Better Berries Project Phase 3 Second Extension

Christopher Menzel
QLD Department of Primary Industries & Fisheries

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Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

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Better Berries Program Phase 2 – Towards a Sustainable Strawberry System

Better Berries Program Phase 3 – Enhancing Sustainable Strawberry Production

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Better Berries Project Phase 3 Second Extension

Christopher Menzel
Department of Primary Industries and Fisheries, PO Box 5083, SCMC, Nambour, Qld 4560
Phone: 07-5444-9600 Facsimile: 07-5441-2235 E-mail: chris.menzel@dpi.qld.gov.au

Purpose of report

This report documents research on the Sunshine Coast, at Cleveland and Indooroopilly in Brisbane, at Stanthorpe on the Granite Belt and in Toolangi in Victoria, to improve the profitability and sustainability of the Australian strawberry industry. Chris Menzel collected data on runner quality while Geoff Waite was responsible for the section on Entomology. Chris and Geoff also edited the report. Don Hutton and Apollo Gomez were responsible for efforts in Plant Pathology, Jenny Moisander and Mark Herrington responsible for the research on Plant Nutrition, and Noel Vock and Neil Greer developed the information products stemming from the project. Neil Greer was responsible for the development and initial management of the project from 2002 to 2004. Scott Mattner from Primary Industries Research Victoria (PIRVic) at Knoxfield initiated the experiments on methyl bromide conducted in southern Australia. Claire Streten and Karen Gibb from Charles Darwin University, Darwin, NT 0909 and Denis Persley from the Department of Primary Industries and Fisheries, 80 Meiers Road, Indooroopilly, Brisbane, Qld 4068 assisted with the identification of the organisms associated with strawberry lethal yellows. Annice Lloyd, Ed Hamacek and Thelma Peek from the Department of Primary Industries and Fisheries, 80 Meiers Road, Indooroopilly, Brisbane, Qld 4068 provided information on the biology of fruit flies in strawberries. Dave Lyons from Department of Natural Resources and Mines, 80 Meiers Road, Indooroopilly, Brisbane, Qld 4068 contributed to the section on strawberry nutrition, while Matt Dagan from Growcom, PO Box 202, Fortitude Valley, Qld 4006 provided information on water use in strawberries. Helen Hutton, Shirlene Dillon, Mary Grace, Warwick Grace, Roger Smart, Grant Bignell and Matt Adkins from DPI&F helped collect the data on plant diseases.

30 October 2006

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Media summary

Australia produces about 40,000 tonnes of strawberries worth $200 million each year. The main production centres are located in Queensland, Victoria and Western Australia, with winter production worth $120 million in South-East Queensland. Research conducted mostly in southern Queensland addressed major issues identified by the National Strawberry Industry in its strategic plan to improve agronomic management of the crop. The main areas of interest included runner quality, irrigation and nutrition management and the control of key pests and diseases.

Agronomy

Plug plants in 75 cm^3 containers yielded 15 to 40% less than bare-rooted plants, suggesting that plugs grown in small containers offer no economic advantage to commercial growers. Plugs in 125 cm^3 containers yielded 24% more than small runners and 17% more than large runners, while runners from Stanthorpe yielded 15% more than the runners from Toolangi. Further research needs to be conducted to determine the relative performance of plugs and runners, especially a comparison of the two plant types at different planting times in southern Queensland.

Micro-sprinklers can save up to 80% of the water used during establishment compared with knockers, when they are used with correct water pressure. Reducing plant establishment water use by 80% would save 30% of the total crop water use or 1.8 ML per ha. It is recommended that micro-sprinklers be installed in new plantings.

Pests

Bifenazate provided excellent control of spider mites and is compatible with the predatory mite, so that it can be used to correct an imbalance between pest and predator if necessary. Registration of this miticide is recommended to assist growers to manage miticide resistance in their crops. Indoxacarb, emamectin and spinosad controlled all species of caterpillar in test plots with no adverse effect on predatory mites. These chemicals are also less toxic to humans and the environment than the chemicals currently registered for this purpose. Spinosad has been registered for use in strawberries. The other two chemicals should also be registered. Although laboratory studies indicated that strawberries are an excellent host for Queensland fruit fly, the pest represents a minor issue in ground-grown strawberries on the Sunshine Coast. Bait sprays should be registered as acceptable treatments for Queensland fruit shipped to southern states after 20 September.

Depending on the season, 1 to 4% of runners supplied by Stanthorpe nurseries were infected with strawberry lethal yellows (SLY). The disease is associated with the phytoplasmas, *Candidatus* Phytoplasma australiense and tomato big bud, and a rickettsia-like-organism (RLO). SLY is probably transmitted by a planthopper, most likely *Orosius argentatus*, which is distributed throughout south-east Australia. Continuing research into the etiology of this disease is required in order to develop an effective management strategy.

Diseases

There was generally a very low level of infection with crown rot caused by *Colletotrichum gloeosporioides* (*Cg*) in the strawberry nurseries, with an average of only 0.06% of symptomless petioles testing positive for the presence of *Cg* over five years. Visual symptoms of crown rot, including lesions on the petioles and stolons and wilting plants, were relatively rare in the nurseries, with plant losses ranging from 0 to 0.5%. Losses on fruit farms were highly variable (up to 20%), but generally low and less than 0.1%. There was no evidence of resistance to prochloraz. A fungicide based on cyprodininil plus fludioxinil offers promise for inclusion in a resistance management program with prochloraz.

A strategy based on applications of tolylfluanid with trifloxystrobin gave the best control of the fruit diseases powdery mildew and grey mould, and the best yields. This work contributed to a national registration for trifloxystrobin for the control of powdery mildew in strawberries.

There is a range in the level of resistance in strawberry cultivars to wilt diseases caused by *Fusarium oxysporum*, with severe losses suffered by some cultivars in non-fumigated soils. Cultivars with high levels of resistance to Fusarium wilt need to be developed for the strawberry industry.

Strawberry fields in southern Queensland are affected by a range of soil-borne diseases and weeds that have been traditionally controlled by fumigation with methyl bromide. Telone C35, chloropicrin and methyl iodide could replace methyl bromide. In contrast, metham potassium and metham sodium were less effective and would not be suitable replacements. Telone C35 should be quite safe for fruit production in coastal southern Queensland (no toxicity after planting two weeks after fumigation), particularly when the directions for its use on the label are followed (planting six weeks after fumigation).

Soil solarisation has the potential to improve strawberry production in the absence of methyl bromide. Soil solarisation with silver plastic reduced weed growth and the incidence of plant diseases, and increased plant growth and yield compared with untreated plots, with the best response recorded after three consecutive years of solarisation. In contrast, soil solarisation with clear or black plastic was less effective. Because the effect is cumulative, solarisation using plastic films must be repeated over several successive years if it is to match the performance of commercial fumigants.

Industry extension

Two new information products were developed during the project. ‘The strawberry problem solver and bug identifier’ field guide is designed to be used in the field, packing shed or farm office to identify the pests, diseases, disorders, and beneficial insects likely to be found in Australian strawberry crops. ‘The strawberry R&D update’ is designed to keep farmers and other industry members in touch with the latest results and findings from our research. These products complemented regular grower field days and seminars held during the project.

Technical summary

Background

Australia produces about 40,000 tonnes of strawberries worth $200 million, each year. This represents less than 1% of world strawberry production, but comprises a significant local horticultural industry, with more than 500 producers and 13,000 full- and part-time employees (Morrison and Herrington, 2002). The main production centres are located in Queensland, Victoria and Western Australia. Winter production in South-East Queensland, based mainly on short-day cultivars, is worth $120 million. The industry in Queensland utilizes planting material supplied each year by local runner producers on the Granite Belt, which is remote from the fruit production area and at elevation, and from nurseries in southern Australia.

Our project addressed major issues identified by the National Strawberry Industry in its strategic plan (Strawberries Australia, 1997). Key issues identified in the plan included the need to improve the quality of planting material, the development of nutrition, irrigation, pest and disease management systems for sustainable production, and the development of information packages for growers.

Runner quality

Plugs or containerized plants can offer several advantages over traditional bare-rooted runners for strawberry production, including earlier production or higher yields in some environments. We investigated the productivity of 'Festival', 'Rubygem' and 'Sugarbaby' propagated as plugs in 75 cm^3 containers, compared with runners from Stanthorpe in southern Queensland (elevation of 872 m), and grown over two years at Nambour on the Sunshine Coast (elevation of 29 m). The plugs weighed only 20% of the weight of the runners at planting, and yielded 15 to 40% less. These results suggest that plugs grown in small containers are not viable for commercial growers in southern Queensland.

In other experiments, we investigated the productivity of 'Festival' and 'Rubygem' strawberries propagated as plugs (125 cm^3 containers compared with 75 cm^3 in the previous experiment), and small and large bare-rooted runners (crowns 8.6 and 12.8 mm in diameter, respectively) from Stanthorpe, and grown at Nambour. At planting, the average dry weight of the plugs and the small runners was 32 to 37% of the weight of the large runners. 'Festival' runners sourced from Stanthorpe were also compared with runners from Toolangi in Victoria (crowns 11.3 and 9.4 mm in diameter, and dry weights of 3.5 and 2.6 g per plant, respectively). The plug plants yielded 24% more than the small runners and 17% more than the large runners, while the runners from Stanthorpe yielded 15% more than the runners from Toolangi. These results suggest that plug plants in large containers can produce yields similar to or greater than yields of bare-rooted plants, while planting material from Toolangi may not always have an advantage in terms of overall cropping.

Irrigation

Traditionally, strawberry growers have relied on high output impact sprinklers for plant establishment, maintenance irrigation and frost protection. These sprinklers are

particularly wasteful of water, putting out large droplets that can compact and erode the soil. We compared the efficiency of these sprinklers with that achieved with micro-sprinklers in a strawberry field on the Sunshine Coast. Knocker sprinklers delivered 600 to 700 L per h with a 10 to 12 m wetting radius, while micro-sprinklers delivered 90 L per h (under high pressure) with a wetting radius of 2 to 3 m. There was about a 50% reduction in water use for the micro-sprinklers under high pressure compared with the knockers, and a potential saving of 80% with the correct water pressure. Reducing plant establishment water use by 50 to 80% would save of 20 to 30% of the total crop water use or 1.2 to 1.8 ML per ha.

Plant nutrition

Experiments were conducted to assess the impacts of nitrogen applications on yield and plant nitrogen status in thirteen strawberry cultivars over four years at Redlands. There was no effect of nitrogen on yield in any of the 14 experiments in the red clay loam soil, with average yield ranging from 542 to 720 g per plant. There were mixed effects of nitrogen on petiole nitrate (NO_3) concentration, with higher rates increasing plant nitrogen status in eight cases, and having no effect in six cases. The lowest petiole NO_3 concentration observed in the different treatments was considered to be the optimum level of plant nitrogen in these experiments, with mean concentrations during the season ranging from 100 mg per L for 'Festival' to 1000 mg per L for 'Harmony'.

