele (2000) mentioned that sweetpotato weevils were not a problem at higher altitudes (more than 1 800 meters above sea level) but can be economically important in dry areas or during periods of drought.

Feeding and food host sources

Cylas formicarius completes the entirety of its life cycle on the host sweetpotato plant. Females excavate small pits in the vines near the plant's crown above the soil, or in exposed sweetpotato roots, in which to lay their eggs. One egg is laid per pit. Once the egg hatches, the larva tunnels within the host plant's tissue causing instant economic damage in the marketable sweetpotato. Pupation then occurs within these tunnels. Adults emerge and begin feeding on the host plant's leaves, leaf petioles and stems.

According to Pinese (2001) *C. formicarius* has a wide host range including relatively common wild hosts that are botanically related to the commercial sweetpotato. Alternate plant hosts in Australia include: *Ipomoea polpha, I. aquatica, I. pes-caprae, I. saintronaensis, I. cairica, I. nil, I. angulata, Meremia quinata, Pachyrhizus* spp. Pinese (2001) suggests that while wild hosts for *C. formicarius* increase the risk of migration of weevils into commercial crops, migration from within cultivated crops, particularly of sweetpotato left on top of the ground after harvest, is a more significant threat.

Kumar (1992) mentioned that the sweetpotato *I. batatas* is the primary host of sweetpotato weevil. Its other host plants include maize, several *Ipomoea* spp. and wild species of Convolvulaceae.

Sutherland (1984) reported that a preliminary study of wild hosts was made and three species of *Ipomoea* are wide spread in PNG. Of these only *Ipomoea congesta* has been found to support breeding populations of the weevil. Because the cultivation of the sweetpotato is so abundant, wild host plants are unlikely to be a significant factor in the spread and infestation of *C. formicarius*.

Damage to tubers can reach up to 90% (Sutherland 1985) and relatively minor damage can both reduce yield and render infested tubers unmarketable due to the presence of feeding marks and oviposition holes. Weevil-infested tubers emit offensive odours due to the presence of terpenes[13] produced as a result of insect feeding. Tuber shrinkage also occurs due to the loss of water through feeding or oviposition cavities made by the weevils. The main damage is due to larval feeding inside the edible tubers, but yield losses also occur due to adults and larvae feeding on the vines (Sutherland 1985). Despite the considerable importance of sweetpotato to the subsistence economy of PNG, there are few published studies that examine the interactions of sweetpotato weevil with sweetpotato, its primary host. Kurika (1982) reported yield losses at Keravat of up to 40% in some varieties. All selected varieties are susceptible, but with some degree of tolerance. Most recorded less than 10% losses. Masamdu and Solulu (1988) reported that weevil infestations in the Gumine District of Chimbu province ranged from 1% to 78%. This variation was due to the age of plants and cropping intensity

Adult flight

Adults are active fliers and are usually noticed in the field when storage root formation begins (Kumar 1992). Moriya and Hiroyoshi (1998) found that males had greater flight ability than females of the same age, their locomotion was higher for males than females, and females seemed to disperse mainly by walking because of their extremely low flight ability.

Pheromone trapping trials undertaken by Pinese (2001) in north Queensland attracted significant numbers of adult weevils at certain times of the year from distances of 10 km from the nearest sweetpotato crop, which suggests either high levels of mobility or the presence of the pest in other host plants in the north Queensland environment. When determining the required buffer zone for an eradication program for *C. formicarius* in Japan, Miyatake *et al.* (1997) found that the maximum dispersal distance for male weevils was two kilometres. It was concluded that a buffer zone of 2 to 4 km should surround an eradication area.

According to Sar (2006) peak flights of *C. formicarius* in the lowlands of Papua New Guinea were significantly positively correlated to before or soon after periods of heavy rain and when evenings were warm and calm (wet season). Flights were negatively correlated with the number of windy days, typically occurring during the dry season when strong south-easterly winds are blowing. These flight patterns are not in response to changes in the population of *C. formicarius* as Sar (2006) states that the weevil population increases during the dry season and are abundant enough that if weevils were flying they would likely have been trapped. Miyatake *et al.* (2000) also found that the flight distance of sweetpotato weevils in the field in Japan was influenced by the climate, mainly temperature. Mean dispersal distances of released males increased with temperature. In general, this data suggests male sweetpotato weevils are more active in warm seasons.

[13] Unsaturated hydrocarbons found in the essential oils of plants

Control

Australia

Current practice in the Australian sweetpotato industry for control of sweetpotato weevil is a monthly spray application of bifenthrin or chlorpyrifos once adults are detected in the crop. Pinese (2001) assessed six insecticides in the field, recording sweetpotato yield (kg/plot); proportion of roots undamaged; rated damage on individual roots; the number of infected crowns and the number of adult weevils in crowns. Bifenthrin was the most effective at controlling the sweetpotato weevil, out performing all other insecticides. The insecticides trialled and rates applied included:

- bifenthrin (Talstar®) – 60 mL/100L
- fipronil (Regent®) – 37.5 mL/100L
- chlorpyrifos (Lorsban™) – 200 mL/100L
- fenthion (Lebaycid®) – 100 mL/100L
- carbaryl (Carbaryl®) – 200 mL/100L

Australian growers previously relied on carbaryl but reported poor efficacy in the field. Pinese (2001) confirmed this when it was found it provided an inferior kill when compared with bifenthrin, fipronil and chlorpyrifos. Fenthion (Lebaycid®) also provided an inferior kill to bifenthrin, fipronil and chlorpyrifos.

Coleman (pers. comm. 2006) suggests that as phorate is taken up into the plant (systemically) it has a benefit on decreasing the attack from sweetpotato weevil especially during the early stages of a crop's development.

PNG

Smee (1965) describes both the life cycle and the cultural control methods for the weevil, as does Sutherland (1983). The latter recommends the use of a DDT dip, which has since been shown to be ineffective. Kimber (1973) also mentions the life cycle and damage caused by the weevil and suggests the standard cultural control methods plus the 0.4% DDT dip.

Sutherland (1984) reported that since 1980 there have been six trials to evaluate insecticides for the control of *C. formicarius* in PNG. A total of 14 insecticides have been tested: acephate, aldicarb, carbaryl, carbofuran, DDT, diazinon, fenthion, fenitrothion, formothion, gamma HCH (lindane), malathion, trichlorfon, pirimiphos ethyl and CGA 73102 (soil insecticide).

All assessments used conventional high volume foliar sprays, and some soil treatments and one vine dip were evaluated. None of the insecticides evaluated provided clear-cut and consistent control of the weevil from initial trials conducted at Bubia and Laloki. Sutherland (1985) recommended that from trials conducted at Bubia sweetpotato weevil could be controlled using fenthion (as Lebacid® 55) or formothion (as Anthio® 33). Fenthion was considered to be more effective. In addition, the Bubia trials have shown an experimental soil insecticide and DDT dip to be ineffective.

When using non-motorized sprayers, the leaves of the sweetpotato should be sprayed until they are wet and the spray is just beginning to run-off them. The spray should be applied every 14 days, commencing 14 days after planting. For use of non-motorized sprayer, 0.1% fenthion or 0.2% formothion are recommended. Mean total yields of 28.67 t/ha on treated plots compared to 5.73 t/ha on untreated plots have been measured.

These trials have also quantified the relationship between vine and foliage populations of the weevil, and damage to the storage roots. Sutherland (1984) mentioned a strong positive correlation existed between weevil numbers on the surface foliage and storage root damage, and similarly between populations in vines and storage root damage. There was a strong correlation between surface foliage and vine populations of the weevil. Kumar (1992) reported that there are a number of effective chemicals available for weevil control. Dipping planting material in gamma-BHC or malathion is effective. Drenching soil fortnightly with 0.1% gamma-BHC is quite effective.

Entomopathogenic fungi

Jansson (1992) reports that the fungal pathogens that attack *C. formicarius* include:

- *Beauveria bassiana*
- *Metarhizium anisopliae*

The predominant fungus isolated from or tested against sweetpotato weevil is *B. bassiana* (Jansson 1992). Jansson (1992) reports that the fungus has been isolated from *C. formicarius* in the United States, Hawaii, Cuba, and Taiwan. On the International Potato Centre website (http://www.cipotato.org) it mentions the potential for the *B. bassiana* to control sweetpotato weevil and its success in Cuba for controlling the weevil. *B. bassiana* is a fungus that grows naturally in soils throughout the world and causes disease in various insects by acting as a parasite.

Although common in soils, Jansson (1992) states that large populations of the fungi are required to achieve effective population suppression. According to Jansson (1992) the population level in the soil environment needs to be at an epizootic or epidemic level to suppress weevil populations. This requires the host and the pathogen to be present in sufficient densities and the environmental conditions to be favourable. The favourable environmental conditions for *B. bassiana* were not listed by Jansson (1992), but *B. bassiana* densities of 0, 100 and 1000 conidia per gram of soil resulted in 0, 30 and 100% *C. formicarius* mortality respectively in Taiwan.

Laboratory assays found superior infectivity of sweetpotato weevil by *B. bassiana* conidia when applied in a corn oil formulation, than when applied as a conidia only formulation (Yasuda *et al.* 2000). Currently experiments are being conducted to assess the efficacy of *B. bassiana* on *C. formicarius* in Indonesia (E. Coleman pers. comm. 2006). An internet search found that the *B. bassiana* is already sold commercially in America and Europe as Botanigard® ES and Mycotrol® O.

Predatory ants

Jansson (1992) lists three ants which are predators of sweetpotato weevil:

- Argentine ant (*Iridomyrmex humilis*) in Louisiana, USA
- *Tetramorium* sp. in the Philippines
- big headed ant (*Pheidole megacephala*) in Cuba.

The big headed ant was reported to be more effective than chemical insecticides at managing weevil populations in Cuba (Jansson 1992). Some ants (*Pheidole* sp.) have been observed in PNG removing larvae from infested vines, but this is not considered a significant control influence (Sutherland 1984).

Wasps

Jansson (1992) reports that there are 15 wasp parasitoids of sweetpotato weevil, but states there is limited information on how effective they actually are at suppressing weevil populations and suggests extensive studies on these parasitoids should be undertaken in India as this is where *C. formicarius* originated from.

Entomopathogenic nematodes

Research in Florida, U.S.A. has demonstrated efficacy of entomopathogenic nematodes against sweetpotato weevil in the field, the most effective strain of nematode being *Heterorhabditis* (Georgis *et al.* 2006). Jansson *et al.* (1991) found nematodes to be more effective than chemical insecticides (methamidophos and endosulfan) at reducing weevil densities. Adoption of these nematodes to control sweetpotato weevil by growers in the Australian sweetpotato industry has not occurred.

Georgis *et al.* (2006) suggest the limited adoption of nematodes in comparison with broad spectrum insecticides can be attributed to product cost, poor or inconsistent efficacy, refrigeration requirements for most formulations, sub-optimal nematode species being used and lack of detailed information on how to use them effectively.

Major factors which need to be considered when applying nematodes to control sweetpotato weevil include:

- moisture. Irrigation enhances persistence
- thatch depth. This determines depth to which nematodes need to reach to be effective
- soil type. Movement of nematodes decreases with an increase in the proportion of clay in the soil
- seasonal temperature. Nematodes do not like extremes in temperature
- nematode strain. Certain strains are used for highly mobile soil insects while others are better suited to less mobile insects (sweetpotato weevil larvae)
- nematode application method
- production and storage of the product.

Cultural controls

Pinese (2001) recommends that good cultural control methods should include:

- using runners from a non-infested area to establish a new crop. If uncertain spray twice at two week intervals before harvesting runners for planting
- harvesting crop as soon as possible
- destroying crop residues promptly by discing and/or rotary hoeing
- avoiding continuous cropping.

Kimber (1973), Sutherland (1984) and Kumar (1992) mentioned that the cultural control methods most effective for non-chemical control include:

- clean fields after harvest. Old vines, left over storage roots and alternate hosts (e.g. related plants of the family Convolvulaceae) should be destroyed
- crop rotations
- use of clean planting material
- prompt harvesting or use of early maturing varieties
- planting on light soils which do not crack when dry, allowing weevil access
- re-covering storage roots with soil exposed by heavy rain
- using varieties that form storage roots deep under ground or varieties with long necks between the tubers and the stem.. These are less likely to be attacked by weevil, or are less affected because the weevil cannot burrow more than 1 cm, respectively.

Pinese (2001) states that the most significant contributor of weevil infestation in existing crops is due to the large population increases occurring in commercial sweetpotato blocks after harvest. Regular trapping by Pinese (2001) within commercial crops showed that populations of sweetpotato weevil increased dramatically after harvest. This is most likely due to the large amount of roots that are left exposed to weevil attack on the soil surface after harvest.

Increasing or retaining the layer of soil above the developing sweetpotato root is a tactic used to prevent sweetpotato weevil feeding and depositing eggs into the marketable storage root. Such strategies include hilling up to increase/maintain a layer of soil above storage roots, irrigation to ensure soil does not crack open and expose developing roots, or deep planting to decrease the chances of hills slumping or cracking open and exposing storage roots. According to Pinese (2001) hilling up was not an effective form of control as it was only possible to hill up before runner growth covered-in hills.

Other controls

CAB International (2004) in its 2nd revision of the global distribution of *C. formicarius* states that established populations of the sweetpotato weevil have been successfully eradicated in the southern most parts of Japan (UK 2004). Moriya and Miyatake (2001) and Setokuchi *et al.* (2001) report that such eradication programmes involved the use of the sterile insect technique (SIT). Setokuchi *et al.* (2001) reported that on Kiyamajima, a 35 ha island off the coast of Japan, that the SIT was successful because it controlled the release of sterile males over time. Males are sterilised by exposing them to high levels of irradiation. To reduce the wild population in the release zone to zero, 16,000 sterile weevils were required to be released every 10 days for a period of 14 months (Setokuchi *et al.* 2001). Pheromone lures were used to monitor weevil populations over a year following the final release of sterile males (Setokuchi *et al.* 2001).

Insect pest monitoring

Pheromone traps

Pheromones are and have been used to successfully attract male sweetpotato weevils in Japan (Setokuchi *et al.* 2001; Yasuda *et al*. 2004), America (Jansson 1992) and Australia (Pinese 2001). Pinese (2001) successfully undertook seasonal population studies in north Queensland and southern Queensland (Australia) using rubber septa lures. The lures were each baited with one milligram of the male pheromone (Z)-3-dodecenyl (E)-2-butenoate and placed in a simple funnel trap (Pinese, 2001). Pheromone traps sometimes include an insecticide to insure a better insect kill. Yasuda *et al.* (2004) describe a pheromone formulation with insecticide, with visual stimulation, for controlling sweetpotato weevil. The formulation combines the sex pheromone (Z)-3-dodecenyl (E)-2-butenoate, and an insecticide (MEP) impregnated into a blue ball (2 mm in diameter) made of diatomaceous soil. Yasuda *et al.* (2004) state that the male weevils were attracted to the visual stimulation in addition to the pheromone and would attempt to mate with the ball. Formulations combining the fungus *B. bassiana* and the pheromone also successfully attracted male weevils, which then become infected with the disease and on returning to the field continue to spread the disease to female weevils.

Sticky traps

The flight activity of sweetpotato weevil has also been successfully monitored using yellow sticky traps in PNG (Sar 2006). The sticky traps consisted of empty vegetable or fruit cans supported and positioned by a 1.2 m wooden post. Cans were wrapped with Tanglefoot 'stickum' (The Tanglefoot Company, Grand Rapids, Michigan, USA).

Main points

- **Sweetpotato left on the surface after harvest cause large population increases.**
- **Sweetpotato weevil cannot burrow deeply into the soil.**
- **The male pheromone (Z)-3-dodecenyl (E)-2-butenoate is a strong attractant for sweetpotato weevil.**

Resistant cultivars

In Australia the most important commercial sweetpotato cultivar is Beauregard, which has a brown to pink skin and orange flesh. Beauregard accounts for 90 to 95% of the sweetpotato market in Australia (J. Maltby pers. comm. 2006). Beauregard is classed as a susceptible cultivar to sweetpotato weevil attack.

Pinese (2001) reviewed 16 sweetpotato cultivars currently in Australia for their susceptibility to sweetpotato weevil damage, concluding that flesh colour is the most reliable indicator for determining sweetpotato weevil resistance, with orange fleshed cultivars generally being more susceptible than white fleshed cultivars. Currently white fleshed cultivars only account for approximately 5% of the sweetpotato market in Australia and have significantly poorer agronomic and consumer characteristics in comparison to Beauregard. Pinese (2001) found one orange fleshed cultivar (L93-93Q9) displayed higher levels of resistance than the other 10 orange fleshed cultivars tested. Again, this cultivar has significantly poorer agronomic characteristics in comparison to Beauregard.

Svent-Ivany (1956) recorded large areas of sweetpotato weevil attack at Wau (Morobe Province) PNG noting that there were differences between red and white skinned varieties and in the same year he claims a red skinned variety was 100% resistant.

One trial was conducted at Kuk (PNG) to investigate the effect of the trypsin content of sweetpotatoes on breeding and feeding activities of the weevil (report not sighted). Kurika (1982) reported that preliminary observations suggest that cultivar characteristics may have influenced the incidence of weevils and degree of damage to sweetpotato storage roots. All selected varieties exhibited some degree of tolerance. Lutulele (2000) reported that none of the 441 PNG varieties has demonstrated any degree of resistance to sweetpotato weevil.

Resistance factors: Individual factors resulting in cultivar resistance to sweetpotato weevil damage is poorly understood. Research has been undertaken to explore individual factors such as dry matter content, periderm resin content levels, nutrient availability etc., but research continually concludes that genotype is the only reliable factor for determining insect resistance (Harrison *et al.* 2006; Harrison *et al.* 2003; Mao *et al.* 2003).

Breeding programs: The United States of America has a considerable sweetpotato breeding program and believes it has developed a cultivar 'Ruddy' (Image 1.04), with consumer and agronomic characteristics similar to that of Beauregard as well as having resistance to sweetpotato weevil attack. Grown under South Carolina conditions Bohac *et al.* (2002) describe 'Ruddy' as having attractive red skin and medium orange flesh colouring. Storage root shape is uniform and per plant production is greater than Beauregard. 'Ruddy' is also resistant to cracking, a common characteristic with many red skinned varieties.

Other soil insect pests

Introduction

Sweetpotato growers have reported a range of soil insect pests that cause sporadic damage to sweetpotato crops in Australia. These include and are not limited to scarab beetles such as African black beetle (*Heteronychus arator*) and black beetle (*Metanastes vulgivagus)* and cane grubs (several genera), and whitefringed weevil (*Naupactus leucoloma*). These pests are also listed as pests of sugarcane (Agnew 1997) and potato (Horne *et al.* 2002). The listed pests are mostly controlled by incorporating insecticide into the furrow (sugarcane) or hill (potato) either at planting or just prior to planting. Insecticides registered for such uses include chlorpyrifos, fipronil, imidicloprid, phorate and bifenthrin. Labels must be checked for specific crop registrations and application rates/methods. Cultural control methods for these pests commonly include deep ploughing to expose larvae to heat and predators, weedless fallows, planting non-preferred food source crops and restricting planting to periods of low insect activity.

Black beetles

According to Agnew (1997) there are two types of these beetles that damage sugarcane:

- African black beetle: *Heteronychus arator*
- Black beetle: *Metanastes vulgivagus*

Horne *et al.* (2002) lists African black beetle as a pest of potato, occurring from Maryborough south. Black beetle is a native insect and occurs in all cane growing areas (Agnew 1997). These pests commonly inhabit native grasslands or old pasture country (Agnew 1997).

Agnew (1997) suggests that both species have a one year life cycle. The adult beetles mostly emerge mid summer until the end of autumn. Adults then rest during winter, becoming very active again in spring, when they cause damage to cane and lay eggs from early September to February. Eggs of both species are laid singly in the soil and hatch in about 2-4 weeks depending on temperature. Both species then go through three larval growth stages which take about three months in total, with the pupal stage lasting two weeks. Over the spring-autumn period there is usually a range of insects at different growth stages present at the one time. Larvae feed mainly on organic matter in the soil while older larvae prefer grass roots.

Cane grubs

Cane grubs are reported to damage sweetpotato storage roots in Northern NSW and Bundaberg growing regions. There are many different types (species) of cane grub. Agnew (1997) lists and describes 19 species of cane grub that cause major economic damage to sugarcane. The grubs can be identified by looking at the hair pattern at its tail end or raster. Variation in the number of rows of hairs per line and the hairline shape are important for telling the different grub types apart (Agnew 1997).

Cane grubs can be classified into either one year lifecycle grubs (Table 1.04) or two year lifecycle grubs (Table 1.05). Agnew (1997) describes the typical one year cane grub lifecycle in Table 1.04.

Table 1.04: Summary of the one-year cane grub lifecycle (Agnew (1997)).

Month	**Stage description**
Dec – Jan	First stage (small) larvae hatch and feed on organic matter.
Jan – Feb	Second stage (medium) larvae feed on organic matter and some roots.
Feb – May	Third stage (large) larvae feed on roots. Cane turns yellow, lodges.
June – Aug	third stage (large) larvae burrow down 35 cm in the soil and form cells.
Sept – Oct	Third stage (large) larvae pupate and transform to beetles.
Nov – Dec	Beetles emerge with first soaking rains, fly to feed on surrounding trees, mate and return to soil to lay eggs.

Table 1.05: Summary of the two year cane grub lifecycle (Agnew (1997)).

Month	**Stage description**
Jan – Feb	First stage (small) larvae hatch and feed on organic matter
Mar – April	First stage (small) larvae moult to second stage which feeds on organic matter and a few roots.
May – Sept	Second stage (medium) larvae descend to moist sub-soil, 45-60 cm deep, form a chamber and hibernate (over winter). In September they moult to third stage.
Oct – April	When warm days return, the third stage (large) larvae come up to feed on the roots of young plants and ratoons so that the cane turns yellow and wilts. Fully fed larvae remain in the upper soil layers.
May – Sept	Third stage (large) larvae burrow down again 45 – 60 cm to overwinter.
Sept – Oct	Third stage (large) larvae pupate and transform to beetles.
Nov – Dec	Beetles emerge with the first heavy rains, mate, fly to feed on surrounding trees (some species do not feed as adults) and return to the soil to lay eggs.

Weather greatly affects cane grub numbers from year to year (Agnew 1997). Agnew (1997) states that heavy showers cause beetles to emerge and lay eggs. If prolonged hot dry conditions follow, beetles may be killed while feeding on surrounding trees, and eggs and young larvae may dry out in the hot dry soil. Irrigation as practiced in the Burdekin and Bundaberg cane growing areas probably reduces these effects.

An alternative to soil incorporated insecticides for controlling cane grub is to incorporate BioCane^{TM}. BioCane^{TM} contains a strain of *Metarhizium anisopliae* which is commercially cultured and encapsulated. *Metarhizium* strains are quite specific between species and so it is important to know the strain used in the product and the species of the cane grub targeted (L. Robertson pers. comm. 2006).

Whitefringed weevil

Whitefringed weevils are reported to damage sweetpotato storage roots in many commercial growing regions. According to Horne *et al.* (2002) whitefringed weevil cause economic damage to potato tubers, in all states of Australia. Agnew (1997) lists whitefringed weevil as a pest of sugarcane and states that they are present in all cane growing areas.

Adult beetles grow to about 13 mm long, and are grey with white stripes down their sides. The larvae are responsible for the economic damage to potatoes and sweetpotatoes. The larvae burrow into the tubers/storage roots, leaving round holes or a channel shaped scar tracking along the storage root. Agnew (1997) reports that larvae of the weevil cause major economic damage to cane when they feed on the roots of germinating setts of ratoons, causing the plant to die or become very weak. The larvae are short, fat, legless and grow to 15 mm long. They are white with pale yellow heads and black mouthparts (Agnew 1997).

Agnew (1997) describes the life cycle of whitefringed weevil. Adults are present throughout summer and autumn. Eggs are laid during this period in batches of 12 – 60 attached to plant stems, dead leaves or stones. Each female can lay up to 1500 eggs. Eggs hatch in 2-4 weeks in summer and autumn. Larvae then take up to three months to develop, depending on food supply. Adults emerge from their pupal chamber after rain and walk to nearby crops as they are unable to fly. Adults lay more eggs and grubs grow faster and survive better when feeding on legumes rather than grasses. Agnew (1997) also notes that all whitefringed weevils in Australia are females.