Entomology

Two-spotted spider mite, *Tetranychus urticae*, is the major pest of strawberries in Queensland, but under good management, is readily controlled by the predatory mite, *Phytoseiulus persimilis*. There are some situations in which miticides are required because the predatory mites have not been introduced, or because of extremely heavy pest infestations that cannot be contained by the predators. Research showed that bifenazate controls spider mites and is compatible with the predatory mite. Registration of this chemical would provide growers with a back-up miticide and assist them to manage miticide resistance in their fields.

Helicoverpa (*Heliothis*) and other caterpillars attack strawberries in Queensland and elsewhere. Although the loss of fruit is usually not great, the young larvae tunnel into the fruit where they are safe from insecticides and detection not only by pickers and packers, but also by consumers. There is also potential for the caterpillars to attack the plant crown. Indoxacarb, emamectin and spinosad controlled the caterpillars, with little impact on predatory mites, and were less toxic to humans and the environment than currently registered chemicals. Spinosad has been registered for use in strawberries, with hopefully indoxacarb and emamectin to follow.

Cover sprays of dimethoate are obligatory for strawberry fields where the fruit are sold interstate after 20 September because of the risk posed by Queensland fruit fly, *Bactrocera tryoni*. These sprays jeopardize control of two-spotted spider mite by the predatory mite. Fruit fly larvae were recorded in five fruit from a strawberry patch in the first week of September 2003, before protein bait was applied. No strikes were recorded in the other two years of the research, even though traps indicated the presence of flies. These results, together with wider observations in commercial

fields suggest that fruit flies are a minor issue in ground-grown strawberries in southern Queensland.

Laboratory studies indicated that 'Kabarla' strawberries are susceptible to Queensland fruit fly, with a Host Susceptibility Index of 0.75 ± 0.07 flies per g of fruit. Fly infestations in commercial ground-grown strawberries are extremely low and for market access, the species is considered a very low risk. This indicates that although strawberries are a moderate to good host, other factors related to fly behaviour in this crop (e.g. the reduced risk of fruit on the ground compared with hydroponically-grown strawberries due to their height above the ground), greatly reduce the risk of infestation in the field.

Strawberries grown in Queensland can be affected by a phytoplasma and a rickettsia-like organism (RLO) when infected runners are supplied by the nurseries on the Granite Belt. Research shows that strawberry lethal yellows disease (SLY) is probably transmitted by a planthopper such as *Orosius argentatus*. Early spring rains on the Granite Belt, which are inevitably followed by dry spells in December, encourage the movement of vectors from desiccated weeds into the strawberry runner beds in December and January. The current strategy for control is to apply insecticides to the crop to kill the vectors before they feed on the strawberry plants. However, the daily overhead irrigation required to maintain a moist soil surface to facilitate rooting of the runners, soon washes the chemical from the plants. In contrast, exclusion of insects with fine nets is very effective. In 2005, average infections in strawberry farms on the Sunshine Coast that sourced planting material from Stanthorpe ranged from 1 to 4%, with a few individual plantings suffering losses of 20%.

Strawberry lethal yellows (SLY) is associated with the phytoplasmas, *Candidatus* Phytoplasma australiense, and tomato big bud, and a rickettsia-like-organism (RLO). *Ca*. P. australiense is also associated with strawberry green petal (SGP) disease. Of 363 SLY samples collected, 117 tested positive for the RLO, 67 tested positive for *Ca*. P. australiense AGY strain, and 11 plants tested positive for *Ca*. P. australiense PYL variant strain. On runner production farms at Stanthorpe, the RLO was detected in SLY plants more frequently than were the phytoplasmas, while the reverse was true for samples from fruit farms on the Sunshine Coast.

Thirty-one plant species from south-east Queensland had disease symptoms similar to SLY between 2001 and 2003 and of these, 18 species tested positive for the phytoplasma, indicating that the disease organisms are endemic in this environment.

Plant pathology

One of the major diseases affecting strawberries in Queensland is crown rot caused by *Colletotrichum gloeosporioides* (*Cg*). The fungus is present in a small number of plants in the runner beds, but can cause serious losses in commercial fruit farms on the Sunshine Coast where it is probably introduced with the planting material. There was a very low level of infection in the strawberry nurseries, with an average of only 0.06% of symptomless petioles testing positive for the presence of *Cg* over five years. Visual symptoms of crown rot, including lesions on the petioles and stolons, and wilting plants were relatively rare in the nurseries, with plant losses ranging from 0 to 0.5%.

Losses on fruit farms were highly variable (up to 20%), but generally low and less than 0.1%. There was no evidence of resistance to prochloraz, the chemical used to control the disease in the runner beds. A fungicide based on cyprodininil plus fludioxinil offers promise for inclusion in a resistance management program with prochloraz.

Black spot (*Colletotrichum acutatum*), grey mould (*Botrytis cinerea*), and powdery mildew (*Sphaerotheca macularis*) are the most important fruit diseases affecting strawberries in southern Queensland. Several fungicides and other compounds were assessed over two years for their efficacy against powdery mildew and grey mould at Nambour. A strategy based on applications of tolylfluanid with trifloxystrobin gave the best control of powdery mildew and grey mould, and the best yields. This work contributed to a national registration for trifloxystrobin for the control of powdery mildew in strawberries. Several biological compounds including Ecocarb, synetrol oil, soap, milk and ti-tree oil offered some control of these diseases; however, none of these compounds matched the performance of the standard crop protectant.

Strawberry plants in southern Queensland are affected by a range of soil-borne diseases and weeds that are normally controlled by fumigation with methyl bromide. We investigated the efficiency of several chemicals as potential replacements for this fumigant in light of the phasing out of the use of substances that deplete the earth's ozone layer. Experiments were conducted on both runner and fruit farms over three years. The results showed that Telone C35, chloropicrin and methyl iodide could replace methyl bromide. In contrast, metham potassium and metham sodium are less effective and would not be suitable replacements. Telone C35 should be quite safe for fruit production in coastal southern Queensland (no toxicity after planting two weeks after fumigation), particularly when the directions for its use on the label are followed (planting six weeks after fumigation).

Strawberry plants grown in southern Queensland are susceptible to Fusarium wilt, which is caused by *Fusarium oxysporum*, with severe losses occurring in some seasons in fields that have not been fumigated. We investigated the relative resistance of a range of strawberry cultivars to Fusarium wilt over three years at Nambour on the Sunshine Coast. In the main experiments, 'Jewel' the comparative cultivar, was extremely susceptible to wilt, 'Kabarla' was moderately susceptible, 'Selva' slightly susceptible, and 'Camarosa', 'Festival', 'Gaviotta' and 'Sugarbaby' less susceptible. In other experiments, cultivars with low susceptibility included 'Rubygem', 'Cal Giant 3', 'Adina', 'Earliblush', 'Majestic', 'Redlands Crimson' and 'Parker'. In contrast, 'Earlisweet' was moderately susceptible. These results suggest that losses due to Fusarium wilt could be severe in some cultivars in non-fumigated soils. Cultivars with high levels of resistance to wilt need to be developed for the strawberry industry.

Soil solarisation has the potential to improve strawberry production in the absence of methyl bromide. We compared the effects of different coloured plastics on the performance of strawberries growing at Nambour on the Sunshine Coast over four years. Soil solarisation with silver plastic reduced weed growth and the incidence of plant diseases, and increased plant growth and yield compared with untreated plots, with the best response recorded after three consecutive years of solarisation. In contrast, soil solarisation with clear or black plastic was less effective. Solarisation

using plastic films must be repeated over several successive years if it is to match the performance of commercial fumigants.

Extension

Two new information products were developed during the project. 'The strawberry problem solver and bug identifier field guide' is designed to be used in the field, packing shed or farm office to identify the pests, diseases, disorders, and beneficial insects likely to be found in Australian strawberry crops. Arranged in four colour-coded sections to help quickly find a particular problem or bug, the book contains 198 full colour photographs covering 62 pest, disease, nutritional and other symptoms, 28 pests, and 17 beneficial insects. 'The strawberry R&D update' is designed to keep farmers and other industry members in touch with the latest results from our research. It is envisaged that the update will be produced annually. These products complemented regular grower field days and seminars held during the project.

Recommendations

1. Containerized plants in small 75 cm^3 cells offer no economic advantage to commercial strawberry growers in southern Queensland. In contrast, the yields of plugs in large 125 cm^3 cells were similar to or higher than those of bare-rooted plants. Research also showed that planting material from Toolangi may not always have an advantage over material from Stanthorpe in terms of overall cropping. Further research needs to be conducted to determine the relative performance of plugs and runners, especially a comparison of the two plant types at different planting times in southern Queensland. The relationship between yield and chilling during runner production also needs to be determined in this environment.

2. Micro-sprinklers offer potential savings of 80% in water use compared with knockers when they are used with the correct water pressure. Reducing plant establishment water use by 80% would save 30% of the total crop water use or 1.8 ML per ha. These micro-sprinklers are recommended for new plantings.

3. Assessment of petiole nitrate concentrations can be used to determine the fertilizer requirements of different cultivars. This technology can reduce the amount of nutrients applied to strawberry fields, with savings in fertilizer costs and run-off of applied nutrients into water-ways and estuaries, and it should become standard agronomic practice.

4. Bifenazate controls spider mites in strawberries and is compatible with predatory mites. Registration of this chemical should proceed as it would assist growers to manage miticide resistance in their crops.

5. Indoxacarb, emamectin and spinosad control caterpillars with little impact on predatory mites, and were less toxic to humans and the environment than currently registered chemicals. Spinosad has been registered for use in strawberries. The other two chemicals should also be registered.

6. Although laboratory studies indicated that strawberries are excellent hosts for Queensland fruit fly, and experience is that hydroponically-produced fruit are quite susceptible, the pest is a minor issue in ground-grown crops on the Sunshine Coast (more than 99.9% of production). Bait sprays should be registered as acceptable treatments for Queensland fruit shipped south from ground-grown plants after 20 September.

7. Between 1 to 4% of runners supplied by Stanthorpe nurseries were infected with strawberry lethal yellows. Continuing research into the etiology of this disease is required in order to develop an effective management strategy.

8. Infection of fruit farms with crown rot (*Colletotrichum gloeosporioides*) (*Cg*) was highly variable and was associated with low levels of infection or visible symptoms in the nurseries. Further research is required to determine how the fungus is spread on the nursery and fruit farms. A fungicide based on cyprodininil plus fludioxinil offers promise for inclusion in a resistance management program with prochloraz, and this should be pursued.

9. A strategy based on applications of tolylfluanid with trifloxystrobin gave the best control of grey mould (*Botrytis cinerea*) and powdery mildew (*Sphaerotheca macularis*). This work contributed to a national registration for trifloxystrobin for the control of powdery mildew in strawberries and its integration into current protection strategies is recommended.

10. There is a range in resistance of cultivars to wilt diseases such as those caused by *Fusarium oxysporum*, with severe losses in some cultivars in non-fumigated soils. Cultivars with high levels of resistance to wilt need to be developed for the strawberry industry.

11. Telone C35, chloropicrin and methyl iodide are the best potential replacements for methyl bromide used for soil fumigation in strawberry runner and fruit production. In contrast, metham potassium and metham sodium are less effective and are not suitable replacements. Telone C35 should be quite safe for fruit production in coastal southern Queensland (no toxicity after planting two weeks after fumigation) particularly when the directions for its use on the label are followed (planting six weeks after fumigation). Soil solarisation with silver plastic has the potential to improve production in the absence of methyl bromide, but probably needs to be repeated over several years if it is to match the performance of commercial fumigants. Growers should experiment with these alternatives on-farm to determine which application suits their particular enterprise.

Profile of team members

Chris Menzel

Dr Menzel is a principal horticulturist and has conducted research for the Australian horticultural industries for 24 years, especially on tropical fruit. His main activity has been in the agronomic performance and physiology of the tropical lychee. Dr Menzel has recently published a 300-page book on the crop, and a related fruit longan, with Geoff Waite from Maroochy.

Chris is undertaking research to improve the quality of plant material including containerized plants for the strawberry industry, and is leader of the current Horticulture Australia Limited project on runner quality, plant performance and profitability in the strawberry industry. Chris has a background in plant agronomy and physiology and is interested in determining the factors which influence the productivity of strawberry plants in subtropical environments. His other expertise is in editing and the publication of research results for industry and other scientists. Dr Menzel is currently an Associate Editor of the UK publication "*The Journal of Horticultural Science & Biotechnology*".

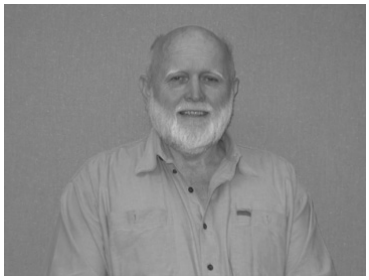
Geoff Waite

Geoff has 38 years' experience researching Integrated Pest Management (IPM) in crops such as lucerne, cotton, soybean, strawberry, avocado, lychee and macadamia. He has worked in strawberries for 26 years, and developed the world-first effective commercial IPM system for field-grown strawberry crops based on the biological control of spider mites with the predatory mite, *Phytoseiulus persimilis*. The 'pest in

first' strategy developed for spider mite in Australia has now evolved into a simultaneous release technique, a procedure that simplifies management of the system and ensures better control, and which is now used extensively in the Queensland strawberry industry.

Geoff also conducts research into the integrated management of pests of subtropical tree crops, including avocado, lychee, macadamia, custard apple, persimmon and passionfruit, and is also engaged in the seemingly endless search for a solution to the problem presented by fruitspotting bugs, which are major pests of subtropical fruit crops throughout coastal eastern Australia.

Don Hutton



Don Hutton is a senior experimentalist who has conducted research on plant pathology for the Department of Primary Industries & Fisheries for 38 years. Don's main interest has been in integrated disease management of strawberries. He has developed control strategies for the main fruit diseases, including blackspot, grey mould and powdery mildew, and also for managing crown rot in the runner beds. He has assisted the industry adopt soil fumigants that are alternatives to methyl bromide which was phased out for most sections of the industry in 2005. Don also plays an integral role in the production of *Passiflora edulis* f. *flavicarpa* seeds that are resistant to Fusarium wilt, and provides a diagnostics service for other horticultural crops in south-east Queensland.

Apollo Gomez

Apollo Gomez is an experimentalist and has over ten years experience in research and development with Department of Primary Industries and Fisheries (DPI & F) in Nambour and Cairns, and the Commonwealth Scientific Industrial Research Organisation (CSIRO) in Darwin. He has provided technical assistance across a range

of disciplines within horticulture, including breeding, propagation, orchard and nursery management, crop protection, diagnostics, and quarantine and eradication. Apollo has worked on a range of crops, including strawberry, macadamia, mango and cashew. Mr Gomez is currently providing technical support for the glasshouse and field research on strawberry diseases at Maroochy.

Mark Herrington

Mark is a principal horticulturist and has over thirty years experience in breeding horticultural crops, with direct involvement in strawberry, tomato, capsicum, melon, zucchini, cucumber and pumpkin. Mr Herrington has released more than 26 cultivars and breeding lines, and published 90 refereed and conference papers. Mark graduated with a Masters degree from the University of Queensland where he studied the inheritance of virus resistance in pumpkin. He leads the LAWS (Late Autumn Winter Spring markets) component of the Australian strawberry breeding program where he is focussing on delivering cultivars that meet the needs of growers, marketers and consumers.

Jenny Moisander

Mrs Moisander is a research scientist with DPI&F and has been involved in strawberry research for 15 years. During this time, she has worked in the subtropical strawberry breeding project and with various aspects of the nutrition work in the Better Berries Program. Jenny is also managing the strawberry tissue culture gene bank and propagation system used to deliver healthy foundation plants to runner growers throughout Australia as a basis for cleaner planting material on fruit farms.

Introduction

Background

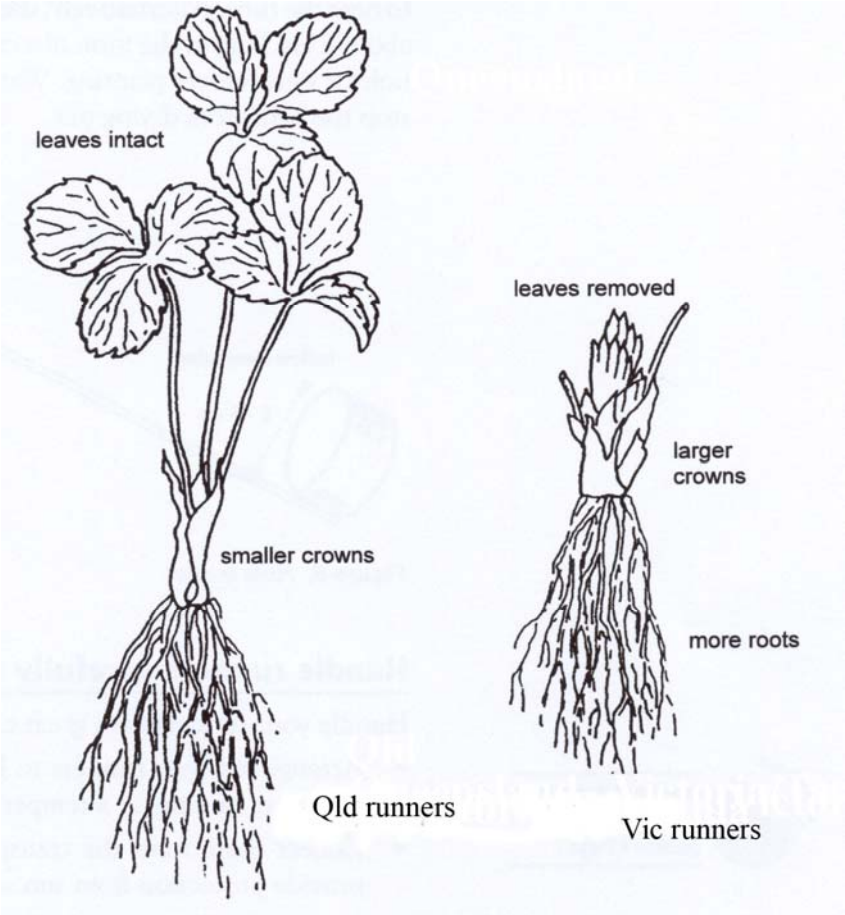
Australia produces about 40,000 tonnes of strawberries worth $200 million, each year. This represents less than 1% of world strawberry production, but comprises a significant local horticultural industry, with more than 500 producers and 13,000 full- and part-time employees (Morrison and Herrington, 2002; Herrington and Chandler, 2006). The main production centres are located in Queensland, Victoria and Western Australia (see below). Winter production in South-East Queensland, based mainly on short-day cultivars, is worth $120 million. The industry in Queensland utilizes planting material supplied each year by local runner producers on the Granite Belt, which is remote from the fruit production area and at elevation, and from nurseries in southern Australia. At this time, about 20 million bare-rooted plants (most leafless) are supplied from Victoria and Tasmania, and 14 million plants with leaves come from Stanthorpe (see below).

The three projects from 2001 to 2006 addressed major issues identified by the National Strawberry Industry in its strategic plan (Strawberries Australia, 1997). Key issues identified in the plan included the need to improve the quality of planting material, the development of integrated nutrition, irrigation, pest and disease strategies for sustainable production, and the development of information systems for growers.

Runner quality

Plugs or containerized plants can offer several advantages over traditional bare-rooted runner plants for strawberry production, including earlier or higher yields in some environments. The performance of strawberry plugs in Australia has not previously been studied, most research being concentrated in southern Europe and along the eastern seaboard of North America. We investigated the relative growth and yield of plugs and runners over three years on the Sunshine Coast. Experiments were also conducted to examine whether bare-rooted plants from Toolangi in Victoria had any advantage over nursery material from Stanthorpe in southern Queensland. Maximum

and minimum temperatures are 2^{o} to 4^{o}C cooler at Toolangi than at Stanthorpe in the four months before digging of the runners.



Irrigation and plant nutrition

Traditionally, strawberry growers have relied on high output impact sprinklers for plant establishment, maintenance irrigation and frost protection. This technology is particularly wasteful of water and energy, putting out large droplets with high physical impact over the entire cropping area. We compared the efficiency of these sprinklers with that achieved with micro-sprinklers in a strawberry field on the Sunshine Coast.

Under- or over-fertilization can reduce yield and fruit quality in strawberries. Excessive fertilizer use also wastes money and pollutes the environment. Previous research by the group showed that optimum fertilizer applications vary with cultivar. Fertilizer recommendations need to be developed for each cultivar as it is released. Sap analysis developed by the team is now used by 50% of commercial growers in Queensland. We report on optimal sap nutrient values for several new cultivars.

Entomology

The major strawberry pest is the two-spotted mite, *Tetranychus urticae*. It can dramatically reduce production and quality, often, despite the application of frequent miticide sprays. Mites live under the leaves, are difficult to contact with chemical sprays, and quickly become resistant to miticides especially when these are overused.

Mite problems are also exacerbated in non-IPM crops by the frequent use of insecticides to control other pests such as aphids, fruit flies and caterpillars. These chemicals inhibit any natural control of the spider mites. Our IPM system addresses this problem by using the "simultaneous release/pest in first" predatory mite control approach. Unfortunately, the current chemical controls for other pests such as cluster caterpillars and Queensland fruit fly, seriously disrupt the mite control system resulting in heavy fruit losses in their own right. We developed strategies to control these pests which are not detrimental to the predatory mites.