Agnew (1997) states that major whitefringed weevil damage often follows legume cover crops or fallows with large numbers of legume weeds.

Nematodes

Although not insects, nematodes are soil dwelling and are a major concern for sweetpotato growers in Australia. Root-knot nematodes (*Meloidogyne arenaria, M. incognita M. javanica and M. hapla*) make up 98% of the root-knot nematodes found in Australia. *M. javanica* is by far the most common species in northern Australia and in southern Australia where there are hot summers (Stirling *et al.* 1996). Those crops that are susceptible to root-knot nematodes include:

- vegetables: beans (mung, french, navy), beetroot, capsicum, carrot, celery, cucurbits (cucumber, melon and pumpkin), eggplant, lettuce, okra, onion, potato, sweetpotato and tomato
- tree and vine fruits: almond, grape, kiwifruit, nectarine, passionfruit, papaw, peach and plum
- other horticultural crops: banana, ginger, pineapple, strawberry
- field crops: aloe vera, clover, cowpea, kenaf, lucerne, lupin, pigeon pea, peanut, soybean, sugar cane, tea, tobacco
- ornamentals: carnation, Chrysanthemum, Dahlia, gerbera, gladioli, Protea, rose.

Currently the nematicide Nemacur® is used to control nematodes in a range of crops. Products such as Nemacur® are being reviewed and are considered old chemistry with little chance of the industry maintaining their registration into the future.

The research of Stirling *et al.* (1996) suggests that rotation with non-host crops can reduce if not eliminate the need for nematicides. Stirling *et al.* (1996) went on to detail a range of cover crops and their resistance to nematodes. These cover crops reduce nematode population as they are not a food source, but they also increase organic matter levels resulting in a build up of entomopathogenic fungi and predatory nematodes. There appear to be large differences in affinity of various root-knot nematode species for different varieties within cover crops. For example the forage sorghum cultivar Speed Feed is slightly susceptible to *M. javanica* while Betta Dan is highly resistant. A list of preferred cultivars taken from Stirling *et al.* (1996) is shown in the Table 1.06.

Table 1.06. *M. javanica*. resistance based on Stirling *et al.* (1996)

Common name	Botanical name	Accessions (varieties)	*M. javanica*. resistance
Grain sorghum	*Sorghum bicolor*	840F	R
		Hylan A7606	HR
		Hylan Hunnicut	HR
		Sugargraze	R
Forage sorghum	*Sorghum bicolour × sudanense*	Jumbo	SS
		Betta Dan	HR
		Cow pow	R
		G93A010	HR
		Hylan 27900	R
		Hylan LB905	R
		Hylan LC900	R
		Hylan lush	HR
		Nectar	R
		Super Chow	R
Sudan grass	*Sorghum sudanense*	Superdan	HR

Highly resistant (HR) and Resistant (R) Virtually no nematode reproduction occurs on these crops. If a highly resistant or resistant crop is grown, there will be no more root-knot nematodes present at the end of the crop than when it was planted.

Slightly susceptible (SS) Limited nematode reproduction occurs on these crops. Such crops usually provide adequate nematode control. However, if an intolerant crop (i.e. sweetpotato) is planted immediately after a crop with an SS rating, nematode population densities may be high enough to cause damage.

Soil applied insecticides

Mobility in soil

Due to the long growing time for sweetpotato, the relatively short active period of current soil incorporated insecticides, and the ability of some soil insect pests to move vertically in the soil profile, growers are often required to re-apply soil insecticides to maintain a barrier that prevents larvae entering the sweetpotato root zone. Having to re-establish a protective barrier means insecticides need to move through the soil i.e. a sweetpotato hill that is approximately 300 to 400 mm high and 1 to 1.5 m across at the base. Chlorpyrifos is one insecticide used to establish this barrier. The major limitation with chlorpyrifos achieving such a barrier is its low mobility due to a strong attraction to soil particles (sorption).

It is well accepted that organic matter and clay minerals are the principal soil constituents involved in pesticide sorption (Kookana *et al.* 1995). Kookana *et al.* (1995) found that on a sandy soil in Western Australia chlorpyrifos did not move deeper then 5 cm within 148 days after being applied to the soil surface and spray irrigated frequently. Pyrethroid insecticides (like bifenthrin) also have a high affinity for soil and low mobility in the soil environment (Laskowski 2002). If larvae have survived below the zone previously treated by the soil incorporated insecticide, it is highly unlikely that by applying chlorpyrifos or bifenthrin through pressurised spray equipment and then watering it in, that it will effectively establish a deep barrier to stop soil insects entering from below the root zone.

Chemical stability

Literature published by Baskaran *et al.* (1999) and Laskowski (2002) suggests that bifenthrin is a more stable chemical in the soil environment then chlorpyrifos. Bifenthrin has been shown to provide adequate crop protection up until commercial harvest for sweetpotato crops in Northern NSW where chlorpyrifos was only able to provide protection up to 65 days after planting (Rochecouste 2003). Laskowski (2002) states that pyrethroid's half life in soils ranges from 3 – 96 days under aerobic conditions.

Degradation processes affecting the efficacy of insecticides

The effectiveness of an insecticide is reduced by a range of factors including its natural breakdown or half-life, efficiency of application and resistance in the target population.

The half life is the period of time that it takes for the chemical concentration in an environment to reduce by exactly a half. Factors that influence the rate of this reduction include:

- volatilisation - the loss of pesticide from plant or soil or water surfaces in the form of vapours (Kookana *et al.* 1998)
- photolysis - the transformation of pesticides due to their exposure to radiation (Kookana *et al.* 1998)
- runoff
- plant uptake
- sorption by soil and organic matter

- leaching
- chemical transformation or biodegradation.

Australian sweetpotato growers commonly find that they are achieving poor soil insect control when weather conditions are hot and dry. Kookana *et al.* (1998) reported that during hot dry weather, half of the endosulfan applied to dry soil was lost to volatilisation, but this did not occur when the pesticide was applied under cooler conditions. Racke *et al.* (1996) reported that chlorpyrifos loss was greatly enhanced under low soil moisture conditions. The method and time of application will therefore have a strong influence on the effectiveness of an insecticide being used to control soil insects. Kookana *et al.* (1998) state that volatilisation losses of soil applied pesticides are different to the foliar applied ones, and similarly the pesticides incorporated in soil will show much lower volatilisation losses than the surface applied ones, concluding that the extent of volatilisation loss is affected by the sorption affinity of the pesticide to soil and its location in the soil profile. Applying chlorpyrifos through a linear move overhead irrigation machine is one method useful in overcoming dry and hot soil environments. Chalfant *et al.* (1993) found that granulated chlorpyrifos was not able to adequately control wireworm when incorporated into hot and dry soil, while chlorpyrifos applied through the irrigation machine achieved better wireworm control in sweetpotato plots in Georgia, U.S.A.

Soil pH and the soils micro-organism population also play important roles in influencing the rate at which soil insecticides are broken down. Kookana *et al.* (1998) state that agronomic management practices such as liming and fertilisation can result in relatively abrupt changes in soil pH and consequently affect the behaviour of pesticides applied to soils. The postulated critical value above which soil pH reduces the activity of chlorpyrifos is 6.2 (K. Chandler pers comm. 2006). Soil amendments with limestone at 5 t/ha prior to planting sugarcane resulted in reduced capacity of granulated chlorpyrifos to control cane grub as soil pH was raised above 6.2 (K. Chandler pers. comm. 2006). Soil amendments with magnesium oxide and pulverised dolomite have also reduced chlorpyrifos effectiveness (K. Chandler pers. comm. 2006). According to Laskowski (2002) bifenthrin is stable at neutral soil pH or above.

Soil micro-organisms are able to develop adaptive mechanisms that increase their ability to degrade soil incorporated insecticides (Suett *et al.* 1996). The initiation, stability and activity of such microbes is influenced by many factors, but the primary determinative factor is always prior application of a specific pesticide of a closely related structure (Suett *et al.* 1996), especially within a 6 to12 month time period (K. Chandler pers. comm. 2006). This means that regular application of insecticides with similar chemistry will result in more rapid breakdown by microbes. Soil pH can also have an indirect effect on the adaptive behaviour of soil micro-organisms (Suett *et al*. 1996). Microbial diversity is greatly influenced by pH, with even small changes inducing significant fluctuations in the composition and activity of the microbial community (Suet *et al*. 1996).

Future pesticide outlook

Currently in America and many other countries all of the organophosphate and carbamate chemicals are targeted for cancellation under food protection legislation (Kuhar *et al.* 2003), with chlorpyrifos already being cancelled for use on potatoes to control wireworms in the U.S. (Kuhar *et al.* 2003).

There is a general trend around the world where older chemistry from group 1B products (i.e. chlorpyrifos, phorate) are not being supported in chemical reviews or future registration work. If industry is reliant on these chemicals, the search for new chemistry is even more important (E. Coleman pers. comm., 2006).

Main points

- **Dry soil reduces effectiveness of soil applied insecticide.**
- **Continual use of insecticides from the same chemical group speeds up bio-degradation, therefore rotation of chemical groups is important.**

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Chapter 2: Improved IPM systems for wireworm in Australian sweetpotato production systems

Introduction

Shotgun is the name used by Australian sweetpotato growers for the random scattering of small holes found on sweetpotato storage roots caused by wireworm feeding. Even though these holes may be quite shallow, as few as three holes can make a sweetpotato unmarketable. Crop losses from wireworm feeding of 100 % are annually reported by Australian sweetpotato growers.

Wireworms are the soil dwelling larval stage of the Coleopteran families Tenebrionidae (ground beetle) and Elateridae (click beetle). Soil insect pests in the family Tenebrionidae are *Gonocephalum* spp. and *Pterohelaeus* spp., commonly known as false wireworms.

Soil insect pests in the family Elateridae include *Agrypnus* spp., *Conoderus* spp., *Heteroderes* spp., *Dicteniophorus* spp. and *Hapatesus* spp. Elateridae are commonly referred to as click beetles[14] or true wireworms[15]. Samson and Calder (2003) sampled and identified five named and 21 unnamed species from five genera of true wireworm in established can fields in north, central and southern Queensland and Northern New South Wales.

Wireworms feed on both living and decomposing organic matter. Some wireworm species are omnivorous and can predate other soil dwelling larvae species. The lifecycle of wireworms varies greatly between species, taking one year with four instars for sugarcane wireworm, *A. variabilis*, to complete its lifecycle (Agnew 1997) and approximately four years with 10 larval instars for the potato wireworm, *H. hirtus* (Horne and Horne 1991).

In conventional sweetpotato production systems wireworms have historically been controlled by applying a preventative insecticide which is soil incorporated prior to planting because the economic consequences of wireworm damage are great and there is no strategy that can predict fields at risk.

At the start of the research project the only insecticides permitted for use soil incorporated on sweetpotato to control wireworm were the organophosphate phorate and the phenyl pyrazole fipronil. Phorate and fipronil are reported to not be working effectively to control wireworm in sweetpotato production systems. In a 2006 survey of Australian sweetpotato growers it was reported that the combined soil incorporated usage of bifenthrin, chlorpyrifos and phorate prior to planting was the only strategy successfully controlling wireworm feeding injury to sweetpotato crops.

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[14] The term click beetle is often used to refer to the adult form of true wireworm i.e. from the Elateridae family

[15] The term wireworm is often used as a substitute for larvae from the family Elateridae

While these methods were preventing wireworm injury to crops, the industry identified a number of factors putting current practices at risk into the future. These included:

- lack of efficacy and residue data for chlorpyrifos soil incorporated prior to planting for wireworm control in sweetpotato
- no minor use permit or label registration for chlorpyrifos soil incorporated prior to planting for sweetpotato
- lack of efficacy and residue data on bifenthrin soil incorporated prior to planting on wireworm in sweetpotato
- no minor use permit or label registration for bifenthrin soil incorporated prior to planting for sweetpotato
- lack of efficacy and residue data on phorate or fipronil soil incorporated prior to planting on wireworm in sweetpotato
- no strategy available that can predict fields at risk prior to planting.

The research was designed to help provide industry with sound management options for control of wireworm in the sweetpotato cropping system into the future. Project activities between 2007 and 2010 have included:

- developing a strategy that can predict fields at risk prior to planting
- efficacy and residue trials on chlorpyrifos and bifenthrin
- efficacy trials into alternative chemistry and delivery strategies of insecticide for wireworm control
- importation and field assessment of tolerant sweetpotato varieties.

Major project results and findings

Major results and findings of the project include:

- Minor use permit (PER 5851., Exp 12 Feb 2012) was obtained for chlorpyrifos soil incorporated prior to planting.
- Minor use permit (PER 9722, Exp 30 Sept 2013) was obtained for bifenthrin soil incorporated prior to planting.
- Label registration of fipronil for soil incorporated prior to planting was obtained.
- Soil incorporated insecticides are only consistently providing approximately 100 days crop protection from wireworm feeding injury.
- Phorate provided the least duration of crop protection.
- Bifenthrin provided the longest duration of crop protection.
- Soil incorporated insecticides are only working to repel wireworm out of the root zone. This is a major concern as sweetpotato has a crop development period greater than 140 days.
- A significantly reduced rate of fipronil applied once through the drip irrigation system provides effective control of wireworm feeding injury in comparison to the ineffective application of fipronil soil incorporated prior to planting. This result is pivotal for changing agro-chemical usage in the sweetpotato cropping system for wireworm control.
- Thiamethoxam soil incorporated prior to planting was not effective at preventing wireworm feeding injury to sweetpotato out to commercial harvest but did provide protection in a Bundaberg trial up to 100 days after planting.

- Even the presence of low numbers of wireworms in blocks detected using a sweetpotato baiting technique prior to planting resulted in unacceptable levels of wireworm feeding injury to sweetpotato at commercial harvest.
- While the common crop rotation of Sudan grass (Sorghum) is likely to contribute to wireworm populations in blocks, damaging populations of wireworm are not subsequently controlled by bare fallow ground management over an 18 month period.

Recommendations

The following actions are recommended:

- The over dependence and use of bifenthrin in the cropping system should be reduced.
- Strategies to replace using large concentrations of agri-chemicals soil incorporated prior to planting with strategic applications of reduced rates of agri-chemicals during the crops development should be developed.
- Further efficacy and residue trials on fipronil applied through the drip tape should be undertaken.
- A strategy that reduces large damaging populations of wireworm prior to planting should be developed. This strategy needs to be considered in relation to the break crop, Jumbo sorghum. Efficacy trials on insecticide coated Jumbo sorghum should be conducted.
- Efficacy trials on the drip application of thiamethoxam and chlorantraniliprole against wireworm in the sweetpotato cropping system should be done.

Conclusions

The Australian sweetpotato industry needs to develop strategies into its farming system that reduce populations of wireworms outside of commercially grown crops. As a result this will:

i) reduce dependence on agri-chemicals in the commercial production system
ii) provide the incentive to attract increasing agri-chemical investment into the crop
iii) help secure the sweetpotato industry as clean and green in the heavily regulated Australian horticultural production environment, and sweetpotatoes as clean and green in the ever fickle domestic marketplace.

Report on the efficacy of soil incorporated insecticides applied prior to planting against wireworm in Bundaberg Queensland

Long growing season 240 days

Introduction

The aim of the experiment reported was to test the efficacy of four insecticides, soil incorporated prior to planting, against the groups of wireworms commonly referred to as true and false wireworm on the sweetpotato variety Beauregard.

This field experiment was conducted on the QLD DEEDI Bundaberg Research Station. The field experiment was conducted on a red volcanic soil from March 2007 to November 2007. This is considered the longest growing period for sweetpotato in the Australian production system.

Materials and methods

The Bundaberg field experiment was a randomised block design with six treatments and six replicates (Table 2.01). Plots were three rows wide by 12 m long. The middle row was the datum row and either side was a buffer row.

The trial site was sampled for wireworm prior to planting to estimate the potential wireworm population. This was achieved by placing a bait in each of the 32 experimental plots. The baits were cut cubes of sweetpotato that were buried approximately 20 cm below the soil surface and left for 14 days. After 14 days the cut cubes were dug up, brushed and then assessed for wireworm feeding injury.

Presence or absence of wireworm feeding holes were then recorded as yes or no. Any wireworm found at the bait site was also collected and then reared through to the adult stage. Adult specimens are required for identification purposes as the key has been developed for the adult beetle stage.

Soil insecticides were applied through a calibrated ground rig. The ground rig consisted of a rotary hoe with a spray bar mounted just forward of where the rotary blades are operating. This allows insecticides to be applied to the soil surface directly in front of the working hoe blades. The rotary hoe width was 1.5 m. The spray boom consisted of six nozzles evenly spaced along the length of the boom. Insecticides were incorporated with rotary blades to a depth of between 20 and 30 cm below the soil surface. Table 2.02 shows treatments applied.

Sampling was conducted on four occasions during the life of the field trial, at 57 days after planting (DAP), 113 DAP, 185 DAP and 234 DAP. Plots were sub-sampled by removing a total of 4 plants from the datum rows. To minimise plant disruption in the plot a buffer of 2 plants was maintained between each subsample. The samples were then washed and visually assessed for wireworm feeding injury.

The assessment consisted of two grades based on levels of commercial marketability. Storage roots showing wireworm feeding injury were deemed unmarketable. Storage roots not showing wireworm feeding injury were deemed as marketable.

Key trial dates

7 March	Placed 30 sweetpotato baits in trial site.
21 March	Collected 30 baits from trial site. 50% of baits had wireworm feeding injury with none of the six baits placed in the UTC plots incurring wireworm feeding injury.
8 March	Soil incorporated insecticide treatments.
13 March	Planted trial.
9 May	First sample harvest (57 DAP).
24 July	Second harvest (113 DAP).
14 September	Third harvest (185 DAP).
2 November	Fourth harvest (234 DAP).

Analyses of variance were conducted on the percentage of storage roots damaged by wireworm feeding injury out of the total number of storage roots collected. The comparison between treatments was made using a protected least significant difference (l.s.d. at 5%) test. Genstat Release 11.1 was used for all analyses.

Table 2.01. Bundaberg trial design

Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6
2	6	3	5	1	4
4	2	5	1	6	3
5	3	6	2	4	1
6	1	4	3	5	2
1	5	2	4	3	6
3	4	1	6	2	5

Table 2.02. Insecticide application rates and methods of application

Treatment	% active constituent	Delivery system	Total rate of product	Application regime
1. bifenthrin	100 g/L	Soil incorporated prior to planting	5 L/ha	Single application prior to planting
2. chlorpyrifos	500 g/L	Soil incorporated prior to planting	6 L/ha	Single application prior to planting
3. phorate	100 g/L	Soil incorporated prior to planting	25kg/ha	Single application prior to planting
4. fipronil	200 g/L	Soil incorporated prior to planting	1 L/ha	Single application prior to planting
5. Brew - bifenthrin chlorpyrifos - phorate	 100 g/L 500 g/L 100 g/L	Soil incorporated prior to planting	 5 L/ha 6 L/ha 25 kg/ha	Single application prior to planting
6. Untreated control (UTC)	–	–	–	–

Results

At 60 DAP wireworm feeding injury was visually detected on sweetpotato. The untreated control plots recorded an average yield loss of 9.4 % as a result of wireworm feeding injury. There were no significant differences between treatments for the percentage of yield loss due to wireworm feeding injury at 60 DAP. The brew recorded the lowest average percentage yield loss at 0%. Bifenthrin recorded an average percentage yield loss of 0.6%, fipronil 0.6%, phorate 5.4% and chlorpyrifos 6.3%.

At 130 DAP wireworm feeding injury was visually detected on sweetpotato. The untreated control plots recorded an average yield loss of 15%. There were no significant differences between treatments for the percentage of yield loss due to wireworm feeding injury at 130 DAP. The brew recorded the lowest average percentage yield loss at 0.4%. Bifenthrin recorded an average percentage yield loss of 2.1%, fipronil 2.9, phorate 15.8% and chlorpyrifos 8.4%.

At 180 DAP wireworm feeding injury was visually detected on sweetpotato. The untreated control plots recorded an average yield loss of 25.7%. There were no significant differences between treatments for the percentage of yield loss due to wireworm feeding injury at 180 DAP. The brew recorded the lowest average percentage yield loss of 2.6%. Bifenthrin recorded an average percentage yield loss of 3.1%, fipronil 26.1%, phorate 42.5% and chlorpyrifos 37.6%

At 240 DAP wireworm feeding injury was visually detected on sweetpotato. The untreated control plots recorded an average yield loss of 61.7%. There were significant differences between treatments for the percentage of yield loss due to wireworm feeding injury at commercial harvest. The brew recorded 22% yield loss and bifenthrin recorded 30% yield loss which were both significantly less then the average percentage yield loss recorded across the UTC plots. Fipronil recorded a 40.2% yield loss which was not significantly worse than bifenthrin or the brew but not significantly better than the UTC. Phorate and chlorpyrifos were not significantly different from the UTC at commercial harvest.

Table 2.03 shows the percentage of storage roots with wireworm feeding injury at each of the four harvests, 60 days after planting (DAP), 130 DAP, 180 DAP and commercial harvest at 240 DAP.

Table 2.03. Average percentage of storage roots with wireworm feeding injury at 60, 130, 180 and 240 days after planting (DAP)

	60 DAP	130 DAP	180 DAP	240 DAP
Treatment	n.s.	n.s.	(P = 0.057)	(P = 0.001)
1. bifenthrin	0.6	2.1	3.1	30a*
2. chlorpyrifos	6.3	8.4	37.6	69.8c
3. phorate	5.4	15.8	42.5	67.3c
4. fipronil	0.6	2.9	26.1	40.2ab
5. Brew	0	0.4	2.6	22a
6. UTC	9.4	15	25.7	61.7bc
l.s.d.	n.a.	n.a.	n.a.	24.23

n.s. = not significant, P = probability level, n.a. = not applicable and l.s.d. = least significant difference. * Means followed by the same letter are not significantly different (P>0.05)

Conclusion

A mixture of insecticides (Treatment 5, Brew) did not provide superior protection to single applications of the synthetic pyrethroid bifenthrin or the phenyl pyrazole fipronil soil incorporated prior to planting.

This trial site had a wireworm larval population which was detected prior to planting in March 2007 using the baiting described in Materials and methods. Soil incorporated insecticides applied in March 2007 did provide significantly better protection from wireworm feeding injury on sweetpotato than the untreated control. The level of wireworm injury sustained in the best soil incorporated insecticide treatment was 30% loss due to wireworm feeding injury, which is commercially very poor.

A large increase in wireworm feeding injury was recorded between September 2007 (180 DAP) and November (240 DAP). The duration of crop maturity (240 days) is a long period of time for soil insecticide activity. Crop protection options that can be delivered through the drip irrigation system mid way through the crop developmental period need to be investigated.

The question needing to be explored is whether the increased wireworm feeding activity found to occur in the second half of the crop development period is the result of:

- existing wireworm moving up in the soil profile to feed in the sweetpotato root zone or

- new populations of wireworm larvae successfully establishing in the crop as the result of click beetle adults flying into the crop and laying eggs.

This trial needs to be repeated during the short sweetpotato production season of 140 days occurring between September–October through to January–February.

Report on the efficacy of soil incorporated insecticides prior to planting against wireworm in the Northern NSW sweetpotato production region of Cudgen

Long growing season 250 days

Introduction

The aim of the experiment reported was to test the efficacy of four insecticides soil incorporated prior to planting against the groups of wireworm commonly referred to as true and false wireworm on the sweetpotato variety Beauregard.

This field experiment was conducted on a grower's property on Plantation Road in the northern New South Wales (NSW) coastal growing region of Cudgen. The field experiment was conducted on a red volcanic earth from May 2007 to January 2008. This is considered the longest growing period for sweetpotato in the Australian production system.

Materials and methods

The Cudgen, northern NSW field experiment was a randomised block design with six treatments and four replicates (Table 2.04). Plots were four rows wide by 10 m long. The middle two rows were the datum row and either side was a buffer row.

The trial site was sampled for wireworm prior to planting to estimate the potential wireworm population. This was achieved by placing 32 baits through out the trial area. The baits were cut cubes of sweetpotato that were buried approximately 20 cm below the soils surface and left for 20 days. After 20 days the cut cubes were dug up, brushed and then assessed for wireworm feeding injury. Presence or absence of wireworm feeding holes were then recorded as yes or no. Any wireworm found at the bait site was also collected and then reared through to the adult stage. Adult specimens are required for identification purposes as the key has been developed for the adult beetle stage.