Strawberry lethal yellows (SLY), green petal and similar diseases have increased over the past three years and have been found in runners from Stanthorpe in Queensland, Toolangi in Victoria and Bothwell in Tasmania. The diseases cause losses on runner farms through the necessary rogueing or non-harvest of infected mother and daughter plants. The long incubation period of the lethal yellow disease organisms in the plant and subsequent delay in the onset of symptoms in the runner beds often results in symptomless plants escaping the final inspection and rogueing, resulting in their subsequent appearance on fruit farms. This frequently causes significant losses to growers through the need to replant, or reduced production from affected plants.

Previous research by Greber and Gowanlock (1979) implicated a rickettsia as the cause of SLY. Recent work by Padovan *et al*. (1998) with strawberry samples from Queensland demonstrated that a phytoplasma that is indistinguishable from the one implicated in papaw dieback was present in plants with SLY and green petal disease. Ongoing work by Padovan *et al*. (2000) has shown that another phytoplasma that is not related to any known phytoplasma, was detected in strawberries with SLY. Although three different agents have now been detected in diseased strawberries, we do not know which ones cause SLY. We attempted to determine which organisms cause lethal yellows, develop diagnostic tests to support early detection, identify alternative plant hosts and insect vectors, and to develop a management strategy for this problem.

Plant pathology

Strawberry production is always at risk from crown and stolon rot caused by the fungus, *Colletotrichum gloeosporioides* (*Cg*). Plant deaths and production losses from this disease can be devastating (Maas, 1998), with the disease usually spread through the planting of infected runners. Previous research by our group developed field prochloraz sprays to reduce the risk of *Cg* infections in the runner beds. Alternative chemicals were also evaluated, including the strobilurins. In this project, we monitored the incidence of crown rot on strawberry runner and fruit farms, assessed the level of resistance to prochloraz and developed strategies to minimize the incidence of this disease.

Strawberry fruit and runner production in Australia and throughout the world are dependent on the use of methyl bromide fumigation for the control of soil-borne diseases, nematodes and weeds. The methyl bromide phase-out was completed in January 2005, and except for critical use exemptions, growers will have to adopt alternative management strategies. We assessed several alternative chemicals as potential replacements, along with soil solarisation.

Fruit rots, especially black spot (*Colletotrichum acutatum*), grey mould (*Botrytis cinerea*) and powdery mildew (*Sphaerotheca macularis*) cost the Australian strawberry industry millions of dollars each year. Control for these diseases is based on routine protective spray programs, but the crop protectants currently registered for powdery mildew control are inadequate. We investigated several new chemicals, some with reputed low toxicity to humans. Potential new cultivars were also screened for their resistance to the major fruit diseases.

Extension

The information needs of the Queensland strawberry industry are currently serviced by a range of products and services provided by DPI&F, consultants, agribusiness and industry organisations. DPI&F has developed a range of information products including the 'Agrilink strawberry information kit', the 'Agrilink strawberry information online CD', annual field days and information booklets. Other information products such as a 'Problem solver field guide' and the 'R&D update' were developed in the present project. To ensure that the results of research and development achieve maximum impact, we also assessed the information needs of the Queensland industry.

Objectives of the work

The key objectives of the research conducted in the three projects from 2001 to 2006 were to:

1. Investigate the productivity of strawberries propagated by plugs in containers (75 and 125 cm^3), and bare-rooted runners from Stanthorpe in elevated southern Queensland, and grown at Nambour on the Sunshine Coast.

2. Compare the productivity of bare-rooted runners sourced from southern Queensland (Stanthorpe) and southern Australia (Toolangi, Victoria).

3. Compare the efficiencies of impact and micro- sprinklers in a strawberry field on the Sunshine Coast.

4. Determine the optimum petiole nitrate concentration in the major cultivars grown in southern Queensland.

5. Screen indoxacarb, emamectin and spinosad as potential replacements for the insecticides currently used to control caterpillars, which can reduce populations of predatory mites used to control two spotted mite.

6. Assess the efficacy of bifenazate against two spotted mite and predatory mites, to provide a back-up miticide and to reduce the risk of resistance developing in the mite pest.

7. Assess the susceptibility of strawberries to Queensland fruit fly under laboratory and field conditions.

8. Determine the incidence of lethal yellows affecting strawberry runner farms and commercial fields on the Sunshine Coast, and to determine the causal organisms, insect vectors, alternate host plants, and possible methods of control.

9. Assess strategies to replace methyl bromide, the standard fumigant used in strawberry fields.

10. Monitor the incidence of crown rot, *Colletotrichum gloeosporioides*, on strawberry runner and fruit farms, and develop strategies to minimize the incidence of this disease.

11. Compare the effectiveness of various chemicals, including standard fungicides and organic products, to control the major fruit diseases.

12. Assess the susceptibility of the commercial gene pool to the major fruit pathogens affecting the crop in southern Queensland.

13. Assess the extension needs of strawberry producers in southern Queensland, and develop appropriate information packages.

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The performance of plugs grown in small containers in Queensland

Christopher Menzel, Dylan Drysdale and Geoff Waite

Commercial summary

Plugs or containerized plants can offer several advantages over traditional bare-rooted runner plants for strawberry production, including earlier production or higher yields in some environments. We investigated the productivity of 'Festival', 'Rubygem' and 'Sugarbaby' strawberries propagated as plugs (75 cm^3 containers) and runners from Stanthorpe in southern Queensland (elevation of 872 m), and grown over two years at Nambour on the Sunshine Coast (elevation of 29 m). At planting, the average dry weight of the plug plants was only 20% of the weight of the runner plants. The plug plants yielded 60 to 85% of the yields of the runner plants, with cropping from 60 to 109 days after planting in year 1, and from 67 to 179 days after planting in year 2. The lower yields of the plug plants probably reflect their small size at planting. These results suggest that plug plants grown in small containers offer no economic advantage to commercial growers in southern Queensland.

Introduction

The strawberry industry in Queensland utilizes runners supplied each year by local producers on the Granite Belt at elevation, and from nurseries in southern Australia. At this time, about 20 million plants are supplied from Victoria and Tasmania, and 14 million plants come from Stanthorpe.

Plugs or containerized plants were developed for sectors of the strawberry industry in Europe about 25 years ago and have become popular along the eastern seaboard of the USA, especially in Virginia, New Jersey and North Carolina (Hennion *et al*., 1993, 1997; Lieten, 2000; Durner *et al*., 2002; Probasco and Garrison, 2003). Plugs offer several benefits including easier planting, better establishment, fewer pests and diseases, and lower water use during plant establishment and therefore less leaching of applied fertilizers (Poling and Parker, 1990; Bish *et al*., 1997; Crawford *et al*., 2000; Durner and Poling, 2000; Poling and Maas, 2000; Maas, 2000; Bish *et al*., 2002). Plugs also offer the potential for mechanical planting.

In some areas of Europe and northern America, plugs provide earlier production, greater productivity and larger fruit than runners. Research has also shown that the plants can be grown under short days and low temperatures to manipulate flower initiation and fruiting. Plugs are more expensive than runners, and will only be adopted by industry if the extra costs are matched by increased fruiting and returns to producers, as well as offering convenience and gains in resource management. We investigated the productivity of strawberries propagated by plugs in 75 cm^3 containers, and bare-rooted runners from Stanthorpe in elevated southern Queensland, and grown at Nambour on the Sunshine Coast. 'Festival' and 'Sugarbaby' were evaluated over two years, while 'Rubygem' was evaluated over one year.

Materials and methods

Year 1

Containerized plants and bare-rooted runners of 'Festival' and 'Sugarbaby' were obtained from Stanthorpe in southern Queensland (elevation 872 m) and planted at Nambour on the Sunshine Coast (elevation of 29 m) on 20 April 2004. The soil was a silty clay loam, with the plants grown on plastic in double row beds 70 cm wide and 60 cm apart. Plants along the rows were planted 30 cm apart, equivalent to a density of 51,000 plants per ha (see Plate 1). The plants were grown as a commercial crop, with standard horticultural practices (Vock, 1997). The volume of the cells used for the plugs was 75 cm^3.

Data were collected on the number of leaves per plant at planting, along with leaf, crown and root dry weight for each cultivar and plant type (n = 10). Data were also collected every two to three weeks on plant growth, and once a week on fruit weight, fruit number and average fruit weight. For the growth data, the experiment was laid out in a split-split plot randomised block design, with cultivars forming the main plots, plant type the first split, and harvest date the second split, with two blocks and three plants per plot (n = 6). For the yield data, the experiment was laid out in a split plot randomised block design, with cultivars the main plots, plant type the split plot, and the fruit harvested each week from the same ten plants in each plot (n = 20). The growth data were analysed by split-split plot analysis of variance, and the weekly yield data by repeated measure analysis of variance.

Year 2

Containerized plants and runners of 'Festival', 'Rubygem' and 'Sugarbaby' were obtained from Stanthorpe and planted at Nambour as in the previous year on 19 April 2005. Data collection was the same as in 2004. For the growth data, the experiment was laid out in a split-split plot randomised block design, with cultivars forming the main plots, plant type the first split, and harvest date the second split, with four blocks and two plants per plot (n = 8). For the yield data, the experiment was laid out in a split plot randomised block design, with cultivars the main plots, plant type the split plot, and the fruit harvested each week from the same ten plants in each plot (n = 40). The growth data were analysed by split-split plot analysis of variance, and the weekly yield data by repeated measure analysis of variance.

Results

Year 1

The runners were larger than the plugs at planting, with leaf, crown and root dry weight all higher (Table 1, Plate 2). There was an average of 4.0 ± 0.2 leaves per plant in the four different groups. There was a co-ordination of growth in the plants from the strawberry nursery, with the small and large plants having a similar allocation of dry matter to the leaves, crowns and roots (data not presented).

Plant growth increased over time in a sigmoid pattern (Figure 1). The runners and plugs had similar average leaf dry weights (10.4 ± 0.8 g per plant versus 8.0 ± 0.9 g per plant), and average crown dry weight (3.0 ± 0.2 g per plant versus 2.0 ± 0.2 g per plant). In contrast, average root dry weight was greater in the runners (1.9 ± 0.1 g per plant) than in the plugs (1.0 ± 0.1 g per plant) (LSD, $P = 0.05$, 0.16). Average plant dry weight was 15.3 ± 1.1 g per plant in the runners and 11.1 ± 1.1 g per plant in the plugs. The allocation of plant dry matter over the season changed, with an increase in the proportion of leaf dry weight and a decrease in the proportion of root dry weight (data not presented).

Average weekly fruit yield was higher in runners (23.6 ± 1.9 g per plant) than in plugs (14.1 ± 1.4 g per plant) (LSD, $P = 0.05$, 5.5). Fruit production peaked about 90 days after planting, with similar patterns of fruiting in the two plant types. Average fruit weight was 15.6 ± 0.3 g, with no effect of cultivar, plant type or harvest time. Thus, the differences in yield between the various treatments were mainly due to differences in fruit set. The relative cropping of the two plant types at the end of the experiment in August is shown in Plate 3.

Year 2

At planting, all components of plant weight were greater in the runners than in the plugs (Table 1).