Insecticides were applied through a calibrated ground rig. The ground rig consisted of a rotary hoe with a spray bar mounted just forward of where the rotary blades are operating. This allows insecticides to be applied to the soil surface directly in front of the working hoe blades. The rotary hoe width was 2.7 m. The spray boom consisted of eight nozzles evenly spaced along the length of the boom. Each nozzle was recorded operating at 1300 mL/minute at an operating pressure of 30 psi. The total output of the boom was calculated at 10.4 L/minute. Insecticides were incorporated with rotary blades to a depth of between 20 and 30 cm below the soil surface. Table 2.05 shows treatments applied.

Sampling was conducted on three occasions during the life of the field trial at 125 days after planting (DAP), 187 DAP and 251 DAP (commercial harvest). Plots were sub-sampled by removing a total of four plants from the datum rows. To minimise plant disruption in the plot a buffer of two plants was maintained between each subsample. The samples were then washed and visually assessed for wireworm feeding injury.

The assessment consisted of two grades based on levels of commercial marketability. Storage roots showing wireworm feeding injury were deemed unmarketable. Storage roots not showing wireworm feeding injury were deemed as marketable.

Key dates

2 March 2007	Placed 32 sweetpotato baits in trial site.
22 March 2007	Collected 32 sweetpotato baits from site. 100% of baits had wireworm feeding injury. 32 true wireworm larvae were collected.
15 May 2007	Soil incorporated insecticides.
16 May 2007	Planted trial.
18 September 2007	First sample harvest at 125 DAP. Destructively sampled 4 plants from each of 20 plots. Washed and assessed storage roots.
19 November 2007	Second sample harvest at 187 DAP. Destructively sampled 4 plants from each of 20 plots. Washed and assessed storage roots.
22 January 2008	Commercial harvest at 251 DAP. Destructively sampled.

Analyses of variance were conducted on the percentage of storage roots damaged by wireworm feeding injury out of the total number of storage roots collected. The comparison between treatments was made using a protected least significant difference (l.s.d. at 5%) test. Genstat Release 11.1 was used for all analyses.

Table 2.04. Cudgen trial design

West < PLANTATION ROAD > East					
Replicate	**Plot**	**Treatment**	**Replicate**	**Plot**	**Treatment**
3	**13**	**1**	**1**	**1**	**2**
3	**14**	**5**	**1**	**2**	**6**
3	**15**	**2**	**1**	**3**	**3**
3	**16**	**4**	**1**	**4**	**5**
3	**17**	**3**	**1**	**5**	**1**
3	**18**	**6**	**1**	**6**	**4**
4	**19**	**3**	**2**	**7**	**6**
4	**20**	**4**	**2**	**8**	**1**
4	**21**	**1**	**2**	**9**	**4**
4	**22**	**6**	**2**	**10**	**3**
4	**23**	**2**	**2**	**11**	**5**
4	**24**	**5**	**2**	**12**	**2**

Table 2.05. Insecticide application rates and methods of application

Treatment	% active constituent	Delivery system	Total rate of product	Application regime
1. bifenthrin	100 g/L	Soil incorporated prior to planting	5 L/ha	Single application prior to planting
2. chlorpyrifos	500 g/L	Soil incorporated prior to planting	6 L/ha	Single application prior to planting
3. phorate	100 g/L	Soil incorporated prior to planting	25 kg/ha	Single application prior to planting
4. fipronil	200 g/L	Soil incorporated prior to planting	1 L/ha	Single application prior to planting
5. Brew - bifenthrin chlorpyrifos - phorate	 100 g/L 500 g/L 100 g/L	Soil incorporated prior to planting	 5 L/ha 6 L/ha 25 kg/ha	Single application prior to planting
6. Untreated control (UTC)	–	–	–	–

Results

Insecticide efficacy:

First harvest (125 DAP): No wireworm feeding injury was present on sweetpotato storage roots in September 2007, 125 days after planting.

Second harvest (187 DAP): Wireworm feeding injury to sweetpotato storage roots did increase across all plots between the first sample harvest and the second harvests. No significant differences in the level of wireworm feeding injury were detected between treatments at 187 DAP. Phorate (100 g/kg) applied at 25 kg/ha rate recorded the highest level of wireworm feeding injury recording 15.6% of storage roots with wireworm feeding injury. Fipronil (200 g/L) applied at 1 L/ha recorded an average of 15.3% of storage roots damaged and the untreated control (UTC) recorded 10.5% of storage roots damaged by wireworm. The brew treatment recorded an average of 7.8%. Bifenthrin (100 g/L) applied at 5 L/ha and chlorpyrifos applied at 6 L/ha recorded the least level of wireworm feeding injury at 6.3%.

Third harvest (251 DAP): Large levels of wireworm feeding injury occurred to the untreated control plots at commercial harvest (251 DAP). Significant differences in wireworm feeding injury did occur between the chemical treatments and the UTC. Treatment 5 termed the 'Brew' which was the combination of soil incorporated bifenthrin, chlorpyrifos and phorate prior to planting had 42.2% of storage roots damaged with wireworm feeding injury. This was significantly less damage in comparison to the untreated control, fipronil and phorate treatments. The UTC plots averaged 79.6% loss, the fipronil plots averaged 87.8% loss and the phorate plots averaged 76.5% loss ($P = 0.0.016$, l.s.d 28.87).

There was no significant difference between the single soil applied applications of bifenthrin and chlorpyrifos in comparison to the Brew. Bifenthrin plots recorded an average of 50.5% storage root loss due to wireworm feeding injury. Chlorpyrifos plots recorded an average loss of 48.7% to wireworm feeding injury.

Table 2.06 shows the percentage of storage roots with wireworm feeding injury at each of the four harvests, 125 days after planting (DAP), 187 DAP, 251 DAP and commercial harvest at 240 DAP.

Table 2.06. Average percentage of storage roots with wireworm feeding injury at 125 DAP, 187 DAP & 251 DAP

	125 DAP (September 2007)	**187 DAP (November 2007)**	**251 DAP (January 2008)**
Treatment	n.s.	n.s.	(P = 0.016)
1. bifenthrin	0	6.3	50.5ab*
2. chlorpyrifos	0	6.3	48.7ab
3. phorate	0	15.6	76.5bc
4. fipronil	0	15.3	87.8c
5. Brew	0	7.8	42.2a
6. UTC	0	10.5	79.6c
l.s.d	n.a.	n.a.	28.87

n.s. = not significant, P = probability level, n.a. = not applicable and l.s.d = least significant difference. * Means followed by the same letter are not significantly different (P>0.05)

Conclusion

A mixture of insecticides did not provide superior protection than a single application of the synthetic pyrethroid bifenthrin or the organophosphate chlorpyrifos soil incorporated prior to planting.

This trial site had extremely high wireworm larvae populations recorded in March 2007, prior to planting. Soil incorporated insecticides applied in May 2007 did provide significantly better protection from wireworm feeding injury on sweetpotato than the untreated control.

The level of wireworm injury sustained in the best soil incorporated insecticide treatment still sustained 42.2% loss due to wireworm feeding injury which is commercially a very poor result. A large increase in wireworm feeding injury was recorded between November 2007 (187 DAP) and January 2008 (251 DAP).

The time to crop maturity (251 days) is a long time for soil insecticide activity. Crop protection options that can be delivered through the drip irrigation system mid way through the crop developmental period need to be investigated.

The question needing to be explored is whether the increased wireworm feeding activity occurring in the second half of the crop development period is the result of :

- existing wireworm moving up in the soil profile to feed in the sweetpotato root zone or
- new populations of wireworm larvae successfully establishing in the crop as the result of click beetle adults flying into the crop and laying eggs.

If late wireworm control is not possible the alternative suggestion is that all commercially grown sweetpotato crops in the Cudgen region need to be harvested before November.

Report on the efficacy of soil incorporated insecticides prior to planting against wireworm in the Queensland sweetpotato production region of Bundaberg

Summer production season 149 Days

Introduction

The aim of the experiments reported, was to test the efficacy of insecticides, soil incorporated prior to planting, against the group of soil dwelling pests commonly referred to as either true or false wireworm on the sweetpotato variety Beauregard.

Wireworm feeding injury is commonly termed as ‘shotgun’ by Australian sweetpotato growers describing the random scattering of small holes found on sweetpotato storage roots. Though these holes are shallow, as few as three holes can make a sweetpotato unmarketable to the major supermarket chain stores.

Sweetpotato growers in Australia commonly apply multiple preventative insecticides which are soil incorporated prior to planting because the economic consequences of wireworm damage are great and there is no strategy that can predict fields at risk. At the time of field experimentation the only insecticide registered or permitted for soil incorporation on sweetpotato to control wireworm was the organophosphate phorate. Phorate is reported to not be effectively controlling wireworm.

This field experiment was conducted on a grower’s property on 10 Mile Road, Bundaberg, QLD. The field experiment was conducted on a sandy loam soil from October 2008 to March 2009. This is considered the shortest growing period for sweetpotato in the Australian production system and the crop most at risk for incurring wireworm feeding injury.

Materials and methods

The field experiment was a randomised block design with seven treatments and six replicates (Table 2.07). Plots were three rows wide by 12 m long. The middle row was the datum row and either side was a buffer row.

The trial site was sampled for wireworm prior to planting to estimate the potential wireworm population. This was achieved by placing 42 baits through out the trial area. The baits were cut cubes of sweetpotato that were buried approximately 20 cm below the soil surface and left for 20 days. After 20 days the cut cubes were dug up, brushed and then assessed for wireworm feeding injury. Presence or absence of wireworm feeding holes were then recorded as yes or no. Any wireworm found at the bait site was also collected and then reared through to the adult stage. Adult specimens are required for identification purposes as the key has been developed for the adult beetle stage.

Table 2.08 shows treatments applied. All insecticide treatments were applied through a calibrated ground rig. The ground rig consisted of a spray boom 3 m wide attached to a Kubota tractor. This allowed insecticides to be applied to the soil surface directly in front of a second tractor operating a rotary hoe. The rotary hoe width was 3 m. The spray boom consisted of eight nozzles evenly spaced along the length of the boom. Insecticides were incorporated with rotary blades to a depth of between 20 and 30 cm below the soil surface.

Sampling was conducted on four occasions during the life of the field trial at 56 days after planting (DAP), 98 DAP, 118 DAP and 149 DAP (commercial harvest). Plots were sub-sampled by removing a total of four plants from the datum rows. To minimise plant disruption in the plot a buffer of two plants was maintained between each subsample. The samples were then washed and visually assessed for wireworm feeding injury.

The assessment consisted of two grades based on levels of commercial marketability. Storage roots showing wireworm feeding injury were deemed unmarketable. Storage roots not showing wireworm feeding injury were deemed as marketable.

Key dates

1 October 2008	Incorporated soil insecticides.
8 October 2008	Planted trial.
3 December 2008	First sample harvest 56 DAP.
14 January 2009	Second sample harvest 98 DAP.
3 February 2009	Third sample harvest 118 DAP.
3 March 2009	Commercial harvest 149 DAP.

Analyses of variance were conducted on the percentage of storage roots damaged by wireworm feeding injury out of the total number of storage roots collected. The comparison between treatments was made using a protected least significant difference (l.s.d at 5%) test. Genstat Release 11.1 was used for all analyses.

Table 2.07. Experimental design

Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6
2	7	3	5	6	3
1	1	6	2	7	2
5	2	4	1	5	7
4	6	7	4	3	1
6	5	1	3	4	6
3	4	5	7	2	4
7	3	2	6	1	5

Table 2.08. Insecticide application rates

Treatment	% active constituent	Total rate of product
1. UTC	–	-
2. bifenthrin	250 g/L	2000 mL/ha
3. chlorpyrifos	500 g/L	6000 mL/ha
4. fipronil	200 g/L	500 mL/ha
5. fipronil	200 g/L	1000 mL/ha
6. thiamethoxam	250 g/kg	500 g/ha
7. thiamethoxam	250 g/kg	1000 g/ha

Results

First harvest (56 DAP): At 56 DAP wireworm feeding was visually detected on less than 1% of storage roots collected from the untreated control plots (UTC). No significant differences between treatments and the untreated control were found.

Second harvest (98 DAP): At 98 DAP wireworm feeding injury was visually detected on 12.8% of storage roots collected from the UTC. No significant differences between treatments and the UTC were found.

Third harvest (118 DAP): At 118 DAP wireworm feeding injury was visually detected on an average of 37.2% of storage roots collected from the UTC plots. Significant differences were found between treatments and the UTC. Soil incorporated treatments of bifenthrin, chlorpyrifos, fipronil at both rates and thiamethoxam at the high rate all recorded significantly less wireworm feeding injury in comparison to the UTC (P=0.001, lsd 16.44). Bifenthrin plots averaged 2.8% loss due to wireworm feeding injury. Chlorpyrifos averaged 1 % loss, fipronil applied at 500 mL/ha averaged 4.8 % loss, fipronil applied at 1 L/ha averaged 2.7 % loss and thiamethoxam applied at 1 kg/ha averaged 12.9% loss. Thiamethoxam applied at 500 g/ha averaged 23.4% loss due to wireworm feeding injury which did not provide significantly better protection from wireworm feeding injury in comparison to the UTC.

Fourth harvest (149 DAP): At commercial harvest wireworm feeding injury was visually detected on 49.3% of all storage roots collected from the UTC plots. Significant differences were found between treatments and the UTC. Soil incorporated treatments of bifenthrin and fipronil applied at 1 L/ha recorded significantly less wireworm feeding injury in comparison to the UTC (P=0.017, l.s.d. 36.79). Bifenthrin plots averaged 9.2% loss due to wireworm feeding injury while fipronil applied at 1 L/ha averaged 7.5% loss. Chlorpyrifos, fipronil applied at 500 mL/ha and thiamethoxam applied at 500 g and 1 kg/ha did not provide significantly better protection than the UTC, averaging 46.8%, 28.7%, 62.8 & 57.4% loss respectively.

Table 2.09 shows the treatment results at four sampling times.

Table 2.09. Average percentage of storage roots with wireworm feeding injury at 56 DAP, 98 DAP, 118 DAP & 149 DAP

	56 DAP December 2008	**98 DAP (January 2009)**	**118DAP (February 2009)**	**149DAP (March 2009)**
Treatment	n.s.	n.s	P=0.001	P=0.017
1. UTC	0.72	12.8	37.2c*	49.3b
2. bifenthrin	1.75	4.5	2.8a	9.2a
3. chlorpyrifos	0.67	4.2	1a	46.8b
4. fipronil (0.5)	0	4.1	4.8a	28.7ab
5. fipronil (1.0)	0	3.3	2.7a	7.5a
6. thiamethoxam (0.5)	2.63	9.7	23.4bc	62.8b
7. thiamethoxam (1.0)	0.64	2.4	12.9ab	57.4b
l.s.d	n.a.	n.a.	16.44	36.79

n.s. = not significant, P = probability level, n.a. = not applicable and l.s.d = least significant difference. * In each column means followed by the same letter are not significantly different (P>0.05)

Conclusion

The soil incorporated insecticides bifenthrin (2 L/ha) and fipronil (1 L/ha) applied in October 2008 were able to provide significantly better protection than the untreated control and all other soil incorporated insecticide treatments through to commercial harvest (149 DAP) in March 2009.

At 118 DAP the soil incorporated insecticides of chlorpyrifos (6 L/ha), fipronil (0.5 L/ha) and thiamethoxam (1 kg/ha) did provide significantly better protection than the untreated control.

A method that will provide protection from wireworm feeding injury through to commercial harvest by delivering fipronil or thiamethoxam through the drip irrigation system mid way through the crop developmental period needs to be investigated.

Chlorpyrifos application through the drip irrigation system is to be disregarded due to it currently being under review by the APVMA for in crop application.

Report on the efficacy of soil incorporated insecticides prior to planting against wireworm in the Northern NSW sweetpotato production region of Cudgen

Summer production season 140 Days

Introduction

The aim of the experiments reported was to test the efficacy of insecticides, soil incorporated prior to planting, against the group of soil dwelling pests commonly referred to as either true or false wireworm, on the sweetpotato variety Beauregard. Wireworm feeding injury is commonly termed as ‘shotgun’ by Australian sweetpotato growers describing the random scattering of small holes found on sweetpotato storage roots. Though these holes are shallow, as few as three holes can make a sweetpotato unmarketable to the major supermarket chain stores.

Sweetpotato growers in Australia commonly apply multiple preventative insecticides, which are soil incorporated prior to planting, because the economic consequences of wireworm damage are great and there is no strategy that can predict fields at risk. At the time of field experimentation the only insecticide registered or permitted for soil incorporation on sweetpotato to control wireworm was the organophosphate phorate. Phorate is reported to not be controlling wireworm effectively.

This field experiment was conducted on a grower’s property on Plantation Road in the northern New South Wales (NSW) coastal growing region of Cudgen. The field experiment was conducted on a red volcanic earth from December 2008 to April 2009. This is considered the shortest growing period for sweetpotato in the Australian production system and the crop most at risk for incurring wireworm feeding injury.

Materials and methods

The Cudgen field experiment was a randomised block design with seven treatments and four replicates (Table 2.10). Plots were four rows wide by 12 m long. The middle two rows were the datum row and either side was a buffer row.

The trial site was sampled for wireworm prior to planting to estimate the potential wireworm population. This was achieved by placing 32 baits through out the trial area. The baits were cut cubes of sweetpotato that were buried approximately 20 cm below the soil surface and left for 20 days. After 20 days the cut cubes were dug up, brushed and then assessed for wireworm feeding injury.

Presence or absence of wireworm feeding holes were then recorded as yes or no. Any wireworm found at the bait site was also collected and then reared through to the adult stage. Adult specimens are required for identification purposes as the key has been developed for the adult beetle stage.

Table 2.11 shows treatments applied. Insecticides were applied through a calibrated ground rig. The ground rig consisted of a spray boom 3 m wide attached to a Kubota tractor. This allowed insecticides to be applied to the soil surface directly in front of a second tractor operating a rotary hoe. The rotary hoe width was 3 m. The spray boom consisted of eight nozzles evenly spaced along the length of the boom. Insecticides were incorporated with rotary blades to a depth of between 20 and 30 cm below the soil surface.

Sampling was conducted on three occasions during the life of the field trial at 70 days after planting (DAP), 104 DAP and 139 DAP. Plots were sub-sampled by removing a total of four plants from the datum rows. To minimise plant disruption in the plot a buffer of two plants was maintained between each subsample. The samples were then washed and visually assessed for wireworm feeding injury.

The assessment consisted of two grades based on levels of commercial marketability. Storage roots showing wireworm feeding injury were deemed unmarketable. Storage roots not showing wireworm feeding injury were deemed as marketable.

Key dates

20 November 2007	Placed 39 sweetpotato baits in fallow
7 December 2007	Collected baits from site. 24 out of 39 baits had wireworm feeding injury present (61.5% hit).
10 December 2008	Incorporated soil insecticides.
11 December 2008	Planted trial.
19 February 2009	First sample harvest 70 DAP.
25 March 2009	Second sample harvest 104 DAP.
29 April 2009	Commercial harvest 139 DAP.

Analyses of variance were conducted on the percentage of storage roots damaged by wireworm feeding injury out of the total number of storage roots collected. The comparison between treatments was made using a protected least significant difference (l.s.d. at 5%) test. Genstat Release 11.1 was used for all analyses.

Results

First harvest (70 DAP): At 70 DAP wireworm feeding was visually detected on 47.7% of storage roots collected from the untreated control plots (UTC). Significant differences between treatments and the untreated control were found.

Bifenthrin and chlorpyrifos recorded significantly less yield loss due to wireworm feeding injury in comparison to the UTC (P=0.021 and l.s.d = 30.3). Bifenthrin recorded an average of 9.2% of storage roots with wireworm feeding injury while the chlorpyrifos plots recorded 10.9% of storage roots with wireworm feeding injury. Fipronil at both application rates and thiamethoxam at both application rates did not record significantly less yield loss due to wireworm feeding injury than the UTC. Fipronil applied at 500 mL/ha recorded 28.8% of storage roots with wireworm feeding injury while fipronil applied 1000 mL/ha recorded 45%. Thiamethoxam applied at 500 g/ha recorded 36.3% of storage roots with wireworm feeding injury while thiamethoxam at 1000 g/ha recorded 30.3%.

Table 2.10. Cudgen field experiment design

Rep 1	Rep 3
5	**1**
7	**3**
6	**4**
2	**7**
3	**5**
1	**2**
4	**6**
Rep 2	**Rep 4**
2	**1**
6	**5**
5	**7**
4	**3**
3	**6**
1	**2**
7	**4**

Table 2.11. Insecticide application rates (All insecticides were soil incorporated prior to planting

Treatment	% active constituent	Total rate of product
1. UTC	–	–
2. bifenthrin	250 g/L	2000 mL/ha
3. chlorpyrifos	500 g/L	6000 mL/ha
4. fipronil	200 g/L	500 mL/ha
5. fipronil	200 g/L	1000 mL/ha
6. thiamethoxam	250 g/kg	500 g/ha
7. thiamethoxam	250 g/kg	1000 g/ha

Second harvest (104 DAP): At 104 DAP wireworm feeding injury was visually detected on 73.5% of storage roots collected from the UTC. Significant differences between treatments and the UTC were found.

Bifenthrin recorded significantly less yield losses due to wireworm feeding injury in comparison to the UTC (P=0.012, l.s.d= 33.16). Bifenthrin recorded 15.1% of storage roots with wireworm feeing injury. Chlorpyrifos, fipronil at both rates and thiamethoxam at both rates did not provide superior protection from the UTC. Chlorpyrifos recorded 43.1% of storage roots with wireworm feeding injury. Fipronil applied at 500 mL/ha recorded 59.2% of storage roots with wireworm feeding injury while fipronil applied 1000 mL/ha recorded 75.1%. Thiamethoxam applied at

500 g/ha recorded 75.4% of storage roots with wireworm feeding injury while thiamethoxam at 1000 g/ha recorded 59.1%.

Commercial harvest (139 DAP): At commercial harvest wireworm feeding injury was visually detected on 68.4% of all storage roots collected from the UTC plots. No significant differences occurred between treatments and the UTC.

Bifenthrin, chlorpyrifos, fipronil at both rates and thiamethoxam at both rates did not provide superior protection from the UTC. Bifenthrin recorded 96.7% of storage roots with wireworm feeding injury. Chlorpyrifos recorded 96.3% of storage roots with wireworm feeding injury. Fipronil applied at 500 mL/ha recorded 86.6% of storage roots with wireworm feeding injury while fipronil applied 1000 mL/ha recorded 88.7%. Thiamethoxam applied at 500 g/ha recorded 84.4% of storage roots with wireworm feeding injury while thiamethoxam at 1000 g/ha recorded 85.2%.

Table 2.12 shows the treatment results at three sampling times.

Table 2.12. Average percentage of storage roots with wireworm feeding injury at 70 DAP, 104 DAP & 139 DAP

	70 DAP (February 2009)	**104 DAP (March 2009)**	**139 DAP (April 2009)**
Treatment	P=0.021	P=0.012	n.s.
1. UTC	47.7b*	73.5b	68.4
2. bifenthrin	9.2a	15.1a	96.7
3. chlorpyrifos	10.9a	43.1ab	96.3
4. fipronil (0.5)	28.8ab	59.2b	86.6
5. fipronil (1.0)	45b	75.1b	88.7
6. thiamethoxam (0.5)	36.3b	75.4b	84.4
7. thiamethoxam (1.0)	30.3ab	59.1b	85.2
l.s.d	30.3	33.16	n.a.

n.s. = not significant, P = probability level, n.a. = not applicable and l.s.d = least significant difference. * In each column means followed by the same letter are not significantly different (P>0.05)

Conclusion

This trial site had extremely high wireworm feeding pressure through out the entire crop development period. It is alarming that none of the soil incorporated insecticides applied in December 2008 were able to provide significantly better protection then the untreated control plots through to commercial harvest (139 DAP) in April 2009. Strategies must be developed that minimise the wireworm populations prior to planting.

Bifenthrin was able to provide protection through to between 104 and 139 DAP. Chlorpyrifos provided protection through to between 70 and 104 DAP.

Crop protection needs to be investigated that can be delivered through the drip irrigation system mid way through the crop developmental period to provide protection out to commercial harvest.

Report on the efficacy of fipronil (Regent®) applied through sub surface drip irrigation at various crop development stages to control true wireworm in sweetpotato

Short cropping season (140 days)

Introduction

The aim of the experiment reported was to test the efficacy of fipronil injected through trickle irrigation against the group of soil dwelling pests commonly referred to as either true or false wireworm on the sweetpotato variety Beauregard.

Sweetpotato growers in Australia commonly apply multiple preventative insecticides, which are soil incorporated prior to planting, because the economic consequences of wireworm damage are great and there is no strategy that can predict fields at risk. Results from field trials undertaken between 2007 and 209 on insecticide rates soil incorporated prior to planting showed that for fipronil to be effective against wireworm in the sweetpotato cropping system it needed to be applied at a rate of 1 L/ha.

Fipronil applied pre-plant at the rate of 500 mL/ha against wireworm in the sweetpotato cropping system was not effective. To increase the amount to 1 L/ha was not considered a commercial option due to the cost of fipronil and BASF Pty Ltd's position on the legally allowable amount of active ingredient per unit of area. It was concluded that investigations then needed to be made that considered applying the permitted rate of 250 mL/ha via a more effective means i.e. drip irrigation system.

This field experiment was conducted to investigate the chemigation use of fipronil at strategic times during the crop's development period on red volcanic soil in the Queensland coastal growing region of Bundaberg. The field experiment was implemented from October 2008 to March 2009. This is considered the shortest growing period for sweetpotato in the Australian production system and the crop most at risk for incurring wireworm feeding injury.

Materials and methods

The field experiment was a randomised block design with four treatments and four replicates (Table 2.13). Plots were three rows wide by 12 m long. The middle row was the datum row and either side was a buffer row.

The trial site was sampled for wireworm prior to planting to estimate the potential wireworm threat. This was achieved by placing 20 baits through out the trial area. The baits were cut cubes of sweetpotato that were buried approximately 20 cm below the soils surface and left for 20 days. After 20 days the cut cubes were dug up, brushed and then assessed for wireworm feeding injury. Presence or absence of wireworm feeding holes were then recorded as yes or no. Any wireworm found at the bait site was also collected and then reared through to the adult stage. Adult specimens are required for identification purposes as the key has been developed for the adult beetle stage.

Table 2.14 shows the treatments applied. Treatments 3 and 4 pre-plant soil insecticides were applied through a calibrated back pack spray rig to the soil surface. This allowed insecticides to be applied to the soil surface directly in front of a tractor operating a working rotary hoe. The rotary hoe width was 1.5 m. The spray rig was a 15 L capacity Echo motorised back pack sprayer with a 1 m lance with three yellow flat fan nozzles.

Treatments 2, 3 and 4 post-plant trickle applied insecticides were applied into the subsurface drip system with a water powered dosing machine supplied by Netafim called a Dosatron D45 RE 3. The Dosatron was installed directly into the water supply line which enabled delivery of the insecticides at a constant dosing ratio in proportion to the flow required to service the Netafim sub-surface drip system. The tape used had emitter spacing of 0.3 m delivering 1 litre per hour of water at 10 psi. Pressure control valves were used to ensure pressure and flow was maintained during the treatment delivery time.

The depth at which fipronil was delivered to the root system was managed through the use of Full Stops. Full Stops are a wetting front detection device. Two Full Stops were placed in treatment 2 at 20 cm and 30 cm below the soil surface. Once the Full Stop at 20 cm detected the wetting front fipronil was injected through the sub surface drip system for approximately 5 minutes. Irrigation continued for a further 10 minutes after the completion of the fipronil injection. The Full Stop at 30 cm below the soil surface would then detect the wetting front confirming the delivery of fipronil to the sweetpotato root system.

Sampling was conducted on three occasions during the life of the field trial, at 70 days after planting (DAP), 112 DAP and commercial harvest at 140 DAP. Plots were sub-sampled by removing 5 plants from the datum rows at each time of sampling. To minimise plant disruption in the plot a buffer of 2 plants was maintained between each subsample. The samples were then washed and visually assessed for wireworm feeding injury. The assessment consisted of 2 grades based on levels of commercial marketability. Presence of wireworm feeding injury was deemed unmarketable. Absence of wireworm feeding injury was deemed as marketable.

Key dates

22 October 2008	Incorporated soil insecticides
27 October 2008	Planted trial
3 December 2008	Injected fipronil into treatments 2 and 3 at a rate of 250 mL/ha
7 January 2009	First sample harvest 70 DAP
15 January 2009	Injected fipronil into treatment 4 at a rate of 250 mL/ha
15 February 2009	Second sample harvest 112 DAP
16 March 2009	Third sample harvest 140 DAP

Analyses of variance were conducted on the percentage of storage roots damaged by wireworm feeding injury out of the total number of storage roots collected. The comparison between treatments was made using a protected least significant difference (l.s.d at 5%) test. Genstat Release 11.1 was used for all analyses.

Table 2.13. Bundaberg experimental field design

REP 1	**1**
	2
	3
	4
REP 2	**2**
	1
	3
	4
REP 3	**3**
	4
	2
	1
REP 4	**4**
	2
	1
	3

Table 2.14. Application rates of insecticides and methods of application.

Treatment	Pre-plant soil incorporation	Post plant trickle injection
1	UTC	UTC
2	-	fipronil (200g/L) 250 ml/ha at 40 DAP
3	bifenthrin (250 g/L) 2 L/ha	fipronil (200g/L) 250 ml/ha at 40 DAP
4	bifenthrin (250 g/L) 2 L/ha	fipronil (200g/L) 250 ml/ha at 80 DAP

Results

The results are shown in Table 2.15. At 70 DAP wireworm feeding injury was visually detected on sweetpotato. The untreated control plot recorded an average of 24.7% of harvested storage roots with the presence of wireworm feeding injury which are termed ‘unmarketable’. No significant differences between treatments were found for the percentage of unmarketable storage roots. Treatment 2 recorded 1.7 % of harvested storage roots as unmarketable while treatment 3 recorded 3.7% of storage roots as unmarketable and treatment 4 recorded 4.3%.

At 112 DAP wireworm feeding injury to sweetpotato was again visually detected. The untreated control plot recorded 86.5% of its harvested storage roots as unmarketable due to wireworm feeding injury. There were significant differences between treatments for the percentage of unmarketable storage roots (P=0.001 and l.s.d 10.14). Treatment 2 recorded 11.3% of harvested storage roots as unmarketable which was significantly less than the UTC. Treatment 3 recorded 0.9% of harvested storage roots as unmarketable which was significantly less than both the UTC and treatment 2. Treatment 4 recorded 2.1% of harvested storage roots as unmarketable which was significantly less than the UTC but not significantly different from either treatment 2 or treatment 3.

At commercial harvest undertaken at 140 DAP the UTC recorded 91.9% of its harvested storage roots as unmarketable due to the presence of wireworm feeding injury. There were significant differences between treatments for the percentage of unmarketable storage roots (P=0.001, l.s.d. 12.09). Treatment 2 recorded 19% of harvested storage roots as unmarketable which was significantly less than the UTC. Treatment 3 recorded 4.9% of harvested storage roots as unmarketable which was significantly less than UTC and treatment 2. Treatment 4 recorded 7.2% of storage roots as unmarketable which was significantly less than the UTC but not significantly different from either treatment 2 or treatment 3.

Table 2.15. Average percentages of storage roots with wireworm feeding injury at 70 DAP, 112 DAP and 140 DAP

Treatments	**70 DAP**	**112 DAP**	**140 DAP**
	P=0.091	P=0.001	P=0.001
1. UTC	24.7	86.5a*	91.9a
2. fipronil at 40 DAP	1.7	11.3b	19.0b
3. bifenthrin soil incorporated prior to planting/ fipronil at 40 DAP	3.7	0.9c	4.9c
4. bifenthrin soil incorporated prior to planting/ fipronil at 80 DAP	4.3	2.1bc	7.2bc
l.s.d	n.a.	10.14	12.09

* In each column means followed by the same letter are not significantly different (P>0.05)

Conclusion

These results provide strong evidence to suggest that fipronil applied at the rate of 250 mL/ha directly to the root zone of the sweetpotato crop can effectively prevent wireworm feeding injury. The finding addresses the industry's long standing need to successfully control actively feeding wireworm in the later stages of crop maturity. The sweetpotato crop is vulnerable to insect feeding injury from storage root initiation right through to commercial harvest. Storage root initiation can occur at any stage between 21 to 42 DAP and commercial harvest can occur anywhere from 140 DAP through to 240 DAP.

The result is also pivotal for changing agro-chemical usage in the crop. It is now feasible that growers could move away from the single large applications of agro-chemicals at planting to smaller multiple applications throughout the crop development providing greater and more consistent wireworm control.

Chapter 3: Improved IPM systems for sweetpotato weevil (*Cylas formicarius*) in Australian sweetpotato production systems

Introduction

Image 3.01: Sweetpotato weevil

Sweetpotato weevil, *Cylas formicarius* (Image 3.01), is a major pest of sweetpotato world wide. In Australia sweetpotato weevil can cause up to 70% crop losses. Chalfant *et al.* 1990, state that production losses from insect feeding, especially sweetpotato weevil can reach 100%.

Sweetpotato weevil feeds on all parts of the plant sweetpotato plant. The larval stage of the sweetpotato weevil causes the major economic damage by tunnelling deep into the storage root making the sweetpotato unmarketable. Sweetpotato weevil can also significantly reduce yield by infesting the crowns and stems of the plant. This interferes with the transport of water, nutrients and assimilates between the crop canopy and below ground storage roots (Pinese 2001).

Sweetpotato is the preferred host for sweetpotato weevil and under ideal temperature conditions it has the ability to complete its entire lifecycle from eggs to adult in approximately 32 to 33 days according to Pinese (2001). If not controlled, this results in the rapid development of large, potentially damaging populations of sweetpotato weevil in a single cropping cycle.

In conventional sweetpotato production systems the weevil has historically been controlled by foliar applications of broad spectrum insecticides every two to four weeks. In the late 1990s Pinese (2001) reported that economic losses to sweetpotato in Australia were increasing from weevil infestation as a result of poor efficacy from the registered insecticide carbaryl. Efficacy work was then undertaken to permit the minor use of chlorpyrifos (organophosphate) and bifenthrin (synthetic pyrethroid) foliar applications every three to four weeks throughout the development of the crop to control adult sweetpotato weevil. In 2006 a survey of sweetpotato growers reported that both these insecticides were still successfully controlling the adult sweetpotato weevil within the crop's development time from planting to commercial harvest. Control of the adult weevil prevents eggs being laid into sweetpotato storage roots.

While current control methods are preventing sweetpotato weevil infestation, the industry has identified a number of factors putting current practices at risk into the future. These include:

- the APVMA's review of the use of chlorpyrifos in horticultural production

- the push from regulators away from broad persistent chemistry (P, Dal Santo pers. comm. 2009)
- the push from regulators towards specific, non disruptive and non persistent chemistry (P. Dal Santo pers. comm., 2009)
- the large increase in year round production of sweetpotato in the Bundaberg region (278,000 18 kg packages in 1998 to 1,550,000 packages in 2007) (J. Lovatt pers. comm., 2008)
- the increasing pest status of sweetpotato weevil in the region as a result of poor crop residue management providing a continuous unmanaged year round food source for the pest.

This research was designed to help provide industry with alternative management options for sweetpotato weevil into the future. Project activities undertaken between 2007 and 2010 have included:

- an area wide sweetpotato weevil management scoping study
- efficacy trials on Biological control agents
- efficacy trials on new non-disruptive insecticides
- importation and field assessment of tolerant sweetpotato varieties.

Major project results and findings

- Male sweetpotato weevil pheromone technology is a tool that can successfully locate areas of high weevil populations. Once hot spots are identified it is then possible to significantly reduce large populations of sweetpotato weevil across major sweetpotato production areas.
- There is strong evidence that thiamethoxam, from the neonicitinoid chemical group, has systemic activity against sweetpotato weevil in the variety Beauregard out to 160 days after planting. The mode of action of thiamethoxam on sweetpotato weevil will reduce the need for using disruptive agro-chemistry in the crop.
- Commercially available strains of the entopathogenic fungus, *Metarhizium anisopliae* from Becker Underwood Pty Ltd are not effective as a biological insecticide in the field against sweetpotato weevil.
- Sweetpotato varieties with high tolerance levels against sweetpotato weevil have been successfully imported from the USA and are ready for field testing in spring 2010.

Recommendations

1. Investigate the mandatory sweetpotato weevil area wide management programs in Japan and Southern USA to ascertain implementing a trapping program in Australian production regions. The ASPG should then implement and lead a mandatory trapping program that locates areas of high weevil populations and instigates necessary control strategies.

2. Investigate ways to better control sweetpotato crop residues post harvest as current sorghum cover crops are not successfully out competing sweetpotato volunteer regrowth. The use of selective herbicides in

conjunction with the sorghum break crop will provide better suppression of sweetpotato weevil throughout the growing districts.

3. Provide efficacy and residue data on thiamethoxam against sweetpotato weevil in Beauregard according to APVMA standards to contribute towards the permitted or label registered use of Sygenta Pty Ltd's insecticide 'Actara®'.

Area wide management

In March 1995 the Louisiana Department of Agriculture and Fisheries introduced a mandatory sweetpotato weevil area wide pheromone trapping program. Areas of Louisiana production are now free of the pest (Hammond pers. comm., 2008). After reviewing literature on the use of pheromone technology in area wide management programs of sweetpotato weevil in Louisiana, Southern USA and Okinawa, Southern Japan, it was decided to undertake a small scale investigation into the implementation of a similar program in the production system on the east coast of Australia.

A scoping study was designed and implemented at an isolated sweetpotato property at Rossmoya, central Queensland, to compare a mass trapping and crop hygiene program with a conventional sweetpotato farming system.

Materials and methods

In August 2007 the farm property boundary was GPS marked and then used to create a 200 m grid of waypoints across the farm. In September 2007 sticky traps loaded with a rubber septum with pheromone for the male sweetpotato weevil were placed on each of the waypoints across the farm's cultivated area. The sticky traps were supplied by Bugs for Bugs Pty Ltd. The sticky traps were 10 by 10 cm yellow cards with a grid pattern on the sticky surface. Sticky traps were placed at a height above the ground of between 20 and 30 cm. This was achieved by mounting them to the top of a wooden stake. Each rubber septum was loaded with 1000 uq concentration of the pheromone and placed in the centre of the sticky trap.

Traps were left in place for 24 hrs. After 24 hrs each sticky card was removed and placed in individual clear plastic zip lock bags and labelled with the date and way point location. These bags were then placed in a freezer for storage at the office site in Bundaberg QLD. The numbers of weevils per trap were then recorded. Once counts were collated areas of high weevil populations were estimated. The identified hot spot area was then the focus of a best bet farm hygiene program and mass trapping program based on similar activities in Japan and the USA.

A second area was also indentified that had low numbers of sweetpotato weevil, but no alternative management practices were to be implemented outside of the conventional management.

Once the 'hot spot' was established the grower implemented a number of mechanical cultivations and herbicide applications between October and November 2008. Mechanical cultivations included; slashing, disc ploughing and square ploughing. Herbicide application included a glyphosate and 2,4-D mixture applied through a spray boom to the hot spot area. This process insured that all sweetpotato crop residue/volunteers were no longer available for the population of sweetpotato weevil to feed on.

Over a four week period from 22 November 2007 to 20 December 2007 a mass trapping program was implemented across the 36 ha hot spot site. Plastic funnel traps loaded with the same rubber septum and pheromone were placed on a 50 m grid across the site area. These traps were then collected four times over the next four week period. Trap contents were emptied into clear plastic zip locked bags and clearly labelled with the date and location name. Counts of sweetpotato weevil per trap were then recorded.

The same sticky trapping process used in September 2007 was then repeated in April 2008 using the same way points across the entire farm. This was necessary to re-assess the sweetpotato weevil populations. These results would provide an estimate of the impact that a mass trapping and crop hygiene program may have on sweetpotato production systems in Australia.

Key dates

August 2007	GPS survey of farm boundary.
September 2007	Grid survey of the entire farm with sticky traps loaded with male sweetpotato weevil pheromone lure for 24 hour period.
October 2007	Farmer implemented crop hygiene program, including slashing, disc ploughing, square ploughing and the application of herbicide mix (glyphosate and 2 4 D) applied through a spray boom rig.
22 November 2007	Placed 140 funnel traps loaded with male sweetpotato weevil pheromone on 50 m grid across the 40 hectare hot spot area.
27 November 2007	First collection of funnel traps.
4 December 2007	Second collection of funnel traps.
12 December 2007	Third collection of funnel traps.
20 December 2007	Fourth collection of funnel traps.
16 April 2008	Grid survey of the entire farm with sticky traps loaded with male sweetpotato weevil pheromone lure.
17 April 2008	Collected sticky traps after 24 hrs in the field.

Results

September 2007 sticky trap survey

Across the 79 sticky traps collected, sweetpotato weevil catches ranged from zero to 173 per trap. The sticky trap survey successfully identified two sites to undertake the sweetpotato weevil management investigation.

> Site A: High weevil count plus new management system (hot spot)
> Site B: Low weevil count plus conventional sweetpotato system

Site A: The first site identified was the hot spot. Four sticky traps out of the 79 each recorded catches greater than 100 sweetpotato weevils. These traps were all located in the northwest corner of the property. The points included B13, A13, A14 and A16 which captured 173, 100, 125 and 133 respectively (refer to Table 3.02). This area was termed the 'hot spot', the area of greatest sweetpotato weevil concentration. The hot spot was approximately 36 ha in size which was bordered by waypoints A11 (150.46369-23.014169), B11 (150.46569-23.04193), B16 (150.46419-23.05059) to A16 (150.46219-23.05059). A total of twelve traps were collected from this site area with counts ranging from 11 to 173 sweetpotato weevil per trap. This area was to be the focus of a mass trapping and crop hygiene program. This area was characterised by large amounts of sweetpotato regrowth which had occurred from sweetpotatoes left over in the field after harvesting the commercial crop early in 2007.

Site B: The second site identified had low sweetpotato weevil numbers in comparison to the hot spot site. The site was approximately 36 ha in size which was bordered by waypoints B1 (150.46869-23.02413), D1 (150.47269-23.02461), D4 (150.47179-23.02995) & B4 (150.46779-23.02947). Twelve trap counts were collected from this site area with counts ranging from zero to 27 sweetpotato weevils per trap. Five sticky traps captured zero sweetpotato weevils. Five sticky traps captured less then five sweetpotato weevils. The two remaining traps captured 15 and 27 sweetpotato weevils (refer to Table 3.03). This site was currently under production and at the commercial harvest stage. Commercial harvest was completed in October 2007. No alteration to conventional land management practices were to occur on this site.

Mass trapping program

Table 3.01 shows the trapping dates, number of male sweetpotato weevils trapped and the range of the number of weevils on the traps.

Table 3.01. Male sweetpotato weevils trapped

Collection number	**Date**	**Total weevils trapped**	**Catch range for traps**
1	27 November 2007	48,578	0 – 3,036
2	4 December 2007	28,812	0 – 884
3	12 December 2007	4,044	0 – 758
4	20 December 2007	8,817	0 – 965
Total		**90,251**	

Due to the onset of the wet season in central QLD access onto the farm or to the Rossmoya district was not possible from late December 2007 until early April 2008.

April 2008 sticky trap survey

Site A: The 12 sticky traps located in the hot spot location recorded between 2 and 27 male sweetpotato weevils. The four sticky traps of greatest concern were B13, A13, A14 and A16 recording 23, 11, 10 and 11 respectively. This was a reduction from 125 for B13, 173 for A13, 133 for A14 and 100 for A16 from September 2007 to April 2008. The other 8 sticky traps, A11, A12, A15, B11, B12, B14, B15 and B16, recorded 4, 27, 11, 2, 23, 2, 14 and 9 male sweetpotato weevils respectively in April 2008 (refer to Table 3.02). These numbers demonstrate a considerable drop in sweetpotato weevil numbers during a wet season period of high plant re-growth and fast/successful sweetpotato weevil lifecycles.

Table 3.02. Sweetpotato weevil numbers captured on sticky traps in September 2007 then in April 2008 where the sweetpotato weevil area wide management study was implemented.

Trap name	Longitude and latitude	September 2007	April 2008
A11	150.46369 – 23.04169	57	4
A12	150.46339 – 23.04347	73	27
A13	150.46309 – 23.04525	173	11
A14	150.46279 – 23.04703	133	10
A15	150.46249 – 23.04881	63	11
A16	150.46219 – 23.05059	100	11
B11	150.46569 – 23.04193	18	2
B12	150.46539 – 23.04371	51	23
B13	150.46509 – 23.04549	125	23
B14	150.46479 – 23.04727	59	2
B15	150.46449 – 23.04881	88	14
B16	150.46419 – 23.05059	11	9

Site B: The 12 sticky traps located in the conventional sweetpotato farming section of the property recorded between 74 and 227 sweetpotato weevils. The five sticky traps B1, C1, C4, D1 and D4 previously recording zero sweetpotato weevils in September 2007 recorded 77, 122, 169, 170 and 155 sweetpotato weevils respectively in April 2008. The five sticky traps B4, C2, C3, D2 and D3 recorded 227, 135, 165, 79 and 177 sweetpotato weevils respectively in April 2008. Sticky trap B2 which recorded 15 sweetpotato weevils in September 2007 recorded 96 in April 2008, while trap B3 which recorded 27 in September 2007 recorded 74 in April 2008 (refer to Table 3.03). These numbers demonstrate a considerable increase in sweetpotato weevil numbers over a seven month period when crop residue were not controlled and sweetpotato mass trapping was not undertaken.

Table 3.03. Sweetpotato weevil numbers captured on sticky traps on the Rossmoya farm in September 2007 and then in April 2008 where the normal sweetpotato farming system took place.

Trap name	Longitude and latitude	September 2007	April 2008
B1	150.46869– 23.02413	0	77
B2	150.46839– 23.02591	15	96
B3	150.46809– 23.02769	27	74
B4	150.46779– 23.02947	4	227
C1	150.47069– 23.02437	0	122
C2	150.47039–.02615	1	135
C3	150.47009–.02793	2	165
C4	150.46979–.02971	0	169
D1	150.47269– 23.02461	0	170
D2	150.47239– 23.02639	3	79
D3	150.47209– 23.02817	4	177
D4	150.47179– 23.02995	0	155

Discussion

Results in Table 3.02 for Site A show a considerable reduction in the numbers of male sweetpotato weevils in April 2008 compared with September 2007 recordings. All mass trapping and farm hygiene management practices were completed by December 2007 and were seen as a success in light of the reduction in weevil population and the length of time between population samplings. It is important to note that the period between January 2008 and March 2008 was extremely wet in the Rossmoya district and no farm operations could be undertaken across the entire cultivated area. These conditions are seen as ideal conditions for rapid sweetpotato weevil reproduction (lifecycle less than 35 days).

Interestingly the results in Table 3.03 for Site B, the cultivated land which was not funnel trapped and managed during the October 2007 to December 2007 period, confirmed that weevil populations will flourish in such environmental conditions if left unchecked.

This case study shows that the Australian sweetpotato farming system is currently generating the large populations of sweetpotato weevil currently present in all production regions due to blocks being poorly managed after harvest. These large populations of sweetpotato weevil put a huge amount of pressure on sweetpotato crops grown for commercial harvest.

While the two broad spectrum insecticides are presently successfully preventing losses in commercially grown crops, these products are put under maximum working pressure 12 months of the year. The current situation has potential to develop insect tolerances to the currently available chemicals. Secondly these products may not be commercially available for use into the near future as old chemistry is increasingly coming under review by the Australian Pesticides and Veterinarian Medicines Authority.

The Australian sweetpotato industry must move away from its agri-chemical dependent farming system and adopt strategies that reduce sweetpotato weevil populations in post harvest blocks. Farm hygiene is key to any long term sustainable reduction in sweetpotato weevil pest pressure. Sweetpotato crop residue is the major food source for the development of large damaging populations of sweetpotato weevil.

Conclusion

The sweetpotato industry must investigate ways in which to better manage crop residue after commercial harvest.