Plant, leaf, crown and root dry weight tended to be higher in the runners than in the plugs from day 37 to 152, while the reverse was true on day 179 at the end of the experiment. For instance, plant dry weight on day 37 was 10.1 g per plant in the runners and 5.4 g per plant in the plugs; and on day 179, 19.8 g per plant in the runners and 26.3 g per plant in the plugs (LSD, $P = 0.05$, 3.4).

Average fruit yield was greater from 137 to 179 days after planting (55.3 to 97.5 g per plant) than from 67 to 130 days after planting (11.1 to 31.2 g per plant) (LSD, $P = 0.05$, 8.0). The runners had higher average yields than the plug plants (41.3 ± 2.1 g per plant versus 35.2 ± 2.2 g per plant) (LSD, $P = 0.05$, 4.2). Average fruit weight from 67 to 109 days after planting and from 123 to 153 days after planting was greater (17.4 to 20.4 g) than that from the other times (11.3 to 15.0 g) (LSD, $P = 0.05$, 1.7). Average fruit weight was 17.3 ± 0.2 g, and not affected by plant type.

Discussion

Containerized plants offer several advantages over traditional runners used in strawberry production (Bish *et al*., 2002). In Europe, they can provide a greater proportion of large fruit, while in parts of eastern USA, they are available from strawberry nurseries before freshly dug runners (Durner *et al*., 2002). In some growing areas, plugs can provide commercial production even when planted late, whereas plantings based on runners would not be viable.

Containerized plants must produce yields equal to or greater than those of runner plants because they are two to three times as expensive. In the present experiments, the plug yields were 60 to 85% those of the runners. The plugs were grown in

relatively small containers of only 75 cm^3, and were only 20% of the weight of the runners at planting. These differences in plant growth at planting carried over to affect the number of fruit produced. The plugs and runners had similar average fruit weight, different to the experience in California, where the former often produce small fruit (Larson *et al*., 2002).

The performance of strawberry plugs in Australia has not previously been studied, most research being concentrated in southern Europe and the eastern seaboard of North America. In one of the earliest experiments in France, Hennion *et al*. (1993) investigated the productivity of plug plants and freshly dug runners, with the plugs planted eight days after the runners. About 97% of the plug plants survived compared with 87% of the fresh runners. The two groups of plants had similar fruit yields. In a similar study in Portugal initiated by Palha *et al*. (2002), plug plants had similar yields to the runner plants in year one (1092 g versus 1069 g), and higher yields in year two (1085 g versus 776 g). D'Anna *et al*. (2003) found that plugs grown under plastic in Italy started to crop 63 days after planting, whereas runners took 125 days. Despite the earlier cropping, the average total yields of four cultivars were similar in the two groups of plants.

In North America, most of the interest in containerized plants has come from producers along the Atlantic coast, with nearly all the one billion plants used in California being supplied as runners from nurseries at high elevation. Larson *et al*. (2002) showed that plugs produced at high elevation had consistent benefits in terms of early and total season yields, however fruit quality was acceptable in only one year out of three. In California, the containerized plants were considered only viable for a relatively small niche market.

Lareau and Lamarre (1993) examined the performance of planting systems on the productivity of two strawberry cultivars, 'Kent' and 'Glooscap' near Montreal in Canada. Plug plants had higher yields than dormant bare-rooted plants dug in spring in one year, and lower yields in another. Fiola and Lengyen (1996) investigated the potential of plugs for early plantings further south in New Jersey, and showed that plugs had higher yields than dormant crowns in all four cases investigated ('Chandler' and 'Allstar' planted in early August and early September).

Recent research has also investigated the potential of containerized plants in Florida, although at this stage virtually all of the plants for that production area are supplied as freshly dug runners. Kokalis-Burelle (2003) evaluated 'Sweet Charlie' and 'Camarosa' plugs and bare root plants over three years. Plugs had healthier roots and earlier yields than bare root transplants, however this translated into significantly higher total yields (12.3 t per ha versus 6.3 t per ha) in only one out of six cases. In the other experiments, the plugs had yields ranging from –7% to +24% of the yields of the bare root plants, but these differences were not significant.

Our plug plants were grown in 75 cm^3 containers compared with 280 cm^3 in Europe. Of course, the larger containers are only beneficial if the larger plants have sufficient time to fill the pots with roots before planting. Bish *et al*. (1997) studied the impact of container size on the performance of strawberry plugs in Florida over a single season. Plugs grown in medium (150 cm^3) and large containers (300 cm^3) had higher total fruit yields for the period covering November to February, and for monthly yields in

February, than plugs grown in small containers (75 cm^3). In contrast, there were only slight or no significant differences in fruit production in the various treatments in November, December or January. Only 10% of Florida's strawberry production occurs in November and December when the prices are high, whereas more than half of the crop is produced in March and April when the value of the fruit is less than the growing costs.

Bish *et al*. (2002) also reported on further investigations into the effects of container volume in Florida. Plants propagated in 150 and 300 cm^3 containers tended to be larger at planting than those in 75 cm^3 containers; however, the larger containers did not necessarily result in greater fruit production. The larger container (300 cm^3) yielded 31% higher (total yield) than the small container (150 cm^3) in year one, associated with better fruiting in January and February. In contrast, in year two, plants grown in the larger containers yielded 22% less than those grown in small containers.

Conclusions

Plug plants weighed only 20% of the weight of runner plants at sowing and yielded 60 to 85% of the crop of the runners. The lower yield of plugs in these experiments appears to be due to their relatively small size at planting. These results suggest that plug plants grown in small containers offer no economic advantage to commercial growers in southern Queensland.

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Table 1. The initial dry weight (g per plant) of the 'Festival', 'Sugarbaby' and 'Rubygem' runner and plug plants (Exps. 1 and 2). Data are the means of ten plants per treatment, with maximum standard errors.

Cultivar and plant type	Year 1				Year 2			
	Leaf	Crown	Root	Total	Leaf	Crown	Root	Total
Festival runners	2.16	0.89	2.05	5.10	1.72	0.76	0.87	3.35
Festival plugs	0.35	0.13	0.15	0.62	0.72	0.31	0.35	1.38
Sugarbaby runners	3.39	0.79	1.32	5.50	3.72	0.87	1.09	5.68
Sugarbaby plugs	0.61	0.22	0.23	1.06	0.75	0.26	0.30	1.31
Rubygem runners					2.47	0.89	1.11	4.47
Rubygem plugs					0.71	0.23	0.23	1.18
Max. SE	0.28	0.15	0.42	0.73	0.52	0.20	0.25	0.94

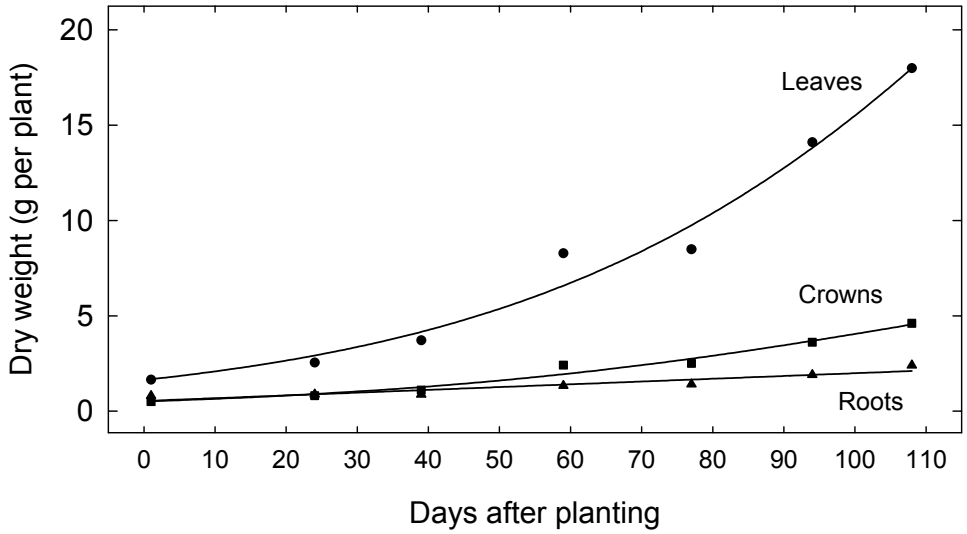

Figure 1. Changes in plant dry weight in the strawberries over time in year 1 at Nambour (Exp. 1). Data are the means of 24 plants and are pooled from the two cultivars and the two plant types. $DW_{leaf} = 64.73/(1+\exp(-(day-146.26)/40.05))$ (R^2 = 99%, $P < 0.01$). $DW_{crown} = 9.95/(1+\exp(-(day-114.79)/39.31))$ (R^2 = 99%' $P < 0.01$). $DW_{root} = 0.53 + 0.015$ day (R^2 = 98%, $P < 0.01$).

Plate 1. The experimental site at Nambour used for the containerized plant trials in 2004 and 2005 (Exps. 1 and 2).

Plate 2. Bare-rooted plants (left) and containerized plants (center and right) of 'Festival' strawberry at planting in 2004 (Exp. 1).

Plate 3. The relative yields of bare-rooted plants (left) and containerized plants (right) of ‘Festival’ strawberry in August 2004 (Exp. 1).

The performance of different planting material in Queensland

Christopher Menzel

Commercial summary

We investigated the productivity of 'Festival' and 'Rubygem' strawberries propagated as plugs (125 cm^3 containers compared with 75 cm^3 in the previous experiment) and small and large bare-rooted runners (crowns 8.6 and 12.8 mm wide, respectively) from Stanthorpe in southern Queensland (elevation of 872 m), and grown at Nambour on the Sunshine Coast (elevation of 29 m). At planting, the average dry weight of the plugs and the small runners was 32 to 37% of the weight of the large runners. There was also a comparison of 'Festival' runners sourced from Stanthorpe and Toolangi in Victoria (crowns 11.3 and 9.4 mm wide, and dry weights of 3.5 and 2.6 g per plant, respectively). The plug plants yielded 24% more than the small runners and 17% more than the large runners, while the runners from Stanthorpe yielded 15% more than the runners from Toolangi. These results suggest that plug plants in large containers can have similar or greater yields than bare-rooted plants, while planting material from Toolangi may not always have an advantage in terms of overall cropping.

Introduction

High quality transplants are important for a profitable strawberry industry. Inferior planting material can fail, or grow and crop poorly after planting, reducing economics returns to producers. Losses across the industry range from 1 to 10%, equivalent to $1.2 million to $12 million in Queensland, with losses on individual farms double these values some seasons. A strawberry plant costs 30 cents, and another 30 cents to establish and maintain during the season. Harvesting and marketing cost $1.50 per plant. This analysis indicates that a new plant accounts for about 50% of the growing costs and 15% of total costs. Some of the larger operators with one million runners outlay $300,000 on plants each season.