Ways growers have begun investigating better crop residue management include:

- using herbicides to control crop residue prior to or during the forage sorghum break crop
- using sweetpotato mulching equipment on the back of sweetpotato harvesters that pulp any unmarketable sweetpotatoes as they go back into the paddock
- removing all of the sweetpotato crop rather than only some of it

Comparison can be made between the tomato industry's pest control history in Bundaberg during the 1990s and that of the present or future problems facing the sweetpotato industry in Bundaberg. Leaf miner (*Phthorimaea operculella*) in tomatoes was becoming a major problem to growers as insecticidal controls were not providing sufficient efficacy against the large population pressure in the region. A lot of research went into developing better ways to control and manage this pest.

One of the key outcomes was that poor crop hygiene after commercial harvest was the single most important factor in leaf miner population management. Tomato growers now, at the completion of harvest, immediately spray out crops with paraquat herbicide, which significantly reduces the opportunity for large damaging populations of tomato leaf miner to occur.

Biological control - Entomopathogenic fungi

The biological pesticides unit of DEEDI has a number of commercial Becker Underwood Pty Ltd strains of *Metarhizium anisopliae* available for screening. Laboratory assays undertaken by the bio-pesticides unit found sufficient infectivity and mortality of sweetpotato weevil from one of the strains of *M. anisopliae*. This was applied to the pest as a formulation of conidia and vegetable oil. It was decided to undertake a field experiment to test the *Metarhizium* as a biological pesticide in comparison to current commercial controls.

Materials and methods

The Bundaberg Research Station field experiment was a randomised block design with four treatments and five replicates (Table 3.04). Each replicate was a 1 m wide by 18 m long sweetpotato seed bed. The sweetpotato variety was Beauregard. Each bed had four treatment plots each 3 m long by 1 m wide. A 1 m buffer separated plots along the bed.

Treatments were applied as foliar applications directly to the seed bed area after each seedbed cutting. This was approximately at 4 week intervals. The spray rig applying the foliar treatments consisted of a 15 L Echo motorised back pack sprayer with a 1 m boom lance with three yellow flat fan nozzles.

Treatments include:

1. control (5% Synertrol® Oil solution)
2. low rate of fungus (1 kg/ha) with 5% Synertrol® Oil solution
3. high rate of fungus (2 kg/ha) with 5% Synertrol® Oil solution
4. bifenthrin (600 mL/ha) – current commercial best practice.

A sweetpotato weevil pheromone trap placed in the trial vicinity showed the presence of sweetpotato weevil throughout the duration of the trial period. In March 2007, 40 seedbed sprouts were removed from each of the 20 plots and destructively sampled for the presence or absence of sweetpotato weevil larval tunnelling.

Key BRS trial dates

August 2007	Seedbed planted.
1 September 2007	Seedbed cut and foliar sprayed with bifenthrin.
2 October 2007	Seedbed cut and foliar sprayed with chlorpyrifos.
5 November 2007	Seedbed cut.
7 November 2007	First foliar application of experimental treatments applied.
7 December 2007	Seedbed cut and second foliar application of experimental treatments applied.
3 January 2008	Seedbed cut and third application of experimental treatments applied.
5 February 2008	Seedbed cut and fourth application of experimental treatments applied.
14 March 2008	Destructively sampled experimental trial plots for the presence of sweetpotato weevil tunnelling in seedbed sprouts.

Analysis of variance was conducted on the number of sweetpotato vine slips with the presence of sweetpotato weevil tunnelling. Genstat Release 11.1 was used for the analysis.

Table 3.04. Trial layout in the field

REP 1	REP 2	REP 3	REP 4	REP 5
3	**2**	**2**	**1**	**4**
4	**3**	**1**	**4**	**3**
2	**4**	**3**	**2**	**1**
1	**1**	**4**	**3**	**2**

Results

A significant difference was found between the untreated control (UTC) plots and the treatments for the presence of sweetpotato weevil (SPW) tunnelling in sweetpotato seedbed sprouts (Table 3.05).

The bifenthrin treatment had significantly fewer sweetpotato sprouts with the presence of sweetpotato weevil tunnelling than did the untreated control plots (P=0.001, l.s.d. 4.53). The bifenthrin plots had an average count of three sprouts with the presence of sweetpotato weevil tunnelling while the UTC plots had an average count of 26 sprouts with the presence of sweetpotato weevil tunnelling.

The half rate and full rate of pathogenic fungi did not provide significant reduction in the presence of SPW tunnelling in sweetpotato seedbed sprouts in comparison to the UTC. The half rate (0.5 kg/ha) treatment of pathogenic fungi recorded an average of 23.8 sprouts with SPW tunnelling, while the full rate (1 kg/ha) treatment of pathogenic fungi recorded an average of 21.4 sprouts with SPW tunnelling.

Table 3.05. The average number of sweetpotato seedbed sprouts with SPW tunnelling out of 40 sprouts destructively sampled in March 2007

Treatment	Average number of seedbed sprouts with SPW tunnelling out of 40 (P=0.001, l.s.d 9.86)
1. UTC + Synertrol® Oil	26a*
2. Fungus (0.5 kg/ha) + Synertrol® Oil	23.8a
3. Fungus (1.0 kg/ha) + Synertrol® Oil	21.4a
4. Bifenthrin 100EC (600 mL/ha)	3b

* Means followed by the same letter are not significantly different (P>0.05)

Conclusion

The Becker Underwood entopathogenic strain of *M. anisoplae* found effective in laboratory bio-assays for sweetpotato weevil mortality was not able to provide effective control of sweetpotato weevil infestation in a sweetpotato seedbed environment in Bundaberg Queensland.

Varietal tolerance

Three varieties were available from the USDA germplasm collection for field assessment under Australian production conditions. These varieties were selected on the basis of their availability, their tolerance to soil insect pests (wireworm, sweetpotato weevil and root-knot nematode) and their agronomic characteristics.

The curator Bob Jarrot suggested Sumor, Regal and Excel. Currently this germplasm is in Australia. It is undergoing processing to ensure virus free status before being released for field evaluations in the major Australian production areas. There is agreement with the USDA plant genetic resources unit that these *Ipomoea batatas* varietal accessions will be used for field testing only and that any data obtained will be shared with the USDA.

P1 566657 Sumor

Description: Skin smooth yellowish to light tan. Flesh white to yellow. Good field resistance to Fusarium wilt or stem rot. Not very sweet. For home use can be prepared similarly to a standard white potato and consumed mashed, creamed or fried.

Parentage: Open-pollinated seedling of W-154 polycrossed to 29 other selections.

P1 566651 Regal

Description: Roots generally well shaped, fusiform to blocky, sometimes short. Skin brilliant purplish-red. Flesh dark orange. Yields often 5 - 10 percent higher than Jewel. Stores acceptably well. Average baking and canning quality. Combination pest resistances superior to that of other available cultivars, resistance to internal cork and Fusarium wilt or stem rot, sclerotial blight, pox or soil rot and southern root-knot nematode.

Parentage: Open-pollinated seedling of W-99 polycrossed with 29 other parental selections.

P1 566625 Excel

Description: The variety has light copper skin colour. Flesh orange. Stores well. Excellent baking and canning qualities. High yield. High resistance to southern root knot, stem rot or wilt disease, internal cork, and to sclerotial blight in plant beds. It also was assessed as having resistance to wireworm.

Parentage: Open pollinated seedling of Regal polycrossed in 1981 to 29 other parental selections.

Report on the efficacy of thiamethoxam soil incorporated prior to planting against sweetpotato weevil infestation at commercial harvest: Short season crop

Introduction

The aim of the experiments reported was to test the systemic efficacy of thiamethoxam against sweetpotato weevil.

Sweetpotato growers in Australia commonly foliar apply either chlorpyrifos or bifenthrin insecticides at four week intervals during the crop's development because the economic consequences of sweetpotato weevil infestation are great. Both permitted products are disruptive to the suppression of other pests (e.g. whitefly) by beneficial organisms (e.g. wasps) in the crop canopy.

Chlorpyrifos is under review by the APVMA and soon may not be permitted or registered for use in sweetpotatoes. Alternative chemistry is needed to alleviate the potential over-dependence on bifenthrin in the cropping system. This chemistry must prevent sweetpotato weevil infestation while not disrupting beneficial organisms working in the crop canopy.

Two preliminary field efficacy screening trials were undertaken on sandy loam soil sites (Moore Park and Ten Mile) in the coastal growing region of Bundaberg between October 2008 and April 2009. These screening trials were part of larger wireworm efficacy field trials. This is considered the shortest growing period for sweetpotato in the Australian production system.

Materials and methods

Trials were conducted at two sites, Ten Mile and Moore Park.

Ten Mile

The field experiment was a randomised block design with seven treatments and six replicates (Table 3.06). Plots were three rows wide by 12 m long. The middle row was the datum row and either side was a buffer row.

Soil insecticides were applied through a calibrated ground rig. The ground rig consisted of a spray boom 3 m wide attached to a Kubota tractor. This allowed insecticides to be applied to the soil surface directly in front of a second tractor operating a rotary hoe. The rotary hoe width was 3 m. The spray boom consisted of eight nozzles evenly spaced along the length of the boom. Insecticides were incorporated with rotary blades to between 20 and 30 cm below the soil surface. Treatments are given in Table 3.07.

Sampling for sweetpotato weevil infestation was conducted 149 days after planting (DAP), which was considered commercial harvest. Plots were sub-sampled by removing four plants from the datum rows. The samples were then washed and visually assessed for sweetpotato weevil infestation. The assessment consisted of two grades based on levels of commercial marketability. Storage roots showing sweetpotato weevil larvae tunnelling were deemed unmarketable. Storage roots not showing sweetpotato weevil larvae tunnelling were deemed as marketable.

Key dates

1 October 2008	Incorporated soil insecticides.
8 October 2008	Planted trial.
3 March 2009	Commercial harvest 149 DAP.

Analysis of variance was conducted on the percentage of storage roots with sweetpotato weevil tunnelling damage at commercial harvest. As only the untreated control and treatment numbers 6 and 7 (thiamethoxam soil incorporated prior to planting at 0.5 kg/ha and 1 kg/ha) were of interest the comparison was made using Fisher's unprotected least significant difference (l.s.d. at 5%) test. This utilised the estimate of variation from the whole experiment, which is more accurate than using the estimate from just the control and the treatments of interest here.

Table 3.06. Field experimental design

Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6
2	7	3	5	6	3
1	1	6	2	7	2
5	2	4	1	5	7
4	6	7	4	3	1
6	5	1	3	4	6
3	4	5	7	2	4
7	3	2	6	1	5

Table 3.07. Treatments applied to the Ten Mile trial

Treatment	% active constituent	Total rate of product
1. untreated control	–	–
2. bifenthrin	250 g/L	2000 mL/ha
3. chlorpyrifos	500 g/L	6000 mL/ha
4. fipronil	200g/L	500 mL/ha
5. fipronil	200g/L	1000 mL /ha
6. thiamethoxam	250 g/kg	500 g/ha
7. thiamethoxam	250 g/kg	1000 g/ha

Moore Park

The field experiment was a factorial design with three soil incorporated treatments by three foliar applied treatments. The nine treatments were replicated four times (Table 3.08). Plots were three rows wide by 12 m long. The middle row was the datum row and either side was a buffer row. The soil incorporated insecticide treatments prior to planting were for testing against wireworm activity. The foliar application of chlorpyrifos according to a calendar schedule or pheromone trapping were to test the use of pheromone monitoring for male sweetpotato weevil as a support tool for when to spray.

Insecticide treatments are shown in Table 3.09.

Soil insecticides were applied through a calibrated ground rig. The ground rig consisted of a spray boom 3 m wide attached to a Kubota tractor. This allowed insecticides to be applied to the soil surface directly in front of a second tractor operating a rotary hoe. The rotary hoe width was 3 m. The spray boom consisted of eight nozzles evenly spaced along the length of the boom. Insecticides were incorporated with rotary blades to between 20 and 30 cm below the soils surface.

Foliar applied treatments were applied through a motorised back pack sprayer with a 1 m hand held boom. An initial foliar application of chlorpyrifos was applied in December but this treatment regime was not continued as a result of damage to the trial site by a cattle herd in early January 2009.

Sampling for sweetpotato weevil infestation was conducted 167 DAP which was considered commercial harvest. Plots were sampled by removing 10 plants from the datum rows. The samples were then washed and visually assessed for sweetpotato weevil infestation. The assessment consisted of two grades based on levels of commercial marketability. Storage roots showing the presence of sweetpotato weevil larvae tunnelling were deemed unmarketable. Storage roots not showing sweetpotato weevil larvae tunnelling were deemed as marketable.

Analysis of variance was conducted on the percentage of storage roots with the presence of sweetpotato weevil tunnelling at commercial harvest. As only the comparison between the untreated control (treatment 1) and the soil incorporation of thiamethoxam at 1 kg/ha (treatment 7) was of interest the comparison was made using Fisher's unprotected least significant difference (l.s.d at 5%) test. This utilised the estimate of variation from the whole experiment, which is more accurate than using the estimate from just the control and the treatment of interest here.

Key dates:

30 October 2008	Soil incorporated insecticide treatments.
5 November 2008	Planted trial.
6 December 2008	Foliar application of chlorpyrifos to treatment plots 2,3,5,6,8 and 9.
21 April 2009	Commercial harvest (167 DAP).

Table 3.08. Field experiment design

Rep 1	Rep 2	Rep 3	Rep 4
5	8	3	9
3	6	1	2
6	2	6	5
7	7	9	3
1	3	5	4
4	5	8	6
2	1	4	7
9	4	7	8
8	9	2	1

Table 3.09. Treatments applied to the Moore Park trial

Treatments		Total rate of product	
Soil incorporated	**Foliar applied**	**Soil incorporated**	**Foliar applied**
1. untreated control	untreated control	–	–
2. untreated	chlorpyrifos every 4 weeks	–	4000 mL/ha
3. untreated	chlorpyrifos when pheromone trap 50 + SPW	–	4000 mL/ha
4. bifenthrin	untreated	2 L/ha	–
5. bifenthrin	chlorpyrifos every 4 weeks	2 L/ha	4000 mL/ha
6. bifenthrin	chlorpyrifos when pheromone trap 50 + SPW	2 L/ha	4000 mL/ha
7. thiamethoxam	untreated	1 kg/ha	–
8. thiamethoxam	chlorpyrifos every 4 weeks	1 kg/ha	4000 mL/ha
9. thiamethoxam	chlorpyrifos when pheromone trap 50 + SPW	1 kg/ha	4000 mL/ha

Note: Chemical active ingredient concentrations - bifenthrin 250 g/L, thiamethoxam 250 g/kg and chlorpyrifos 500 g/L.

Results

Ten Mile

At 149 DAP there was a significant difference in the level of sweetpotato weevil infestation between treatments using Fishers unprotected least significant difference test. The untreated control (UTC) had significantly higher sweetpotato weevil infestation in comparison to both thiamethoxam soil incorporated prior to planting at 0.5 kg/ha and 1 kg/ha (treatments 6 and 7). The UTC had an average of 22.4 % of storage roots with sweetpotato weevil tunnelling while treatment six averaged 4.8 % and treatment seven averaged 2.5 % (Fishers unprotected l.s.d. = 17.09).

Table 3.10 shows the percentage of storage roots infested by sweetpotato weevil at the Ten Mile trial.

Table 3.10. The percentage of storage roots infested by sweetpotato weevil at the Ten Mile trial

Treatment	**% sweetpotato weevil infestation**
	P=0.312
1. UTC	22.4a*
2. bifenthrin 2 L/ha (250 g/L)	10.2ab
3. chlorpyrifos 6 L/ha (500 g/L)	11.7ab
4. fipronil 0.5 L/ha (200 g/L)	11.9ab
5. fipronil 1 L/ha (200 g/L)	5.8ab
6. thiamethoxam 0.5 kg/ha (250 g/kg)	4.8b
7. thiamethoxam 1.0 kg/ha (250 g/kg)	2.5b
Unprotected l.s.d	17.09

* Means followed by the same letter are not significantly different (P>0.05)

Moore Park

At 167 DAP there was no significant difference in the level of sweetpotato weevil infestation between the UTC and thiamethoxam soil incorporated prior to planting. The UTC did have higher sweetpotato weevil infestation in comparison to thiamethoxam soil incorporated prior to planting at a rate of 1 kg/ha (treatment 7). The UTC had an average of 16% of storage roots with sweetpotato weevil tunnelling while treatment seven averaged 2.7% at commercial harvest 167 DAP.

Table 3.11 shows the percentage of storage roots infested by sweetpotato weevil at the Moore Park trial.

Table 3.11. The percentage of storage roots infested by sweetpotato weevil at the Moore Park trial

Treatment	**% sweetpotato weevil infestation**
	P=0.602
1. UTC	16a*
2. UTC + foliar insecticide	7.3a
3. UTC + foliar insecticide	7.9a
4. bifenthrin 2 L/ha (250 g/L) + UTC	13.8a
5. bifenthrin + foliar insecticide	23.1a
6. bifenthrin + foliar insecticide	31.1a
7. thiamethoxam 1 kg/ha (250 g/kg)	2.7a
8. thiamethoxam + foliar insecticide	4.5a
9. thiamethoxam + foliar insecticide	6.4a
Unprotected l.s.d.	30.72

Means followed by the same letter are not significantly different (P>0.05)

Conclusion

There is strong evidence to suggest that thiamethoxam has long lasting systemic activity against sweetpotato weevil infestation in Beauregard sweetpotatoes.

Two dedicated field experimental sites need to be established to compare the soil incorporation of thiamethoxam at 1 kg/ha prior to planting with three reduced rates of thiamethoxam applied through the trickle irrigation system within seven days after planting, and an untreated control plot. The results of such trials would provide the conclusive data necessary for APVMA permission for thiamethoxam to be used in Australian sweetpotato production systems.

Thiamethoxam is seen as strategic chemistry that an integrated pest management program for sweetpotato production could be built around. Work still needs to address the large damaging populations of sweetpotato weevil existing in poorly managed sweetpotato blocks post harvest.

It is possible that the company Syngenta, which owns the thiamethoxam chemistry, will not look to support the minor use permit of their product in sweetpotato if the issue of sweetpotato weevil population is not addressed in blocks post harvest. Exposing the product to such high populations of sweetpotato weevil could reduce its active working life in the crop.

Chapter 4: Root-knot nematode

Introduction

Root-knot nematode (RKN) is a major pest of sweetpotato. RKN cause galling, cracks and lesions to form on the surface of the sweetpotato storage root. These blemishs on the surface of the skin make the product unsuitable for sale. RKN can also reduce crop vigour. The combination of RKN's rapid lifecycle and sweetpotato's long crop development time (140–250 days from planting to commercial harvest), results in small populations of RKN at planting causing major damage by commercial harvest.

Nematicide must be used early on in the cropping cycle to ensure protection from RKN infestation. Prior to August 2008 the sweetpotato industry only had one registered/permitted nematicide available for use, fenamiphos, a nematicide from the organophosphate chemical group. The over-dependence on the single product over the past 10 years has resulted in poor product performance in commercial crops of sweetpotato. The sweetpotato industry needed to find an alternative nematicide from a different chemical group that could be used in rotation with fenamiphos.

Major findings

i) Low RKN soil counts prior to planting result in economic losses due to RKN infestation at commercial harvest (139 days after planting).
ii) Nematicides are required in the sweetpotato production system due to Beauregard's high susceptibility to RKN.
iii) Oxamyl applied via trickle irrigation was effective at preventing RKN infestation to Beauregard in comparison to untreated controls and fenamiphos treatments.

Recommendations

- Studies to investigate ways to further reduce RKN populations prior to planting sweetpotato should be undertaken.
- Studies to investigate ways to better control sweetpotato crop residues post harvest should be done as current sorghum cover crops are not successfully out competing sweetpotato volunteer regrowth. The use of selective herbicides in conjunction with the sorghum break crop may provide better suppression of RKN.
- Alternative nematicides that have low human toxicity under low RKN pressure cropping situations injected late in the crop's development period should be identified and screened.

Report into the efficacy of Vydate® L applied through the drip irrigation system to control root-knot nematode in the sweetpotato production system

This document is the experimental report for the efficacy testing of Vydate® L (oxamyl) from the carbamate chemical group applied at several rates against *Meloidogyne* spp., root-knot nematodes (RKN) on the sweetpotato (*Ipomoea batatas*) variety Beauregard.

The field experiments were conducted at two locations. Bundaberg Research Station (BRS), Queensland from September 2008 to February 2009 and Duranbah, New South Wales from November 2008 to April 2009.

The Bundaberg district (southeast Queensland) and Cudgen/Duranbah district (northern New South Wales) are the two dominant sweetpotato production areas in Australia. From spring to the end of summer is the growing period when the highest risk potential for RKN occurs.

Materials and methods

Experiment 1

The BRS field experiment was a randomised block design with five treatments and four replicates (Table 4.01). Plots were three rows wide by 15 m long. The middle row was the datum row and either side was a buffer row.

The treatments (Table 4.02) were applied into the subsurface drip system with a water powered dosing machine, supplied by Netafim, called a Dosatron D45 RE 3. The Dosatron was installed directly into the water supply line which enabled delivery of the application regime (Table 4.02) at a constant dosing ratio in proportion to the flow required to service the T-Tape sub-surface drip system. The T-Tape used was Model 508-20-500. Emitter spacing was 0.2 m delivering 1 litre per hour of water at 70 kpa. Pressure control valves were used to ensure pressure and flow was maintained during the treatment delivery time.

The depth Vydate® L was delivered to the root system was managed through the use of Full Stops. Full Stops are a wetting front detection device. Two Full Stops were placed in treatment 2 at 20 cm and 30 cm below the soil surface. Once the Full Stop at 20 cm detected the wetting front Vydate® L was injected through the sub surface drip system for approximately 5 minutes. Irrigation continued for a further 10 minutes after the completion of the Vydate® L injection. The Full Stop at 30 cm below the soil surface would then detect the wetting front confirming the delivery of Vydate® L to the sweetpotato root system.

The trial site was sampled prior to planting for RKN by collecting soil samples randomly from each of the four replication areas. The number of RKN present in 200 mL of soil was 56 for replicate 1, 23 for replicate 2, 16 for replicate 3 and 5 for replicate 4 (Table 4.03). The numbers present were deemed to be at sufficient levels to provide high infestation over the life of the crop.

Sampling was conducted on four occasions during the life of the field trial at 57 days after planting (DAP), 84 DAP, 111 DAP and 139 DAP. Plots were sub-sampled by removing five plants from the datum row of the plot at each time of sampling. To minimise plant disruption in the plot a buffer of two plants was maintained between each subsample. The samples were then washed and visually assessed for RKN infestation. The assessment consisted of three grades based on levels of commercial marketability (Table 4.04 and Figures 4.01 – 4.04). At commercial harvest (139 DAP) the sweetpotato were also visually assessed for wireworm feeding injury.

Key BRS trial dates

24 September 2008	Planted trial
26 September 2008	Injected treatments 2, 3, 4 and 5
10 October 2008	Injected treatments 3 and 4
24 October 2008	Injected treatments 3 and 4
7 November 2008	Injected treatments 3 and 4
20 November 2008	First sample harvest 57 DAP
24 November 2008	Injected treatments 3 and 4
17 December 2008	Second sample harvest 84 DAP
13 January 2009	Third sample harvest 111 DAP
10 February 2009	Commercial harvest 139 DAP

Analyses of variance were conducted on the average counts and weights of storage roots assessed per plot at each of the harvests. As only the untreated control and treatment number 3 (18 L/ha at planting followed by four applications of 2 L/ha every 14 days after initial application) were of interest the comparison was made using an unprotected least significant difference (l.s.d. at 5%) test. This utilised the estimate of variation from the whole experiment, which is more accurate than using the estimate from just the control and the treatment of interest here. Genstat Release 11.1 was used for all analyses.

Table 4.01 shows the trial layout and Table 4.02 shows the treatments.