The quality of strawberry planting material is usually defined in terms of plant size (diameter of the crown, number of leaves at planting, etc.) and the amount of chilling accumulated prior to digging. These are presumably determined by the date of digging and weather conditions during runner growing. In 2006, of the 34 million runners planted on the Sunshine Coast, 14 million plants came from the two runner producers at Stanthorpe on the Granite Belt (latitude 28.6^{o}S), and the bulk of the other 20 million from Toolangi in Victoria (latitude 37.6^{o}S). Planting times range from early March to late April, with most growers opting for a planting around mid- to late-March, proving fruit from May to October in southern Queensland. Average daily maximum temperatures between January and May are about 4^{o}C lower at Toolangi than at Stanthorpe, and average daily minimum temperatures 2^{o}C lower.

Little information is available on the optimum size of planting material or the best planting date in terms of chilling during runner production. For the Queensland industry, the new plants must have crowns at least 6 mm wide, along with at least three functional leaves, but whether larger plants are more productive is not known. There is generally a range in the size of the plants supplied by runner producers, with crowns ranging from 6 to 14 mm.

The physiology of runner failure is not well understood. The research (see "References") conducted in Florida and elsewhere indicates that:

1. The best yields are usually obtained with plantings in early- to mid-October (equivalent to early- to mid-March in southern Queensland).
2. Northern nurseries are generally superior to local nurseries in Florida (it is much cooler in these northern nurseries than at Stanthorpe or Toolangi).
3. Most of the experiments on planting date and source of nursery do not separate the effects of "chilling" from those related to plant size.
4. The response to "chilling" is inconsistent, especially when temperatures close to freezing are used. The "benefits" of cool temperatures (around 15^{o}C) for a few weeks before planting seem to be related to better root growth in containerized plants.
5. There have been few studies relating yield to plant or crown size. Larger plugs have higher yields in about 50% of cases.

We compared the growth and performance of containerized plants with small and large bare-rooted transplants sourced from Stanthorpe ('Festival' and 'Rubygem'). We also compared bare-rooted transplants of 'Festival' obtained from Stanthorpe and Toolangi. Both sets of experiments were conducted at Nambour in 2006.

Materials and methods

Comparison of containerized plants with small and large bare-rooted runners (Exp. 1)

Containerized plants and bare-rooted runners of 'Festival' and 'Rubygem' were obtained from Stanthorpe in southern Queensland (elevation 872 m) and planted at Nambour on the Sunshine Coast (elevation of 29 m) on 11 April 2006. The soil was a silty clay loam, with the plants grown on plastic in double row beds 70 cm wide and 60 cm apart. Plants along the rows were planted 30 cm apart, equivalent to a density of 51,000 plants per ha. The plants were grown as a commercial crop, with standard horticultural practices (Vock, 1997). The volume of the cells used for the plugs was 125 cm^3.

Data were collected on the number of leaves per plant at planting, along with leaf, crown and root dry weight for each cultivar and plant type (n = 10). We surveyed the two cultivars to determine the variation in the material supplied by the nursery at Stanthorpe (plant dry weight, diameter of the crowns, etc.). Data were also collected every two to three weeks on plant growth, and once a week on fruit weight, fruit number and average fruit weight. For the growth data, the experiment was laid out in a split-split plot randomised block design, with cultivars forming the main plots, plant

type the first split, and harvest date the second split, with four blocks and two plants per plot (n = 8). For the yield data, the experiment was laid out in a split plot randomised block design, with cultivars the main plots, plant type the split plot, and the fruit harvested each week from the same twenty plants in each plot (n = 80). The growth data were analysed by split-split plot analysis of variance (2 cultivars x 3 plant types x 8 harvests), weekly yield data by repeated measure analysis of variance (2 cultivars x 3 plant types x 17 harvests), and cumulated yield by split-plot analysis of variance (2 cultivars x 3 plant types x 4 blocks).

Comparison of bare-rooted runners from Stanthorpe and Toolangi (Exp. 2)

Bare-rooted runners of 'Festival' were obtained from Stanthorpe in southern Queensland (elevation 872 m) and from Toolangi in Victoria (latitude 37.6^{o}S), and planted at Nambour on 11 April 2006 as indicated above. Only sound undamaged plants with at least three functioning leaves were used.

Data were collected on the number of leaves per plant at planting, along with leaf, crown and root dry weight for each cultivar and plant type (n = 20). Data were also collected every two to three weeks on plant growth (including leaf area), and once a week on fruit weight, fruit number and average fruit weight. For the growth data, the experiment was laid out in a split plot randomised block design, with plant source forming the main plots and harvest date the split, with eight blocks and two plants per plot (n = 16). For the yield data, the experiment was laid out in a randomised block design, and the fruit harvested each week from the same twenty plants in each plot (n = 160). The growth data were analysed by split plot analysis of variance (2 plant types x 8 harvests x 8 blocks), weekly yield data by repeated measure analysis of variance (2 plant types x 17 harvests x 8 blocks), and cumulated yield by one-way analysis of variance (2 plant types x 8 blocks).

Results

Comparison of containerized plants with small and large bare-rooted runners (Exp. 1)

The "small" runners and plugs weighed about 35% of the weights of the "large" runners at planting, with leaf, crown and root dry weight all lower (Table 1, Plate 1). The crowns were also smaller in the "smalls" and plugs. There was an average of 3.9 ± 0.2 leaves per plant in the plugs, 3.1 ± 0.1 leaves per plant in the small runners and 4.2 ± 0.2 leaves per plant in the large runners. As in the previous experiments, there was a co-ordination of growth in the plants from the strawberry nursery, with the small and large plants having a similar allocation of dry matter to the leaves, crowns and roots (data not presented).

We also surveyed the two cultivars to determine the variation in the material supplied by the nursery at Stanthorpe. Most of 'Festival' plants had crown diameters between 8 and 13 mm, while the bulk of the 'Rubygem' runners had crown diameters between 8 and 12 mm (Figure 1). The minimum crown diameter measured was 7 mm, reflecting the industry standard that includes "crowns no smaller than 6 mm". The

small ‘Festival’ runners had crowns ranging from 7 to 11 mm, and the large runners 10 to 15 mm. ‘Rubygem’ ranged from 7 to 10 mm and 11 to 16 mm, respectively.

The growth of the plants followed a sigmoid pattern over time, with similar changes in the two cultivars and three plant types (Figure 2). The plug plants and the large runners produced more leaves than the small runners over the season, whereas plant dry weight was greatest in the large runners (Table 2). The relative growth of the different plant types at the end of the experiment is shown in Plate 2.

Cumulative yield was greater in ‘Festival’ (513 ± 25 g per plant) than in ‘Rubygem’ (392 ± 30 g per plant). The plug plants (510 ± 34 g per plant) yielded 24% more than the small runners (410 ± 38 g per plant) and 17% more than the large runners (437 ± 41 g per plant), however these differences were not significant ($P > 0.05$), possibly due to variation in the yield of the plants in the three treatments. Mean fruit yield was higher later in the season from day 141 to day 169 compared with yields earlier in the season from day 56 to day 134, with no difference in the pattern between the two cultivars or the three plant types (Figure 3). There was no significant ($P > 0.05$) effect of cultivar or plant type on average fruit weight, with a general mean of 15.6 ± 0.4 g. There was no clear trend in average fruit weight over time which ranged from 10.7 to 23.4 g.

Comparison of bare-rooted runners from Stanthorpe and Toolangi (Exp. 2)

The plants from Toolangi were smaller than those from Stanthorpe, with smaller crowns, and lower leaf, root and total plant dry weight (Table 3). It was generally cooler in southern Victoria near the runner farm than at Stanthorpe in southern Queensland in the four months before the runners were dug (Table 4). The southern site thus had more hours below 20^{o}, 15^{o} or 10^{o}C than the northern site.

The plants from Stanthorpe had more leaves during the season (15.3 ± 0.9 leaves per plant) than the plants from Toolangi (14.0 ± 0.9 leaves per plant) ($P < 0.05$). In contrast, all other aspects of plant growth (leaf area, leaf weight, crown weight and root weight) were similar (data not presented). When the data for the two plant types were pooled, growth followed a sigmoid pattern over time (Figure 4). The relative growth of the two plant types at the end of the experiment is shown in Plate 3.

The runners from Stanthorpe (715 ± 27 g per plant) yielded 15% more than the runners from Toolangi (618 ± 34 g per plant), however these differences were not significant ($P > 0.05$). Mean fruit yield was higher later in the season (day 134 to 169) compared with yields earlier in the season (day 57 to 127), with no difference in the pattern between the two plant types (Figure 5). There was no significant ($P > 0.05$) effect of source on average fruit weight, with a general mean of 16.4 ± 0.2 g. Average fruit weight was higher from day 57 to day 71 and from day 92 to day 148 (16.0 to 18.0 g) than from day 78 to day 85 and day 155 to day 169 (12.7 to 14.3 g) (LSD $P = 0.05$, 2.2).

Discussion

These experiments assessed the relative productivity of strawberry plants grown in containers with small and large bare-rooted runners. There was also an examination of the growth and yield of planting material sourced from Stanthorpe in southern Queensland and Toolangi in southern Victoria. The plug plants had higher yields than the bare-rooted runners, while the plants from Stanthorpe were more productive than those from Toolangi.

Comparison of containerized plants with small and large bare-rooted runners

Growth during the season was related to the initial dry weight of the planting material, with the "large" runners (crowns 12.8 mm in diameter) having greater rates of leaf, crown and root production than the 'small" runners (crowns 8.6 mm in diameter) or the plug plants (crowns 9.2 mm in diameter). However, despite their slightly smaller size at planting, the plug plants in 125 cm^3 cells produced 17% more crop than the large runners. This was possibly due to the better establishment of the containerized plants which were less likely to suffer "transplant shock". The large runners had 7% more crop than the small runners indicating only a slight advantage in selecting runners with larger crowns, provided they meet the minimum standard of 6 mm. In these experiments, the small 'Festival' runners had crowns ranging from 7 to 11 mm, and the large runners 10 to 15 mm. 'Rubygem' ranged from 7 to 10 mm and 11 to 16 mm, respectively.

Bish *et al*. (1997) studied the performance of different sized 'Sweet Charlie' runners in Florida. The plants were sourced from Massachusetts and Florida, and divided into three groups, with crown diameters of 8, 12 or 16 mm. There were small differences in the cropping of the three groups of plants, with slightly heavier production per month in the small or large runners in individual months between November and February, but no significant differences in total yield.

Bish *et al*. (1997) also investigated the relationship between cropping and growth in containerised plants, and found that plugs grown in 75, 150 or 300 cm^3 pots had similar yields. This work was extended five years later (Bish *et al*., 2002) to study the response of plants conditioned under low or high temperatures. Plants grown in 300 cm^3 pots had larger roots at planting than those grown in 75 cm^3 pots, but this translated into higher yields (20.5 t per ha versus 15.7 t per ha) only in one year out of two, under cool wet conditions (the other year was warmer and drier than average). It was concluded that the plants grown in large containers might have not been potted up for long enough to fully exploit the larger volume of soil in the pot.

There is also work on crown size in other strawberry growing countries which has relevance to the industry in Australia.

Bussell *et al*. (2002) studied the relationship between yield and crown size in 'Pajaro' and 'Camarosa' from two nurseries in New Zealand. The transplants had crown diameters ranging from 8 to 20 mm and were planted in late autumn in Auckland. There was a strong relationship between yield and end of season growth, and size of the crowns at planting. Similar work in South Africa, showed that yields of 'Selekta' and 'Tiobelle' were higher with crown from 5 to 10 mm or wider compared with

those smaller than 5 mm (Human, 1999). In 'Tioga', runners with crown wider than 10 mm outyielded those smaller than 5 mm. These results contrast to recent work in the UK, where small (8 to12 mm) and large crowns (12 to 16 mm) had similar yields (Mière *et al*., 1998; Perez de Camacaro *et al*., 2004).

Comparison of bare-rooted runners from Stanthorpe and Toolangi

The bare-rooted plants from Stanthorpe were slightly larger than those from Toolangi, with average crown diameters of 11.3 and 9.4 mm, and dry weights of 3.5 and 2.6 g per plant, respectively. The northern planting material yielded 15% more crop than the southern planting material, despite similar plant growth during the season. An analysis of weather data at the two sites indicated greater chilling below 20^{o} (2009 h versus 1799 h), 15^{o} (1183 h versus 569 h) or 10^{o}C (411 h versus 163 h) in the four months before digging at Toolangi than at Stanthorpe. However, this extra chilling did not translate into higher productivity when the material was grown on the Sunshine Coast.

There have been numerous studies on the factors affecting the performance of strawberry planting material in Florida, which has similar climate to southern Queensland, and a strawberry industry based on winter production. Areas of interest include the effects of source of planting material, with runners obtained from northern and southern nurseries; effects of planting date, with runners dug from September to November; and the effects of chilling or low temperatures prior to planting. Some of this research has application to the local industry. Florida produces approximately 75,000 t of strawberries from 2,350 ha. Most of the crop is harvested between December and April, with peak production occurring in mid-March. Only 10% of production occurs in November and December, when the crop is most profitable. About 50% of the crop is harvested in March and April, when the value of the fruit is below growing costs.

Several authors have compared the growth and yield of bare-rooted plants obtained from high latitude or high elevation nurseries (Canada, North Carolina, etc.) with those obtained from local nurseries in Florida.

Albregts and Chandler (1995) obtained 'Sweet Charlie', 'Oso Grande' and 'Seascape' plants from nurseries in Florida and Canada and planted them in Florida over two seasons. Canadian plants had more fruit than those from Florida in December each year. The effects of plant source on total yield were not consistent across year or cultivar. It was suggested that returns due to source of planting material can vary with the season.

Bish *et al*. (1997) obtained 'Sweet Charlie' plants from Massachusetts and Florida, and grew them in the field in Dover, Florida. The northern plants had more fruit in December than the southern plants and the southern plants more fruit in January. They had similar crops in February, and similar total yields. The plants from Massachusetts probably had a slight economic advantage due to the earlier cropping when prices were high. Later research by Stapleton *et al*. (2001) examined the performance of 'Sweet Charlie' plants from nurseries in northern and mid-latitudes (Ontario, Nova Scotia, Quebec, Massachusetts and Oregon; and North Carolina) or southern latitudes (Alabama and Florida) over two years. The plants from northern

and mid-latitude nurseries had larger crowns than those from Florida, and higher yields in one year, but similar yields in the other year. Yields in December were higher in the cooler nurseries in both years. It was recommended that growers use plants from northern and mid-latitude nurseries.

Several authors have assessed the impacts of low or very low temperatures before planting on subsequent growth and fruiting. Plants were cooled for two to four weeks (usually two weeks) at various temperatures, including 2°C, 4.4°C, 10°C, 12°C and 15°C. Temperatures close to freezing were provided by storing the freshly dug plants in a cold-room, while the higher temperature treatments were provided in phytotrons or temperature-controlled glasshouses with the bare-rooted or containerized plants potted up into pots or trays after digging.

Durner (1999) studied the impacts of chilling on the performance of strawberry plants grown in a glasshouse in New Jersey, with the data relevant to similar studies in Florida. Two-to three-week-old 'Sweet Charlie' plants were conditioned by subjecting them to seven 9-h short days without chilling (21° day/21°C night) followed by seven 9-h short days with chilling (21°/12°C) in September. Conditioned plants had more fruit than non-conditioned controls in January and February but not in December, March or April. Total yield from December to April was 368 g per plant in conditioned plants and 226 g per plant in controls. It was indicated that conditioning can increase the productivity of greenhouse strawberries.

In other studies, Durner and Poling (2000) grew 'Sweet Charlie' and 'Camarosa' plants for seven days in a phytotron in North Carolina with the nights at 10° or 16°C (days at 22°C), and then shipped them to Florida for further evaluation. The yield of the 'Camarosa' plants from December to February was greater in chilled plots compared with the non-chilled group, whereas there was no difference in 'Sweet Charlie'. Temperature conditioning had no effect on early cropping in either cultivar.

Bish *et al*. (1997, 2002) conducted two experiments to examine the impacts of low temperatures before planting on the subsequent growth and cropping of 'Sweet Charlie' in Florida. In both experiments, containerized plants were grown in greenhouses at day/nights of 35°/25°C or 25°/15°C for two weeks before planting. These temperatures were much higher than those used in traditional "chilling" experiments. In the first experiment, the low temperature plants had more fruit in November, December and February than the high temperature plants, and greater total yields. In the second experiment, the low temperature plants had 18 to 48% higher yields over two years than the high temperature plants, associated with higher root dry weights at planting.

Conclusions

These results suggest that plug plants in 125 cm^3 containers can have similar or greater yields than bare-rooted plants, while planting material from Toolangi may not always have advantage in terms of overall cropping. Further experiments are required to define the optimum planting material for commercial strawberry producers in Queensland.

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Table 1. The initial dry weight and crown sizes of the 'Festival' and 'Rubygem' runner and plug plants (Experiment 1). Data are the means of ten plants per treatment, with maximum standard errors.

Cultivar and plant type	Diam. of crown (mm)	Dry weight (g per plant) Leaf	Crown	Root	Total
Festival plugs	8.2	0.66	0.18	0.21	1.05
Festival small runners	8.5	1.07	0.26	0.35	1.68
Festival large runners	12.5	3.07	0.62	0.84	4.53
Rubygem plugs	10.1	1.11	0.32	0.41	1.84
Rubygem small runners	8.6	1.16	0.25	0.22	1.63
Rubygem large runners	13.0	3.20	0.64	0.67	4.51
Max. SE	0.5	0.36	0.07	0.06	0.46

Table 2. The effect of plant type on the growth of strawberry plants (Experiment 1). Data are the means of 16 replicates per treatment, pooled for 'Festival' and 'Rubygem'.

Plant type	No. leaves per plant	Dry weight (g per plant) Leaf	Crown	Root	Total
Small runners	14.7	10.8	2.6	1.5	14.9
Large runners	16.9	12.6	3.5	2.3	18.4
Plugs	18.0	9.5	2.7	1.6	13.7
LSD ($P = 0.05$)	1.4	1.4	0.4	0.2	1.9

Table 3. The initial dry weight and crown sizes of the 'Festival' runners from Stanthorpe and Toolangi (Experiment 2). Data are the means of twenty plants per treatment, with maximum standard errors.

Source	Diam. of crown (mm)	Dry weight (g per plant) Leaf	Crown	Root	Total
Stanthorpe	11.3	2.38	0.51	0.61	3.50
Toolangi	9.4	1.55	0.50	0.50	2.56
Max. SE	0.4	0.17	0.08	0.06	0.25

Table 4. Mean monthly temperatures and accumulation of chilling at Stanthorpe in Queensland and Coldstream in Victoria (Experiment 2). Maximum temperatures are about 3.8°C lower at Mount Saint Leonard (near Toolangi) on the runner farm than at Coldstream, while minima are 0.5°C lower.

	Jan.	Feb.	Mar.	Apr.	Means	Totals
				Stanthorpe		
Mean monthly max. temp. (°C)	27.3	27.2	24.4	22.6	25.4	
Mean monthly min. temp. (°C)	16.7	16.6	13.0	8.5	13.7	
Hours below 20°C	331	348	546	574		1799
Hours below 15°C	9	14	176	370		569
Hours below 10°C	0	0	12	151		163
				Coldstream		
Mean monthly max. temp. (°C)	28.8	25.9	26.9	18.1	24.9	
Mean monthly min. temp. (°C)	13.1	11.0	9.1	6.7	10.0	
Hours below 20°C	372	464	489	684		2009
Hours below 15°C	176	201	268	538		1183
Hours below 10°C	35	57	104	218		414

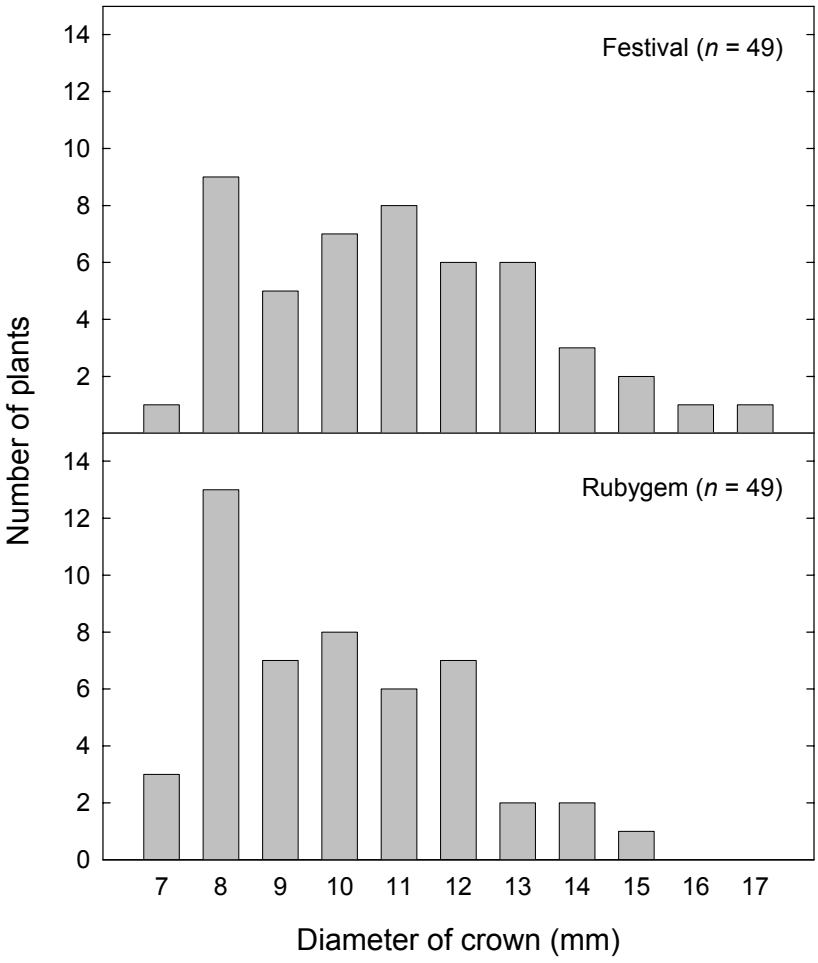

Figure 1. Distribution of crown diameter in the 'Festival' and 'Rubygem' runners supplied from Stanthorpe for the plug and runner experiment (Experiment 1). The small 'Festival' runners had crowns ranging from 7-11 mm, and the large runners 10-15 mm. 'Rubygem' ranged from 7-10 mm and 11-16 mm, respectively.