Table 4.01. Trial layout in the field

Plot	Replicate	Treatment
1	1	1
2	1	3
3	1	5
4	1	4
5	1	2
6	2	5
7	2	2
8	2	3
9	2	1
10	2	4
11	3	4
12	3	2
13	3	3
14	3	5
15	3	1
16	4	5
17	4	4
18	4	2
19	4	1
20	4	3

Table 4.02. Treatments used in the trial

Treatment	Delivery system	Total rate of product	Application regime
1. Untreated control	–	–	–
2. Vydate® L	Sub-surface drip	18 L/ha	Single application at planting
3. Vydate® L	Sub-surface drip	26 L/ha	18 L/ha at planting followed by four applications of 2 L/ha every 14 days after initial application
4. Vydate® L	Sub-surface drip	24 L/ha	8 L/ha at planting followed by four applications of 4 L/ha every 14 days after initial application
5. Nemacur®	Sub-surface drip	10.7 L/ha	Single application at planting

Table 4.03. List of plant parasitic nematodes and the numbers present in 200 mL of soil from each of the four soil samples collected from the site in July 2008

Laboratory ID	Sample ID	Plant parasitic nematodes/200 mL soil (corrected for extraction efficiency)								
		Root-knot	**Lesion**	**Reniform**	**Spiral**	**Spiral**	**Stunt**	**Stubby**	**Sheath**	**Ring**
		Meloidogyne sp.	*Pratylenchus* sp.	*Rotylenchulus* sp.	*Rotylenchus brevicaudatus*	*Helicotylenchus dihystera*	*Tylenchorchorus* sp.	*Paratichodorus* sp.	*Hemicycliophora* sp.	*Criconemella* sp.
NO902	C2 sample 1	56	11	79	0	0	0	0	0	0
NO903	C2 sample 2	23	2	52	0	2	0	0	0	0
NO904	C2 sample 3	16	0	0	0	5	0	0	0	0
NO905	C2 sample 4	5	0	9	0	5	0	0	0	0

Table 4.04. The commercial assessment criteria

Commercial grade	**Infestation level**	**Category**
Marketable	No visual presence of RKN	**1**
Second grade	RKN visually present Defects to skin included: - pimples - large eyes	**2**
Unmarketable	RKN visually present Defects to skin included: - galling - cracking - pinched in ends	**3**

Figure 4.02. Category 2 defect to skin - pimples


Figure 4.01. Category 2 defect to skin - large eyes


Figure 4.03. Category 3 defects to skin - galling and cracking


Figure 4.04. Category 3 defects to skin - pinched ends

Experiment 2

The Duranbah trial was a randomised block design with five treatments and three replicates (Table 4.05). Plots were three rows wide by 20 m long. The middle row was the datum row and either side was a buffer row.

The treatments (Table 4.06) were applied into the subsurface drip system with a water powered dosing machine, supplied by Netafim, called a Dosatron D45 RE 3. The Dosatron was installed directly into the water supply line which enabled us to deliver the treatment application regime (Table 4.06) at a constant dosing ratio in proportion to the flow required to service the T-Tape sub- surface drip system. The T-Tape used was Model 508-20-500. Emitter spacing was 20 cm delivering 1 litre per hour of water at 70 kpa. Pressure control valves were used to ensure pressure and flow was maintained during the treatment delivery time.

The depth Vydate® L was delivered into the root zone was managed through the use of Full Stops. Full Stops are a wetting front detection device. Two Full Stops were placed into treatment 2 at 20 cm below the soils surface and at 30 cm below the soils surface. Once the Full Stop at 20 cm detected the wetting front Vydate® L was injected through the system for approximately 5 minutes. Once Vydate® L was injected into the system irrigation remained on for a further 10 minutes to ensure all Vydate® L had been delivered to the root zone. The Full Stop at 30 cm below the soil surface would then detect the wetting front by the end of this process.

The trial site was sampled prior to planting for RKN by collecting randomised soil samples from the trial area. The number of RKN present in 200 mL of soil was 455 (Table 4.07). The numbers present were deemed to be at sufficient levels as to provide good infestation over the life of the crop.

During the crop's development five sweetpotato plants were sub - sampled from every plot at 56 days after planting (DAP), 85 DAP, 119 DAP. and 154 DAP. Plants were collected from each centre row, the roots were washed and visually assessed for RKN infestation and graded into commercial lines on the bases of marketability (Table 4.04 and Figures 4.01 – 4.04). At commercial harvest (154 DAP) eight sweetpotato plants were sub-sampled from every plot and visually assessed for RKN. No wireworm feeding injury was assessed in this trial due lack of crop damage.

Key NSW trial dates

26 November 2008	Planted trial
11 December 2008	Injected treatments 2, 3, 4 and 5
26 December 2008	Injected treatments 3 and 4
12 January 2009	Injected treatments 3 and 4
21 January 2009	First sample harvest 56 DAP
27 January 2009	Injected treatments 3 and 4
9 February 2009	Injected treatments 3 and 4
18 February 2009	Second sample harvest 84 DAP
25 March 2009	Third sample harvest 119 DAP
29 April 2009	Commercial harvest 154 DAP

Note: The decision to delay initial nematicide treatment applications was due to large amounts of rain received on the trial site at planting and the possibility of further forecasted rainfall.

Analyses of variance were conducted on the average counts and weights of storage roots assessed per plot at each of the harvests. As only the untreated control and treatment number 2 (18 L/ha at planting) or treatment 3 (18 L/ha at planting followed by four applications of 2 L/ha every 14 days after initial application) was of interest the comparison was made using an unprotected least significant difference (l.s.d. at 5%) test. This utilised the estimate of variation from the whole experiment, which is more accurate than using the estimate from just the control and the treatment of interest here. Genstat Release 11.1 was used for all analyses.

Table 4.05. Trial layout in the field

Plot	Replicate	Treatment
1	1	1
2	1	3
3	1	5
4	1	4
5	1	2
6	2	5
7	2	2
8	2	3
9	2	1
10	2	4
11	3	4
12	3	2
13	3	3
14	3	5
15	3	1

Table 4.06. Treatments used in the trial

Treatment	**Delivery system**	**Total rate of product**	**Application regime**
1. Untreated control	–	–	–
2. Vydate® L	Sub-surface drip	18 L/ha	Single application at planting
3. Vydate® L	Sub-surface drip	26 L/ha	18 L/ha at planting followed by four applications of 2 L/ha every 14 days after initial application
4. Vydate® L	Sub-surface drip	24 L/ha	8 L/ha at planting followed by four applications of 4 L/ha every 14 days after initial application
5. Nemacur®	Sub-surface drip	10.7 L/ha	Single application at planting

Table 4.07. List of plant parasitic nematodes and the numbers present in 200 mL of soil from soil collected at the trial site in July 2008

Laboratory ID	Sample ID	Plant parasitic nematodes/200 mL soil (corrected for extraction efficiency)								
		Root-knot	**Lesion**	**Reniform**	**Spiral**	**Spiral**	**Stunt**	**Stubby**	**Sheath**	**Ring**
		Meloidogyne sp.	*Pratylenchus* sp.	*Rotylenchulus* sp.	*Rotylenchus brevicaudatus*	*Helicotylenchus dihystera*	*Tylenchorchorus* sp.	*Paratichodorus* sp.	*Hemicycliophora* sp.	*Criconemella* sp.
NO907	House	455	0	475	90	0	0	0	0	0

Results and discussion

Experiment 1

First harvest (57 DAP)

No RKN infestation was visually detected on storage roots from any treatment plots at 57 DAP (refer to Table 4.08).

Table 4.08. Results presented are the average count and weight of storage roots assessed per plot at 57 DAP

	Marketable (no visual presence of RKN)	
Harvest 1	**Counts**	**Weight (grams)**
Treatments	n.s.	n.s.
1 UTC	31.5	1,538
2 Vydate® L 18 L	31.0	1,424
3 Vydate® L 26 L	32.3	1418
4 Vydate® L 24 L	28.3	1,408
5 Nemacur®	28.3	1,325

n.s. indicates no significant difference between treatments

Second harvest (84 DAP)

RKN infestation was visually detected on sweetpotato at 84 DAP as pimples and enlarged eyes (second grade). There was no significant difference between treatments for the number or weight of storage roots in either the marketable or second grade categories (refer to Table 4.09).

Table 4.09. Results presented are the average count and weight of marketable and second grade storage roots assessed per plot at 84 DAP

	Marketable (no visual presence of RKN)		**Second grade (RKN visually present)**	
	counts	**weight**	**counts**	**weight**
Treatments	n.s.	n.s.	n.s.	n.s.
1 UTC	33.5	1,905.5	1.3	232
2 Vydate® L 18 L	32	2272	1.3	164
3 Vydate® L 26 L	33	2808	0.5	231
4 Vydate® L 24 L	27	2854	0.3	38
5 Nemacur®	30.8	1,843.8	0.3	78

n.s. indicates no significant difference between treatments

Third harvest (108 DAP)

Root-knot nematode (RKN) infestation was visually detected on sweetpotato at 108 DAP as pimples and enlarged eyes (second grade). There was no significant difference between treatments in the number of storage roots in either the marketable or second grade categories (refer to Table 4.10).

A significant difference between treatments was found for the weight of marketable storage roots recorded. Treatments 2 and 3 recorded significantly higher yield, 13,498 and 13,739 grams respectively, in comparison to treatment 1 (UTC) yielding 10,724 grams.

Table 4.10. Results presented are the average count and weight of marketable and second grade storage roots assessed per plot at 108 DAP

	Marketable (no visual presence of RKN)				**Second grade (RKN visually present)**			
	counts		**weight**		**counts**		**weight**	
Treatments	n.s.				n.s.		n.s.	
1 UTC	34.5		10,724	c	0.8		150	
2 Vydate® L 18 L	33.8		13,498	ab	0.8		404	
3 Vydate® L 26 L	30.8		13,739	a	0.5		346	
4 Vydate® L 24 L	29.8		11,583	bc	0.5		250	
5 Nemacur®	25.8		12,181	abc	0.3		16	
Unprotected l.s.d. (5%)			2,108					

n.s. indicates no significant difference between treatments

In each column means followed by the same letter are not significantly different (P>0.05).

Commercial harvest (139 DAP)

At commercial and final harvest no unmarketable sweetpotato were recorded. There were significant differences between treatments for numbers of storage roots adversely affected by RKN (refer to Table 4.11).

Vydate® L applied at 18 L/ha at planting followed by four applications of 2 L/ha every 14 days after initial application (Treatment 3) resulted in significantly less second grade storage roots due to RKN infestation in comparison to the untreated control plot. The average number of second grade roots recorded per plot in treatment 3 was 2.5 out of a total of 28.5 storage roots in comparison to an average count of 9.3 out of a total of 28.8 recorded for the untreated control (unprotected l.s.d. of 5.4 at 5% level). This result indicates Vydate® L can provide commercially relevant levels of protection from RKN infestation in sweetpotato.

After the initial grading to assess RKN infestation the sweetpotato were then re-assessed to record the number and weight of those with wireworm feeding injury. The treatment plots where Vydate® L was applied a total of four times every 14 days after the initial application (Treatments 3 and 4) showed a significantly reduced weight of storage roots with wireworm feeding injury in comparison to the untreated control plot and the single application of Vydate® L at planting. This result does not indicate commercially appropriate levels of protection from wireworm feeding injury.

Table 4.11. Average count and weight of storage roots assessed per plot for RKN infestation and wireworm feeding at commercial harvest

	Marketable (no visual presence of RKN)				Second grade (RKN visually present)				Wireworm			
	counts		**weight**		**counts**		**weight**		**counts**		**weight**	
Treatments	n.s.						n.s.		n.s.			
1 UTC	19.2		11,017	b	9.3	a	5,273		28.5		16,585	a
2 Vydate® L 18 L	24.8		14,852	ab	3.8	ab	3,015		27.8		18,200	a
3 Vydate® L 26 L	26.2		17,853	a	2.5	b	3,307		19.8		11,500	ab
4 Vydate® L 24 L	20.2		14,740	ab	3.0	b	2,862		19.0		7,473	b
5 Nemacur®	14.0		10,129	b	6.8	ab	6,525		20.5		17,090	a
Unprotected l.s.d. (5%)			6,091		5.4						8,243	

n.s. indicates no significant difference between treatments
In each column means followed by the same letter are not significantly different (P>0.05).

Experiment 2

First harvest (56 DAP)

RKN infestation on sweetpotato was detected at 56 DAP as pimples and enlarged eyes (second grade). There were significant differences found between treatments for the number of marketable sweetpotato (refer to Table 4.12).

Vydate® L applied at 18 L/ha at planting followed by four applications of 2 L/ha every 14 days after initial application (Treatment 3) resulted in significantly more marketable storage roots in comparison to the untreated control plot. The average number of marketable storage roots recorded per plot in treatment 3 was 24.3 out of a total of 43.7 in comparison to an average count of 6 out of a total of 39.7 recorded for the untreated control (unprotected l.s.d of 14.28 at 5% level).

Table 4.12. Results presented are the average count and weight of storage roots assessed per plot at 56 DAP

	Marketable (no visual presence of RKN)				Second grade (RKN visually present)			
	counts		weight		counts		weight	
Treatments			n.s.		n.s.		n.s.	
1 UTC	6.00	a	0.13		33.70		1.74	
2 Vydate® L 18 L	13.30	ab	0.50		24.70		1.43	
3 Vydate® L 26 L	24.30	b	0.81		19.30		1.24	
4 Vydate® L 24 L	7.70	a	0.20		24.30		1.73	
5 Nemacur®	7.70	a	0.01		36.30		2.05	
Unprotected l.s.d. (5%)	14.28							

n.s. indicates no significant difference between treatments
In each column means followed by the same letter are not significantly different (P>0.05).

Second harvest (84 DAP)

RKN infestation on sweetpotato was detected at 84 DAP as pimples and enlarged eyes (second grade). There were differences found between treatments for the number of second grade sweetpotato (refer to Table 4.13).

Vydate® L applied at 18 L/ha at planting (Treatment 2) resulted in less second grade storage roots in comparison to the untreated control plot. The average number of second grade roots recorded per plot in treatment 2 was 2 out of a total of 34.7 in comparison to an average count of 10.67 out of a total of 37.7 recorded for the untreated control (unprotected l.s.d of 7.04 at 5% level).

Table 4.13. Results presented are the average count and weight of storage roots assessed per plot at 84 DAP

	Marketable (no visual presence of RKN)				Second grade (RKN visually present)			
	counts		weight		counts		weight	
Treatments	n.s.		n.s.				n.s.	
1 UTC	27.30		2.340		10.67	b	2.17	
2 Vydate® L 18 L	32.70		4.190		2.00	a	0.35	
3 Vydate® L 26 L	34.00		3.910		5.33	ab	1.22	
4 Vydate® L 24 L	33.70		3.920		8.00	ab	1.20	
5 Nemacur®	30.70		3.750		10.00	b	1.74	
Unprotected l.s.d. (5%)					7.04			

n.s. indicates no significant difference between treatments
In each column means followed by the same letter are not significantly different (P>0.05).

Third harvest (119 DAP)

RKN infestation on sweetpotato was detected at 119 DAP as pimples and enlarged eyes (second grade). There were differences found between treatments for the number of second grade sweetpotato. Unmarketable sweetpotato were recorded in plots at 119 DAP at very low levels (refer to Table 4.14).

Vydate® L applied at 18 L/ha at planting (Treatment 2) resulted in less second grade and unmarketable storage roots when combined. The average number of second grade and unmarketable storage roots combined recorded per plot in treatment 2 was 9 out of a total of 30 in comparison to an average count of 25.7 out of a total of 32.4 recorded for the untreated control.

Table 4.14. Results presented are the average count and weight of storage roots assessed per plot at 119 DAP

	Marketable (no visual presence of RKN)				Second grade (RKN visually present)				Unmarketable (RKN visually present)			
	counts		weight		counts		weight		counts		weight	
Treatments	n.s.		n.s.		n.s.		n.s.		n.s.		n.s.	
1 UTC	6.7		1.56		25.0		6.89		0.7		0.15	
2 Vydate® L 18 L	21.0		5.30		7.3		3.28		1.7		0.37	
3 Vydate® L 26 L	11.3		2.77		14.3		3.91		0.0		0.00	
4 Vydate® L 24 L	22.0		5.76		10.3		3.55		0.3		0.04	
5 Nemacur®	14.0		3.59		15.3		3.99		4.7		1.11	

n.s. indicates no significant difference between treatments

Fourth harvest (154 DAP)

RKN infestation on sweetpotato was visually detected at 154 DAP as both second grade (pimples and enlarged eyes) and unmarketable (galling, cracking and pinched ends) sweetpotato. There were differences found between treatments for the number of sweetpotato infested by RKN (refer to Table 4.15).

A single application of Vydate® L applied at a rate of 18 L/ha just after planting (treatment 2) resulted in significantly less unmarketable storage roots due to RKN infestation in comparison to the untreated control. The average number of storage roots per plot in treatment 2 was 12.7 out of a total of 52 storage roots in comparison to 24 storage roots out of a total of 44.7 storage roots for treatment 1 (UTC) (Unprotected LSD of 11.2 at 5% level). There was no difference between the single application of Vydate® L (treatment 2) and the multiple application regimes' of Vydate® L (treatments 3 or 4). Vydate® L applied at 18 L/ha just after planting followed by four applications of 2L/ha every fourteen days (treatment 3) resulted in an average of 13.7 unmarketable storage roots out of 46 storage. Vydate® L applied at 8 L/ha just after planting followed by four applications of 4 L/ha (treatment 4) resulted in 15 out of 44.4 storage roots. This result indicates Vydate® L can provide commercially relevant levels of protection from RKN infestation in sweetpotato.

Table 4.15. Results presented are the average count and weight of storage roots assessed per plot at 154 DAP

	Marketable (no visual presence of RKN)				Second Grade (RKN visually present)				Unmarketable (RKN visually present)			
	counts		**weight**		**counts**		**weight**		**counts**		**weight**	
Treatments	n.s.		n.s.		n.s.		n.s.				n.s.	
1 UTC	3.7		1.43		17.0		6.73		24.0	a	8.77	
2 Vydate® L 18 L	15.7		6.83		23.7		10.03		12.7	b	3.82	
3 Vydate® L 26 L	11.3		4.07		21.0		8.70		13.7	ab	3.52	
4 Vydate® L 24 L	11.7		5.20		17.7		7.89		15.0	ab	4.68	
5 Nemacur®	8.0		3.35		21.0		7.91		22.7	ab	7.45	
Unprotected l.s.d. (5%)									11.2			

Conclusion

A submission was made by Agware Pty Ltd in consultation with DEEDI, the Australian Sweetpotato Growers Association Pty Ltd and Dupont Pty Ltd to the APVMA to permit the usage of Vydate® L applied at 18 L/ha through the trickle irrigation system at transplanting.

APVMA permit 10762 for the use of Vydate® L applied at 18 L/ha at transplanting has been granted, valid from August 2008 to March 2012.

Chapter 5: Survey of growers' practices and further needs

April 2010

Key points

This report gives the results of a second survey carried out by the *Improving the Management of Sweetpotato Soil Insects* (VG05037) project financed by DEEDI, HAL, and SPGA. The first survey was done in 2006 at the beginning of the project, and reported on growers' practices and perceived research needs. The 2010 survey, carried out with many of the same growers at the end of the project, records changes in the way that soil insects are managed, and how a new project on soil insect management might help growers in the future. Key points from the 2010 survey are as follows:

General

- The relative areas of sweetpotatoes varieties grown remains unchanged - Beauregard retains 98% of production;
- Trickle irrigation is the dominant method, both pre- (95%) and post-plant (90%); in 2006, it was 55% and 65%, respectively.

Soil pest management

The **perceived** potential for soil pests to cause damage is as follows:

- Sweetpotato weevil – up slightly to 30%, with increased concern in Cudgen;
- White-fringed weevil – unchanged: not a problem;
- Cane grub – down sharply, from 30% to less than 10%;
- Wireworm – unchanged at 60%;
- Nematodes – sharp increase to >90%.

Chemical treatments: Pre-plant applications

- Talstar® - remains chemical of choice for sweetpotato weevil and wireworm;
- Lorsban® - use has decreased by about 12% in Bundaberg and 25% in Cudgen;
- Thimet® – use has decreased by 75% in Bundaberg, and 20% in Cudgen;
- Nemacur® - use has halved in Bundaberg (now 25%), and it is not used in Cudgen or Rockhampton;
- Regent® - use in Bundaberg (40%) is unchanged; not used in Cudgen;
- Confidor® - rarely used pre-plant in any location.

A majority of growers (94%) are applying Talstar® pre-plant for wireworm management; the applications are mostly within permitted limits.

Chemical treatments: Post-plant applications

- Confidor® - applied via trickle tape soon after planting against sucking insects, whiteflies and aphids, but thought to be active against weevil, wireworm and cane grubs. Now used by 65% of growers.
- Confidor® 200 SC - applied "over-the-top" against whiteflies, aphids, thrips and caterpillars by only 12% of growers;

- Lorsban® - applied “over-the-top” against weevil and wireworm; use remains unchanged in Bundaberg (60%); not reported from Cudgen (40% in 2006);
- Talstar® – applied “over-the-top” against weevil and wireworm, used by 75% of growers, more in Bundaberg (83%) than Cudgen (50%);
- Vydate® - applied via trickle tape against nematodes by 75% of growers in both Bundaberg and Cudgen. Mostly applied within 7 days of planting; in one instance, applications split between 1-2 weeks and 5 weeks.

Analysis of survey results shows that the amounts of Talstar® applied post-plant are often above permit rates, irrespective of bifenthrin formulations (100 g/l or 250 g/l).

Growers reported a number of occasions when specific chemicals failed to give the desired control. These failures are similar to those reported in 2006, except that failures of Talstar® and Vydate® are reported due to high rainfalls after application.

Cultural methods of control
- Overhead irrigation - during dry times to “seal” the soil to prevent entry of sweetpotato weevil;
- Removal of crop residues and volunteers - by cultivation (from 55% in 2006 to 70%), or volunteers by herbicides (50%), to prevent sweetpotato weevil 'hotspots' developing;
- Crop rotation - practiced by all growers with results are similar to 2006: 70% use sorghum; 22% cane and 17% use vegetables in the rotation.

Problems in growing sweetpotato in 'new' land
Cane grub problems following sugarcane show an increase from 40% in 2006 to 60%, whereas wireworm is similar (40%). Two of 12 growers in Bundaberg reported problems with nematodes after sugarcane. In Cudgen, one grower reported wireworm problems following sugarcane or grassland.

Monitoring crop pests
- Most growers check their crops by “having a scratch” (Bandicoot method);
- Many growers in Bundaberg use the sweetpotato weevil pheromone (6% in 2006; now 80%);
- Three growers are purchasing the pheromone and/or making traps;
- One grower is timing spray application based on sweetpotato trap counts;
- Cudgen growers are keen to use the pheromone for monitoring sweetpotato weevil infestations, which have increased in recent years;
- Growers in Bundaberg and Cudgen arrange for nematode counts to be done (30%).

Future directions
Activities for inclusion in a new soil insect management project are:
- A need to:
  a) screen other pesticides; and
  b) develop strategies to prolong the effectiveness of those now in use - there is a concern that growers are reliant on too few chemicals (mainly, Talstar®, and Lorsban®);

- There is need to confirm that expiry dates of permits to use Talstar® (September 2013), and Lorsban® and Vydate® (until early 2012) will be extended;

- A need for a better understanding of the biology of wireworm, leading to a more strategic approach to its management, and a move away from routine applications of chemicals irrespective of pest numbers;

- A need for an IPM systems approach for all pests which combines a number of techniques to prevent pest damage - biological control, cultural practices and, perhaps, resistant varieties - with pesticides used only when necessary;

- All growers expressed a willingness to provide land for trials to develop monitoring systems and new pest management strategies, and a willingness to take part in training programs for their implementation.

Acknowledgements
I wish to thank the farmers in the three areas surveyed, Bundaberg, Cudgen and Rockhampton, for making the time to be interviewed and providing information on their current production practices and needs for the future. I thank Russell McCrystal, DEEDI, for organising farmer visits, and for useful advice and comments throughout the survey and report writing.

Abbreviations

2,4-D	2,4-Dichlorophenoxyacetic acid
ai	Active ingredient
APVMA	The Australian Pesticides and Veterinary Medicines Authority
DEEDI	Department of Employment, Economic Development and Innovation
ec	Emulsifiable concentrate
ha	Hectare
HAL	Horticulture Australia Ltd.
IPM	Integrated pest management
L	litre
sc	Suspension concentrate
SPGA	Sweetpotato Growers Association
u/k	unknown

Soil pests referred to
Note, the soil pests referred to in this report are as follows:

Sweetpotato weevil: *Cylas formicarius*
Wireworm: True and false wireworms (Families Elateridae and Tenebrionidae)
Whitefringed weevil: *Naupactus leucoloma*
Cane grub: *Lepidiota crinita*
Nematode: *Meloidogyne* species

1. Introduction

This is the second survey on sweetpotato management practices carried out by The Department of Employment, Economic Development and Innovation (DEEDI), Queensland. It concerns the activities of the project *Improving the Management of Sweetpotato Soil Insects* (VG05037) supported by DEEDI, Horticulture Australia Ltd., and the Australian Sweetpotato Growers Inc.

The first survey was carried out in 2006. It provided a baseline of growers' production systems at the time, and the most pressing needs of the industry, which were:

- Effective insecticide registrations and minor use permits;
- A practical monitoring technique for wireworm;
- New varieties;
- Reduced reliance on pesticides and/or identification of chemicals with "softer" action, the identification of biological and cultural methods of pest control;
- Reduced insecticidal use, to reduce the rate of insect resistance.

Since its inception, the project has completed an extensive literature survey on sweetpotato soil insects and nematodes. It has also identified many aspects of wireworm and sweetpotato weevil biology that can be used to control these pests in management systems with low pesticide input.

The purpose of the second survey was twofold. Firstly, to gauge how the project has helped farmers in managing soil insects; in particular, how it has brought about change in production practices based on the research done. Secondly, it was to obtain the views of farmers on the direction of future research to develop an integrated pest management system for sweetpotato soil pests.

2. Methods

A questionnaire compiled for the first survey was provided by DEEDI, and used with modification for the present work. The question about production costs was omitted, and three added: 1) whether monitoring techniques would be used if demonstrated (Question 7); 2) willingness to provide land for the long term to develop techniques for monitoring populations of soil pests (Question 8); and 3) when Chemcert accreditation was last undertaken, and whether there were any difficulties (Question 12). The questionnaire is attached as Annex 1.

In order to obtain the information required, farmers were interviewed in two ways. Six growers were visited in the Bundaberg area 6-7 April, and 11 growers – six from Bundaberg, five from Cudgen and one from Rockhampton - were interviewed by phone. The questions put to the three groups were the same.

The information obtained was pooled and compared to that obtained during the 2006 survey. The results are presented in graphs and tables, and as far as possible summarised in and abbreviated fashion.

3. Results

The results of the survey follow the sequence defined in the first survey for ease of comparison.

3.1 Varieties grown

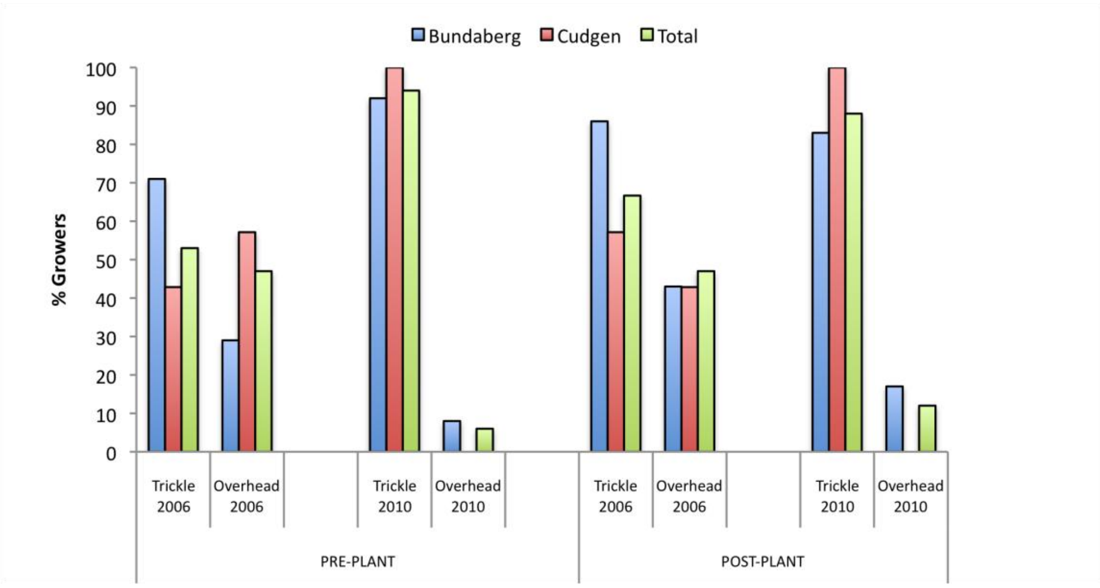
The survey found that all 17 farmers interviewed grew Beauregard, and this variety was grown on 98% of 860 ha of land devoted to sweetpotato production by the group. Northern Star was grown by three farmers in the Bundaberg area and one in Cudgen, and accounted for most of the remaining 2%. Two of the three farmers who grew Northern Star, also grew small amounts – 1 ha or less - of other reds or whites.

3.2 Irrigation system

In 2006, overhead irrigation systems and trickle were on a par; today, most farmers use trickle pre-plant and during the growing season (Figure 5.01). None of the growers in the Cudgen area uses overhead irrigation. Presumably, the change to trickle irrigation has come about in part to conform to the conditions for use of oxamyl (Vydate®), now the preferred chemical for nematode control. The conditions for use of Vydate® under permit PER10762 stipulate its application through trickle/drip irrigation.

Of those growers who do not use trickle irrigation in every crop, one uses it if Vydate® is applied when sweetpotatoes follow cane, but at other times uses overhead irrigation; a second farmer, irrigates using sprinklers and a water winch. In this case, Nemacur is used for nematode control.

Figure 5.01. Irrigation pre- and post-planting: comparisons between 2006 and 2010 in Bundaberg, Cudgen, and total including Rockhampton



In addition, five of the 17 growers mentioned that extra water was given by overhead irrigation if conditions were dry for a prolonged period.

3.3 Major pests

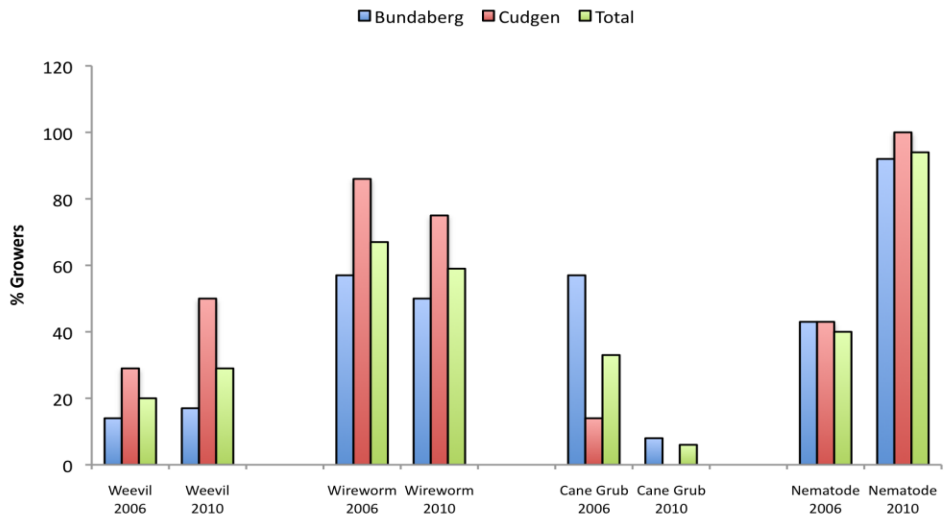
Farmers were asked whether they experience damage from soil pests, and which ones. Most said that soil insects and nematodes were no longer a problem, but most considered them **potentially damaging**. Where there was a **perception** of potential damage, they were categorised as 'major', and where they were not, 'minor'. Growers gave an approximation of damage when outbreaks of each of the pests occurred. The results (Figure 5.02) compared 2006 and 2010 surveys:

- Sweetpotato weevil: an **increase** in the potential damage in Cudgen (from 30% to 50%), with little change in Bundaberg (<20%);
- Wireworm: **little change** in the potential damage caused by wireworm (60% of growers still considered it “major”);
- Cane grub: a large **decrease** in the potential damage from cane grub (down from 33% of growers saying it was “major” to <10%);
- Nematode: a large **increase** in the threat from nematodes (40% to >90%) .

Farmers reported very low damage from the White-fringed weevil (data not shown in Figure 5.02); it barely registered as a 'minor' problem.

In general, growers were concerned about the potentially damaging effects of wireworm and nematode; rarely were they concerned about either kind of weevil – sweetpotato or white-fringed - or cane grubs. The perception was that these could be controlled relatively easily by insecticides, although, in Cudgen, problems with sweetpotato weevil have increased in recent dry years.

Figure 5.02. Major pests perceived by growers as a threat to sweetpotato production: comparisons between 2006 and 2010 in Bundaberg, Cudgen, and total including Rockhampton



The estimated damage caused by weevils, wireworm and nematodes is given in Table 5.01. This is the maximum damage that is likely, not the recurring effect of these pests. It records farmers’ perceptions of damage: that which is likely to occur without adequate control measures.

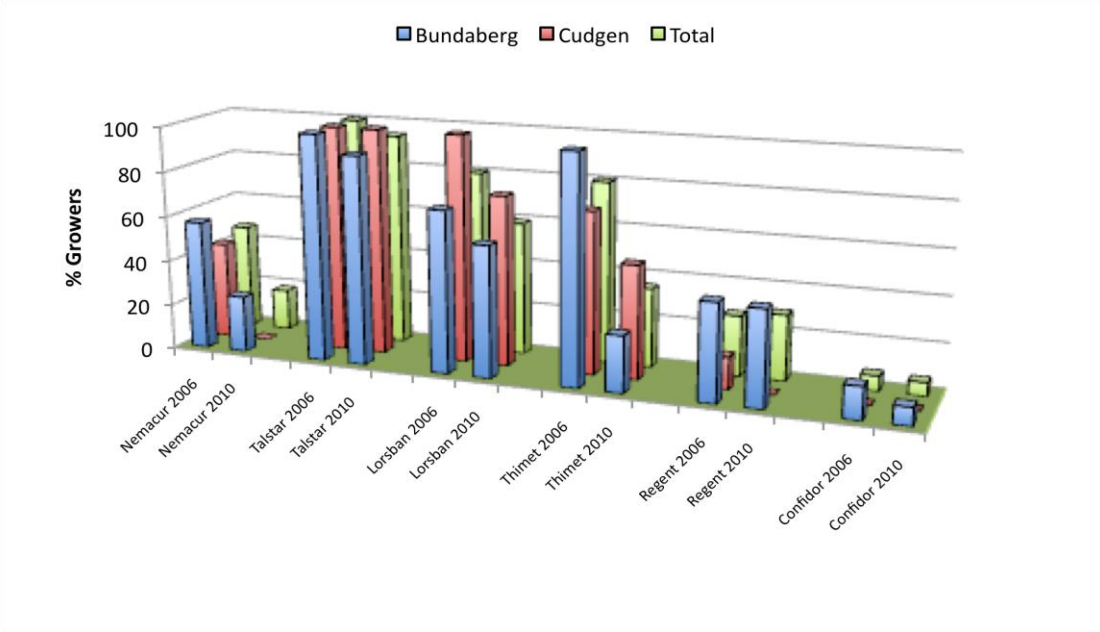
Table 5.01. Damage to sweetpotato roots by soil pests: farmers' estimates in Bundaberg and Cudgen

Pest	Bundaberg (Total 12 farmers)				Cudgen (Total 4 farmers)			
	Nos. farmers reporting damage in 4 categories							
	<5%	5-25%	25-50%	>50%	<5%	5-25%	25-50%	>50%
Weevil	9	2	1	0	2	1	0	1
Wireworm	8	1	2	1	1	1	0	2
Cane grub	11	1	0	0	4	0	0	0
Nematode	1	3	5	1	0	2	2	1

3.4 Chemical control treatments

Six chemicals are available for pre-plant applications to control populations of wireworm, weevils, cane grub and nematode (Figure 5.03). They are the same six identified in 2006. However, for some chemicals, their frequency of use has changed between then and 2010. A summary is provided:

Figure 5.03. Chemicals applied pre-plant: frequency of use at Bundaberg, Cudgen and the total of all growers, including Rockhampton



- For those chemicals used commonly in 2006 - Talstar®, Lorsban® and Thimet® - the situation in 2010 is:
    - Talstar® - it remains the chemical of choice for the control of sweetpotato weevil and wireworm, and is applied by almost all growers;
    - Lorsban® - it is used less frequently; a decrease of about 12% in Bundaberg and 25% in Cudgen;
    - Thimet® - it is used much less; the decrease is most marked in Bundaberg (75% less), with also substantial changes in Cudgen (20%).
- For those chemcials used less frequently in 2006 – Nemacur®, Regent® and Confidor® – the situation in 2010 is:
    - Nemacur® - its use has halved in Bundaberg (now 25%), and it is not used by the growers surveyed in Cudgen or Rockhampton;
    - Regent® - it is not used in Cudgen; use in Bundaberg (40%) is unchanged;
    - Confidor® - it is rarely used pre-plant in any of the three locations.

In addition, four of 17 growers apply Talstar® and Regent® pre-plant against wireworm and weevil (permits, PER9063, PER9722 and PER10273); seven growers apply Talstar® and Lorsban® - the latter is also approved for pre-plant wireworm control (PER5851); one grower applies all three; and, another, Regent® and Lorsban®. Applying two or more chemicals was said to reduce the risk of pest resistance developing.

The 2006 survey compared the amount of Talstar® used by 10 growers against the rate permitted for weevil (Figure 5.04). Actually, there is no recommended rate for weevil pre-plant; it is for post-plant applications. However, the data from the 2010 survey was used to compare pre-plant use of Talstar® by 11 growers from Bundaberg for wireworm control (Figure 5.05).

Figure 5.04. Use of Talstar® (bifenthrin) against weevil of 10 growers compared with the permitted use (600 mL/ha of 100 ec), represented as a green line: 2006

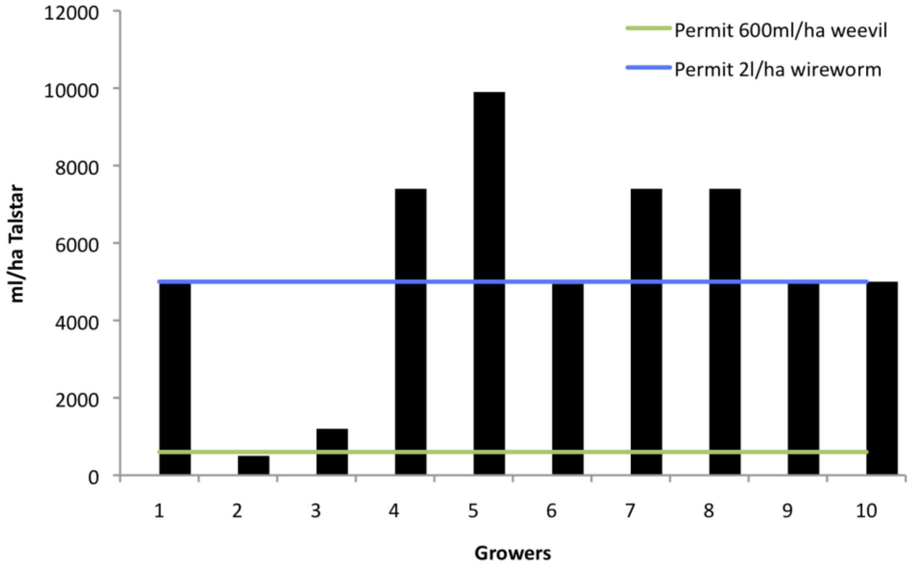
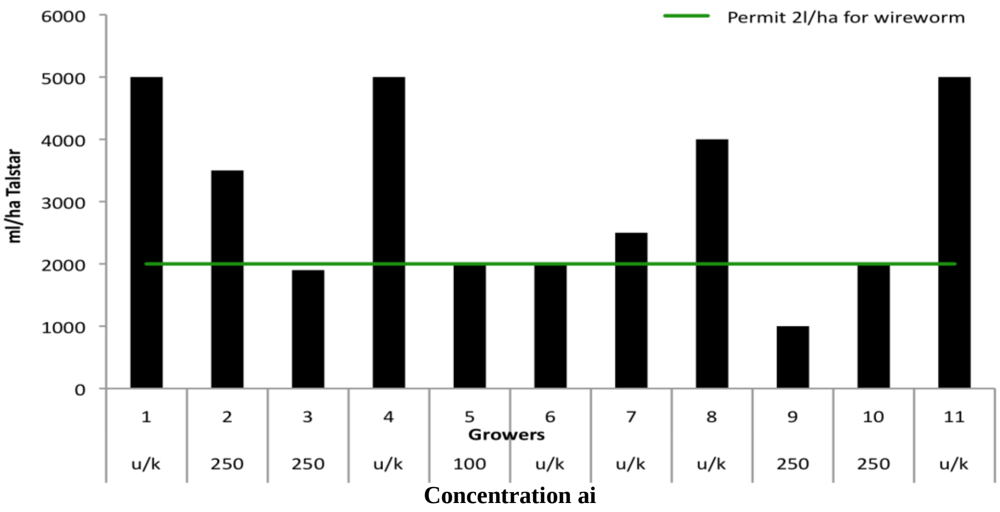


Figure 5.05. Use of Talstar® (bifenthrin) of 11 growers compared with permitted use rate of 2 L/ha of 250 ec (or 5 L/ha of 100 ec), represented as a green line: 2010. The concentration (ai) of Talstar® used by growers is given where known; otherwise, u/k = unknown



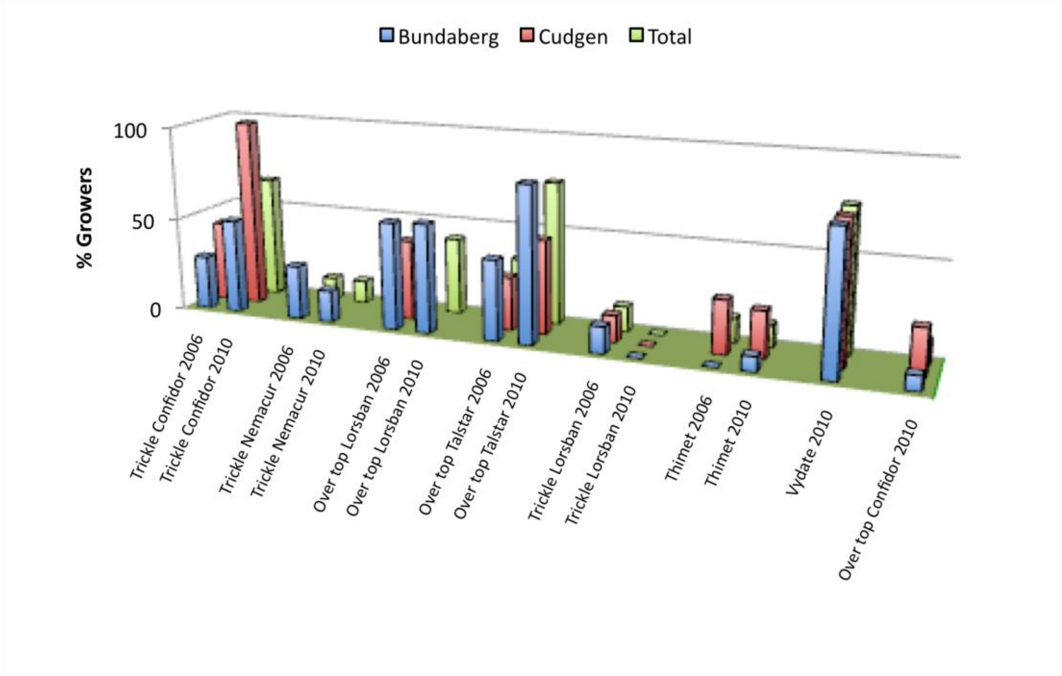
In the 2006 survey, it was suggested that the amount of Talstar® used against weevil was in excess of the permitted 600 mL/ha (100 ec), but that is the post-plant rate for sweetpotato weevil. The amount permitted pre-plant is 5 L/ha (100 ec) for wireworm, or 2 L/ha (250 ec); the blue line in Fig. 5.0 4 indicates this. With this change, the two graphs can then be compared. It is apparent that most growers are now applying Talstar® within permitted limits. In Figure 5.05, it is assumed that where growers were unsure of the concentration during the survey (u/k), they were using Talstar® 100 EC.

Eight chemicals were recorded as post-plant treatments (Figure 5.06). There were many permutations depending on the pests of concern, pest history of the land and other crops in the rotation. Some points of interest are as follows:

- Four chemical dominate post-planting production – Confidor®, Lorsban®, Talstar® and Vydate®; comparing each with the 2006 survey showed:
  - Confidor® Guard - applied through trickle tape is used by 65% of growers (40% in 2006); applied once after planting, against whiteflies and aphids, but thought to be active against weevil, wireworm and cane grubs. Three of 11 growers in Bundaberg specifically said they used Confidor® Guard, as did all growers in Cudgen;
  - Confidor® 200 SC - applied 'over-the-top'" against whiteflies, aphids, thrips and caterpillars was used by only 12% of growers (similar to 2006);
  - Lorsban® - applied 'over-the-top' against weevil and wireworm, was not reported from Cudgen (down from 40%), but unchanged in Bundaberg (60%). By contrast to 2006, no instance of application through trickle tape;
  - Talstar® – applied 'over-the-top' is the chemical of choice post-plant against weevil, used by three quarters of the growers, more in Bundaberg (83%), compared to Cudgen (50%);
  - Vydate® - applied through trickle tape is the chemical of choice against nematodes for three quarters of growers in both Bundaberg and Cudgen.

Mostly, it is applied within 7 days of planting; in one instance, a split application is given, at 1-2 weeks and later at 5 weeks.

Figure 5.06. Chemicals applied post-plant: frequency of use at Bundaberg, Cudgen and totals of all growers (including Rockhampton)



A comparison was made between the amounts of Talstar® used by growers post-plant and that permitted (Figure 5.07 and Table 5.02). The results show that in a majority of cases the amounts are outside those stipulated under the conditions of use. Post-plant applications are permitted for sweetpotato weevil control at 600 mL/ha for a 100 g/L formulation (or equivalent for a 250 g/L formulation). Multiple applications are permissible at 2-4 week intervals depending on weevil numbers.

Talstar® is not permitted at the higher – wireworm – rate as a post-plant application; the 5 L/ha (100 g/L) or 2 L/ha (250 g/L) rate is for pre-plant only.

Figure 5.07. Use of Talstar® (bifenthrin) of 12 growers compared with permitted use rate of 600 mL/ha (100 g/L bifenthrin) for sweetpotato weevil, represented by green line. The concentration (ai) of Talstar® used by growers is given where known; otherwise, u/k = unknown

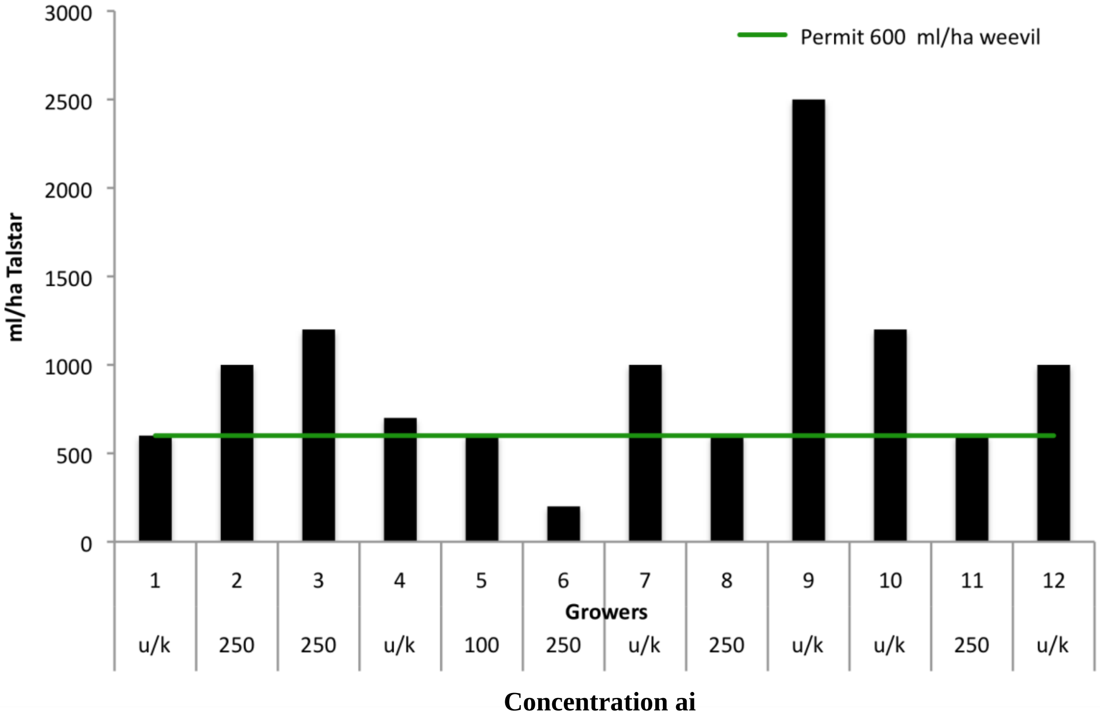


Table 5.02. Target pests of the 12 growers listed in Figure 5.07 against which Talstar® is applied

Growers	Whitefly	Aphid	Hornworm/ Armyworm	Weevil	Wireworm	Cane grub	Within permit?
1			√				Possibly
2				√			no
3			√		√		no
4				√	√		Possibly
5			√	√			yes
6			√				yes
7				√	√		no
8				√	√	√	no
9	√			√			no
10				√	√		no
11			√		√		no
12				√			no

'Possibly' assumes that the concentration of Talstar® is 100g/L.

Frequently, Talstar® and Lorsban® are applied together or alternated. Growers expressed concern that repeated application of one alone may lead to insect populations resistant to the chemicals' effect. It was felt that this had happened with Thimet® and Nemacur®.

Of the others chemicals reported in the 2006 survey, Thimet® is no longer used post-plant, and there is only occasional use of Nemacur® (it is not used in Cudgen), having been replaced by Vydate®.

There were only minor variations in the chemical schedules used by growers:

- Growers reported increased intervals between applications of "over-the-top" Lorsban®, Telstar® and Regent® on winter crops, often in response to lower incidence of caterpillars, or adult weevils and wireworms in the crop;
- Applications of insecticides against sweetpotato weevil for one grower were dependent on pheromone trap results;
- Different chemicals were used, often as trials. One grower was using neem cake for the control of nematodes with good results; and another was applying Regent® through the trickle tape.

3.5 What chemical treatments have not worked?

For the most part, chemical treatments have worked well, especially those used at present, for which the project has obtained minor use permits from the APVMA. However, growers did report occasional failures, and these are worth recording:

- Thimet® – failure to control wireworms (four growers);
- Regent® – failure pre-plant to control weevil (one grower); and high losses from wireworm when using Lorsban®/Regent® (two growers);
- Lorsban® – failure to control wireworm and cane grub (one grower);
- Vydate® – failure when using bore water (it is a pH sensitive chemical) (several growers); also failure in Bundaberg in December 2009/January 2010 plantings, possibly washed out by high rainfall after application (several growers);
- Talstar® – failure in Cudgen last season after 5/6 inches of rain (all growers)
- Nemacur® – failed to give consistent results in the past, and growers worried about resistance to the chemical, driving the need for a replacement (several growers).

These failures were similar to those reported in 2006 and, in fact, may have included the same instances. In 2006, it was reported that Lorsban failed against wireworm; Nemacur® against nematodes; Confidor® and Lorsban® against cane grub; and Regent® pre-plant against wireworm.

The impression given is that Thimet® and Nemacur® are less effective than required, and are being phased out by growers or have already been deleted from chemical regimes. The usefulness of Regent® is being questioned; it is no longer used in Cudgen.

3.6 Cultural control treatments

3.6.1 Overhead irrigation

Growers are not reliant totally on chemicals to control soil borne pests: they apply several cultural measures to reduce damage to sweetpotatoes, watering the crop at key times, being one of them. Six growers specifically mentioned that they irrigate crops to maintain a damp soil profile and to prevent cracks from developing, which can be used by adult sweetpotato weevils to reach the tuberous roots.

3.6.2 Specific hygiene measures

Growers realise that the destruction of crop residues is important in keeping soil insects under control, particularly sweetpotato weevil. This realisation is based on research carried out by the project that has shown the importance of destroying crop residues and volunteer plants. If this is not done quickly after harvest, “hot-spots” of high weevil numbers occur and these can flare into major weevil outbreaks. Destruction of residues is done by cultivation or by the application of herbicides.

Of the 15 growers who reported the destruction of crop residues and volunteer sweetpotatoes, seven used soil cultivation alone, three used herbicides alone, and five used both. The herbicide of choice was 2,4-D, although Starane (Fluroxypyr) and Roundup (glyphosate) were also mentioned.

In 2006, 56% of growers destroyed crop residues and volunteer sweetpotato plants by cultivation; in 2010, it was 70%, and nearly 50% use herbicides, with or without cultivation.

3.6.3 Crop rotations

All farmers practice crop rotations, although in some cases the time between crops of sweetpotato is short, only 12 to 18 months, or less. Growers realise that intensity of cropping is a major factor in the incidence of soil borne pests, which under present production systems can only be managed satisfactorily with the frequent use of chemicals. Therefore, it was not possible to determine the impact of rotations on any soil pest populations, as the effect is masked. However, the rotations used were recorded (Table 5.03).

Table 5.03. Types of rotations used in Bundaberg, Cudgen and Rockhampton (17 growers) between crops of sweetpotato. Note, some growers use more than one type of rotation.

Rotation	Bundaberg	Cudgen	Rockhampton
	No. of times reported		
Cane	2	0	0
Cane/Sorghum	2	0	0
Sorghum	3	0	0
Sorghum (winter cereals or vegetables or short fallow)	6	2	0
Sweet corn	0	1	0
Green panic*/fallow	0	0	1

*Green panic is *Panicum maximum* var. *trichoglume*

The results are similar to those of 2006, where 22% of growers used cane in the rotation, 72% Sorghum, and 17% vegetables.

The advantage of Sorghum in the rotation is threefold: 1) it is not a host of the major sweetpotato pests, so its use will reduce pest populations; 2) it is easily incorporated into the soil, and provides the soil with organic matter; and 3) it smothers volunteer sweetpotatoes.

Two growers had tried Lablab (*Lablab purpureus*), but were concerned that it was a host for soil nematodes.

3.7 Problems in cultivating 'new' ground

In the 2006 survey, 40% of growers in Bundaberg reported difficulty with cane grub in sweetpotato crops following sugarcane, and a similar number with wireworm. In 2010, nearly 60% reported cane grub difficulties, whereas those caused by wireworm had not changed. Two of 12 growers in Bundaberg reported difficulties with nematodes after sugarcane in the 2010 survey.

One of the four growers in Cudgen surveyed had problems with wireworm following sugarcane, or where sweetpotato was planted on previously grassy land.

3.8 Monitoring sweetpotato crops for insect pests

The majority of growers 'have a scratch' or use the Bandicoot method for monitoring their crops of sweetpotato. For sweetpotato weevil, however, there is keen interest in the use of the pheromone for monitoring purposes. In 2006, only 6% of growers used the pheromone; now it is more than 80% in the Bundaberg. The project helps most growers with supplies of the chemical and traps, but some growers are purchasing the chemical, making the traps and putting them out, often near grassy headlands. One grower said that chemical treatments against weevil were based on trap counts. This is a new trend.

In Cudgen, the growers do not yet use the pheromone routinely, although there has been discussion to do so. They do, however, have a light trap, the results of which are shared. In this way, they can monitor insects that fly into the crops, allowing them to take appropriate action.

In 2006, there were no reports of growers having nematode counts done before planting; in 2010, three growers in Bundaberg and two in Cudgen (30% of the total growers surveyed) said they were doing so.

3.9 Chemcert course

All the growers responded that they or their staff were up to date with Chemcert accreditation. In general, there were no difficulties with the courses that they had attended, although one grower mentioned that the facilitator was more familiar with low volume applications used in cotton than the pesticide application methods used in sweetpotato production.

3.10 Future research – new directions

There is unanimous satisfaction with the work of the project, and growers consider that its objectives have been met. In particular, there is praise for the minor use permits that have been obtained from the APVMA.

However, growers are concerned that there is reliance on too few chemicals, and that any new project should continue to screen products as potential replacements for those used currently. Most growers use Talstar® and Vydate®, and the fear is that such intense use will select resistant strains, or soil pests will be able to biodegrade them. Strategies are needed to increase the time when these two chemicals remain in use.

Under the current permits for Talstar® (PER9722 and PER102730) use is allowed until 30 September 2013, and Lorsban® (PER5851) and Vydate® (PER10762), till early 2012. Growers asked what would happen after these dates.

Furthermore, growers feel that wireworm, in particular, is going to remain a problem into the future, and its management requires a better understanding of its biology.

With this information a more strategic approach to wireworm management would be possible, based on an understanding of basic ecological processes, and a move away from routine applications of chemicals irrespective of pest populations. What is required is an IPM system that focuses on reduction of damage by a combination of techniques, such as biological control, cultural practices and, perhaps, resistant varieties, with a judicious use of pesticides.

Such a system may be some way off for sweetpotato pests, but growers are interested in being part of the development and testing of new methods for managing major and minor soil pests. Growers have already collaborated with the project to test the sweetpotato weevil pheromone and, from answers provided in this survey, they are willing to provide land, although two growers made the proviso that they might not be able to spare the time to monitor the trials. However, there is a willingness among all growers to be trained in new soil pest management procedures, once developed.

Annex 1: Questionnaire: Management of Sweetpotato Soil Insects (VG05037)

Questionnaire: Management of Sweetpotato Soil Insects 2006

The Department of Employment, Economic Development & Innovation (DEEDI) is working to promote profitable primary industries for Queensland by providing its expertise and support to assist the State's food and fibre industries to increase productivity, improve sustainability, grow markets and adapt to change.
DEEDI is committed to delivering world-class research and development, providing leadership on industry policy, protecting industries against pests, diseases and maintaining animal welfare standards, managing fisheries sustainably, and maximising the value of state-owned forests.
This survey is the second undertaken as part of the project: Management of Sweetpotato Soil Insects (VG05037). *The information gathered will be used for two purposes: Firstly, to gauge how the Project has helped farmers in the development of their current production practices, by carrying out its work on: i) product efficacy; ii) minor use permit registration; and iii) residue testing. Secondly, as input into further studies, which aim to develop an integrated pest management system for sweetpotato soil insects. Participants in this survey will not be identifiable and all information provided will be treated in confidence.*

Name: ______________________________

Date: ______________________________

Question 1: Varieties grown?

Variety	**Area**
Beauregard	
Northern Star	
Other Reds	
Other Whites	

Question 2: Irrigation systems?

Production Stage	**Irrigation system**
At Planting	
During growing season	

Question 3: Do you experience damage to sweetpotato from soil insects, i.e., holes in the roots. If so, what is causing the damage?

Insects	Major	Minor	% contribution of crop damage
Sweetpotato weevil			
Wireworm			
White-fringed weevil			
Cane grub			
Nematodes			
Others			

Question 4: What is your current insect control program? What are you targeting?

Pre –plant:

Specific pest 1:

Rate:

Method:

Product:

Specific pest 2:

Rate:

Method:

Product:

Specific pest 3:

Rate:

Method:

Product:

Post-Plant:

Specific pest 1:

Rate:

Method:

Product:

Specific pest 1:

Rate:

Method:

Product:

Specific pest 1:

Rate:

Method:

Product:

Does the control program vary from season to season, i.e., Time of year, rainfall or temperature?

Question 5: Do you use any cultural methods to specifically control/manage soil insects, i.e., Spray irrigation to seal the top of the ridges to prevent entry of weevil?

Question 6: What insect control practices have not worked for you?

Question 7: Do you monitor for soil insects? Yes or No

If yes, how do you monitor insects?

Question 8: What crop rotations/fallow periods do you use between sweetpotato crops?

Do you remove volunteer sweetpotato plants from fields? How is this done?

Question 9: What are your experiences when growing sweetpotato in new ground, either rented or bought?

Question 10: In what way could the soil insect project assist your current practices?

Questionnaire: Management of Sweetpotato Soil Insects 2010

The Department of Employment, Economic Development & Innovation (DEEDI) is working to promote profitable primary industries for Queensland by providing its expertise and support to assist the State's food and fibre industries to increase productivity, improve sustainability, grow markets and adapt to change.
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Name: ____

Date: ____

Question 1: Varieties grown?

Variety	**Area**
Beauregard	
Northern Star	
Other Reds	
Other Whites	

Question 2: Irrigation systems?

Production Stage	**Irrigation system**
At Planting	
During growing season	

____

____

Question 3: Do you experience damage to sweetpotato from soil insects, i.e., holes in the roots. If so, what is causing the damage?

Insects	Major	Minor	% contribution of crop damage
Sweetpotato weevil			
Wireworm			
White-fringed weevil			
Cane grub			
Nematodes			
Others			

Question 4: What is your current insect control program? What are you targeting?

Pre –plant:

Specific pest 1:

Rate:

Method:

Product:

Specific pest 2:

Rate:

Method:

Product:

Specific pest 3:

Rate:

Method:

Product:

Post-Plant:

Specific pest 1:

Rate:

Method:

Product:

Specific pest 1:

Rate:

Method:

Product:

Specific pest 1:

Rate:

Method:

Product:

Does the control program vary from season to season, i.e., Time of year, rainfall or temperature?

Question 5: Do you use any cultural methods to specifically control/manage soil insects, i.e., Spray irrigation to seal the top of the ridges to prevent entry of weevil?

Question 6: What insect control practices have not worked for you?

Question 7: Do you monitor for soil insects? Yes or No

If yes, how do you monitor insects?

If no, would you use traps/attractants/soil sampling to monitor soil pests, if the techniques were shown to you?

Question 8: Would you like to provide long term sites to develop techniques/tools for monitoring and managing populations of the major and minor sweetpotato pests?

Question 9: What crop rotations/fallow periods do you use between sweetpotato crops?

Do you remove volunteer sweetpotato plants from fields? How is this done?

Question 10: What are your experiences when growing sweetpotato in new ground, either rented or bought?

Question 11: In what way could a new soil insect project assist your current practices?

Question 12: When did you do a Chemcert accreditation course? Where there any difficulties?

Chapter 6: Technology transfer

Methods used

1. Field experiments
2. Information sessions
3. Media news releases
4. Newsletter
5. Farm visits
6. Australian sweetpotato growers association
7. HAL VG05037 Milestone reports

1. Field experiments

Of the 11 field experiments 7 were carried out on cooperating grower properties. There was a scientific need to assess the efficacy of products at a number of soil types and production regions to obtain adequate and robust efficacy data. Apart from this obvious scientific need to work on cooperating grower properties, growers were personally involved in the design, implementation and interpretation of results. These lead growers become key players in the information transfer process.

1. Efficacy of soil incorporated insecticides applied prior to planting against wireworm. March to November 2007
Place: Bundaberg Research Station (QLD)

2. Efficacy of soil incorporated insecticides applied prior to planting against wireworm. May 2007 to January 2008
Place: Cudgen (NSW), Grower: Doug Paddon

3. Area wide mass trapping program study for the adult male sweetpotato weevil. August 2007 to April 2008
Place: Rockhampton (QLD) Grower: Rodney Wolfenden

4. Efficacy of foliar applied entomopathogenic fungi against sweetpotato weevil in sweetpotato seedbeds. August 2007 to March 2008
Place: Bundaberg Research Station (QLD)

5. Efficacy of trickle irrigation applied oxamyl against root-knot nematode in sweetpotato. Sept 2008 to February 2009
Place: Bundaberg research station (QLD)

6. Efficacy of soil incorporated insecticides applied prior to planting against wireworm. October 2008 to March 2009
Place: Bundaberg (QLD), Grower: Duane Joyce

7. Efficacy of trickle applied oxamyl against root-knot nematode in sweetpotato. November 2008 to April 2009.
Place: Cudgen (NSW), Grower: Kevin Kennedy

8. Efficacy of soil incorporated insecticides applied prior to planting against wireworm. December 2008 to April 2009
Place: Cudgen (NSW), Grower: Doug Paddon

9. Efficacy of soil incorporated thiamethoxam prior to planting against sweetpotato weevil infestation at commercial harvest. October 2008 to April 2009

10. Efficacy of soil incorporated thiamethoxam prior to planting against sweetpotato weevil infestation at commercial harvest. October 2008 to Arpil 2009
Place: Bundaberg (QLD), Grower: Dave Fisher

11. Efficacy of fipronil applied through trickle irrigation against wireworm in sweetpotato. October 2009 and March 2010
Place: Bundaberg Research Station (QLD)

2. Sweetpotato grower and service providers information days

On average of 35 to 50 people attended the Bundaberg information days and around 20 attended the Cudgen information days.

Date	**Venue**	**Content presented**
1. April 2006	Bundaberg Research Station	Project aims, objectives and project activities
2. June 2006	Cudgen Fishing Club	Project aims, objectives and planned activities
3. August 2007	Bundaberg DEEDI shed	Literature review findings and planned field experiments
4. September 2007	Cudgen, Doug Paddon shed	Literature review findings and planned field experiments
5. June 2008	Bundaberg DEEDI shed	Wireworm and Sweetpotato weevil findings
6. July 2008	Cudgen, Doug Paddon shed	Wireworm and sweetpotato weevil findings
7. November 2008	Bundaberg DEEDI shed	Nematode control
8. May 2009	Cudgen, Kevin Kennedy's shed	Nematode control
9. November 2009	Bundaberg DEEDI shed	Project findings and recommendations for wireworm, sweetpotato weevil and root-knot nematode

3. Media

- ABC nightly news (state wide)
- Landline (national)
- ABC Wide Bay local radio (regional)

- QLD Country Life (state wide)
- Good Fruit and Vegetables magazine, Vol.22 No.1 July 2010, p10 (national)
- Bundaberg and Gympie district newspapers (regional)
- Vegetables Australia magazine (national).

4. Newsletters (sweetpotato research updates)

Project activities and trial results have appeared in four editions of the sweetpotato research update: February 2006, December 2007, June 2008 and January 2009. The update is distributed to all Australian states with a distribution list of 149 growers and 32 market merchants, retailers and agribusinesses.

5. Farm visits

A structured part of the information review process was for project staff to visit key growers in the major sweetpotato growing regions for one on one discussion of project results. During the course of the project in excess of 100 farms visits specifically related to the project were carried out in the following production areas; Rockhampton, Bundaberg and Cudgen.

6. Australian Sweetpotato Growers Association

One of the key activities of the project was the project steering committee with grower representation from the key sweetpotato production areas of Rockhampton, Cudgen and Bundaberg. The steering committee met once per year to review project results and plan further experimentation as part of VG05037. Meeting dates and are shown below:

- 23 Jan 2007, DPI&F Bundaberg town office, 9 attendees.
- 12 March 2008, Bundaberg Motor Inn conference room facility, 8 attendees.
- 27 May 2009, Kelly's Beach Resort Bargara, 9 attendees.
- 5 May 2010, Kelly's Beach Resort Bargara, 11 attendees.

7. HAL VG05037 Milestone reports

- 30/11/2006
- 30/11/2007
- 30/11/2008
- 31/5/2010

Impact and adoption

If meeting attendance is a measure of impact and adoption then the technology transfer activities would be rated as extremely successful with 70% + of growers attending events in each region. Clients from agri-businesses that service the sweetpotato industry were also in strong attendance at all meetings in the regions. At Bundaberg shed meetings it was common to have all local rural supply store agronomists present (Rural Advantage, BGA, Lindsay Rural, Norco and Elders Rural) and agri-chemical representatives present from Dupont, Syngenta, Nufarm, Crop Care, Bayer & Dow.

Chapter 7: Conclusions and recommendations

Introduction

The Australian sweetpotato industry must develop strategies that reduce pest populations of the wireworm, root-knot nematode and sweetpotato weevil plaguing their production system. The combination of all year round sweetpotato production, the stable sub-tropical environment of the production regions and difficulties in managing volunteer sweetpotato growth post harvest are all contributing to the ideal conditions for continuous and rapid pest cycles. Subsequently, industry is constantly putting insecticides under maximum working pest pressure. Strategies that reduce overall pest populations will result in:

- minimal commercial crop losses due to pest injury
- increased effectiveness of agri-chemicals when used
- greater attraction for agri-business investment into the industry
- securing our sweetpotato industry as clean and green in the heavily regulated Australian horticultural production environment and ever fickle domestic marketplace.

Below are the recommendations for each of the major sweetpotato pests.

Wireworm recommendations

- Develop strategies to move away from large concentrations of agri-chemicals soil incorporated prior to planting to strategic applications of reduced rates of agro-chemicals during the crop's development.
- Undertake further efficacy and residue trials on fipronil applied through the trickle tape.
- Develop a strategy that reduces large damaging populations of wireworm prior to planting. This strategy needs to be considered in relation to the break crop jumbo sorghum. Efficacy trials on insecticide coated jumbo sorghum need to be undertaken.
- Undertake efficacy trials on the trickle application of thiamethoxam and chlorantraniliprole against wireworm in the sweetpotato cropping system.

Sweetpotato weevil recommendations

- Investigate the mandatory SPW weevil area wide management programs in Japan and Southern USA to ascertain implementing a trapping program in Australian production regions. The ASPG should then implement and lead a mandatory trapping program that locates areas of high weevil populations and instigates necessary control strategies.
- Investigate ways to better control sweetpotato crop residues post harvest as current sorghum cover crops are not successfully out competing sweetpotato volunteer regrowth. The use of selective herbicides in conjunction with the sorghum break crop will provide better suppression of sweetpotato weevil through out the growing districts.
- Provide efficacy and residue data on thiamethoxam against sweetpotato weevil in Beauregard according to APVMA standards to contribute

towards the permitted or label registered use of Sygenta Pty Ltd's insecticide 'Actara®'.

Root-knot nematode recommendations

- Investigate ways to further reduce RKN populations prior to planting sweetpotato.
- Investigate ways to better control sweetpotato crop residues post harvest as current sorghum cover crops are not successfully out competing sweetpotato volunteer regrowth. The use of selective herbicides in conjunction with the sorghum break crop may provide better suppression of RKN.
- Identify and screen alternative nematicides that have low human toxicity under low RKN pressure cropping situations injected late in the crops development period.

Chapter 8: Acknowledgements

We gratefully acknowledge the interest of the sweetpotato growers and industry representatives who have supported this project. In particular, the chairman and executive committee members of the Australian Sweetpotato Growers Association Inc., Rodney Wolfenden, Dean Akers, Dave Fisher, Doug Paddon, Matthew Prichard, Darren Zunker and secretary Eric Coleman.

We would like to thank those growers that have directly helped in allowing us to implement trials on their properties. These include Dave Fisher, Duane Joyce, Dean Akers, Doug Paddon, Kevin Kennedy, Matthew Prichard, Troy Prichard, Dave Holt and Darren Zunker.

Agri-chemical company representatives have contributed and assisted in trial work associated with this project. In particular we would like to thank Geoff Cornwell (DuPont), Jamie Cox (Nufarm), Ken McKee (Syngenta), Glen Tucker (Crop Care) and Mitch Faint (Bayer CropScience).

The industry members who service the sweetpotato industry deserve special mention. In particular Henry Prichard (Northern Rivers Rural Buying Service) Andrew Gahan (Rural Advantage), Neil Innes (Lindsay Rural), John Damiano (Norco), Simon Andreoli (BGA) and Dave Richardson (Elders Primac).

Particular thanks to Peter Dal Santo from AgAware Consulting for his support and advice regarding agri-chemical access for the sweetpotato industry. Thankyou to Grahame Jackson from Sydney for undertaking the survey of sweetpotato grower practices and preparing the report comparing grower practices from 2006 to present.

We thank DEEDI staff, in particular Malcolm Smith, Gavin Berry and Warren Flor (Bundaberg Research Station) and Mal Rutherford (Rockhampton) and Dr Andrew Robson (Kingaroy).

Appendices

Sweetpotato research handout 6

Sweetpotato research handout 7

Sweetpotato research handout 8

Sweetpotato research handout 9

Guide to the identification of pests of sweetpotato

Wireworm fact sheet

Better management of sweetpotato soil insect pests

Sweetpotato weevil handout

Sweetpotato weevil trap comparisons