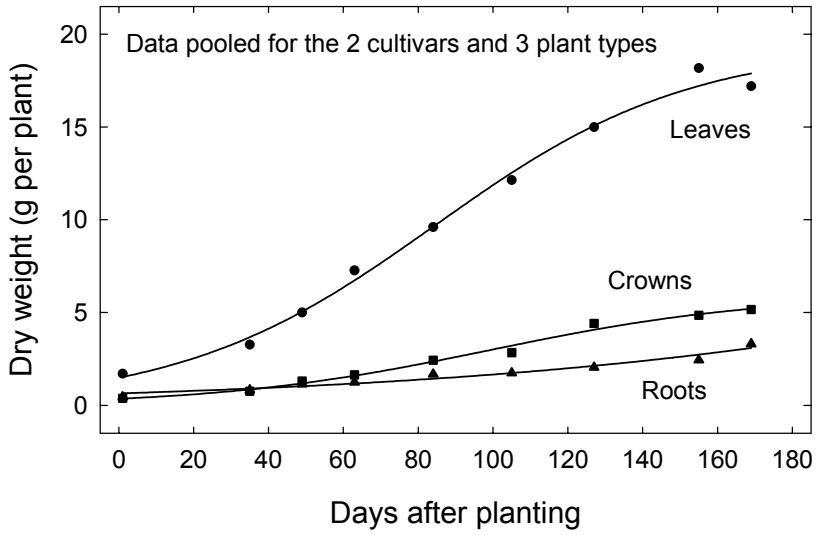

Figure 2. Changes in plant dry weight in the strawberries over time in the containerized plant experiment at Nambour (Experiment 1). Data are the means of 24 replicates pooled from the two cultivars ('Festival' and 'Rubygem') and the three plant types (small runners, large runners and containerized plants). DW_{leaf} = 19.38/(1+exp(-(day-84.42)/34.04)); DW_{crown} = 5.96/(1+exp(-(day-99.11)/36.13)); and DW_{root} = 26.31/(1+exp(-(day-374.05)/101.77)) (R^2 = 98%, $P < 0.01$).

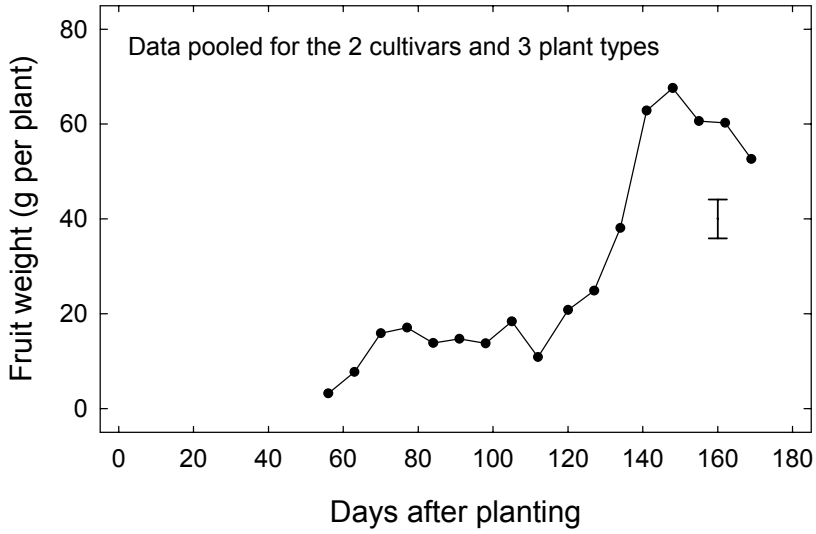

Figure 3. Changes in fruit production in the strawberries over time in the containerized plant experiment at Nambour (Experiment 1). Data are the means of 24 replicates pooled from the two cultivars ('Festival' and 'Rubygem') and the three plant types (small runners, large runners and containerized plants). Vertical bar indicates LSD (P = 0.05).

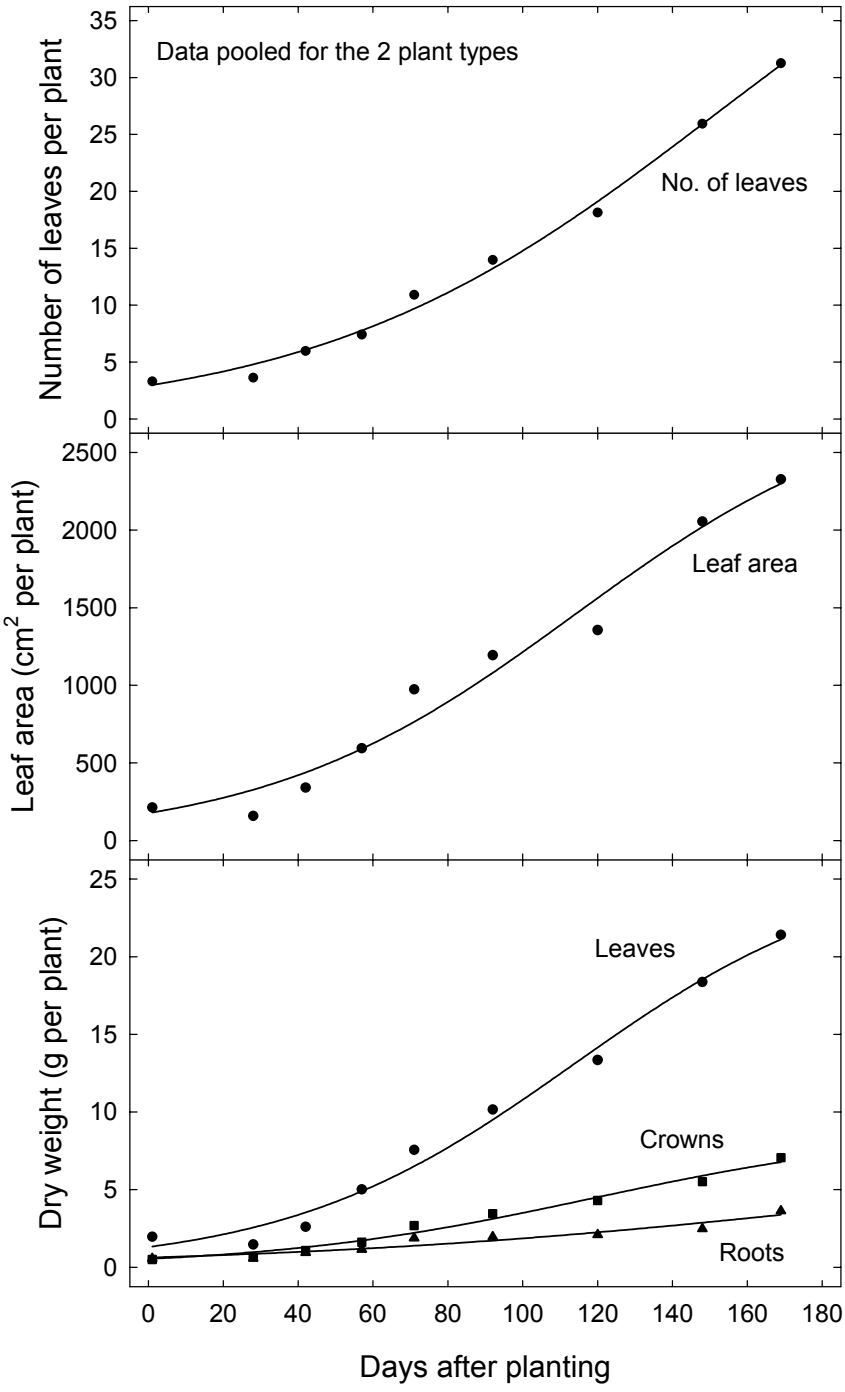

Figure 4. Changes in leaf production, leaf area and plant dry weight in the strawberries over time in the source experiment at Nambour (Experiment 2). Data are the means of 16 replicates pooled from the two plant types ('Festival' runners from Stanthorpe and runners from Toolangi). No. of leaves = 53.09/(1+exp(-(day-150.58)/53.10)); Leaf area = 2911.41/(1+exp(-(day-113.93)/41.62)); DW_{leaf} = 26.13/(1+exp(-(day-113.56)/38.56)); DW_{crown} = 8.90/(1+exp(-(day-118.72)/43.34)); and DW_{root} = 7.98/(1+exp(-(day-193.07)/78.33)) (R^2 = 97%, $P < 0.01$).

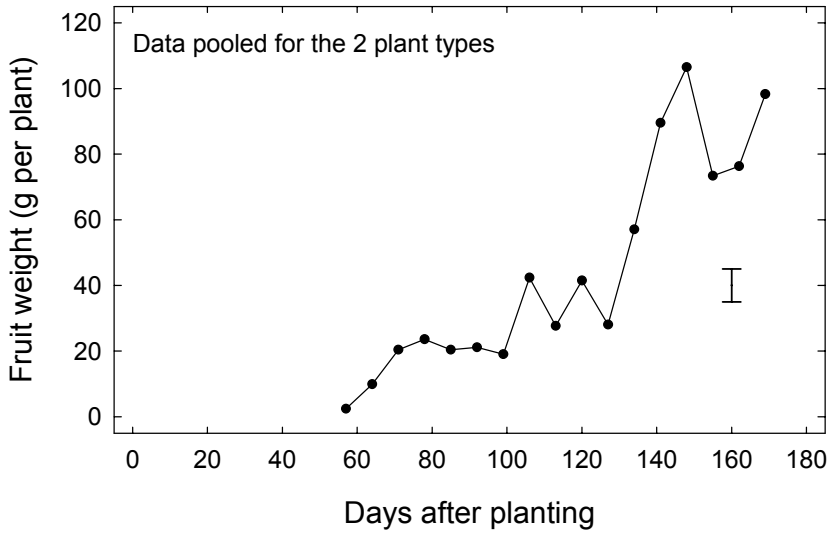

Figure 5. Changes in fruit production in the strawberries over time in the source experiment at Nambour (Experiment 2). Data are the means of 16 replicates pooled from the two plant types ('Festival' runners from Stanthorpe and runners from Toolangi). Vertical bar indicates LSD ($P = 0.05$).

Plate 1. Small (left) and large (center) bare-rooted plants and containerized plants (right) of ‘Festival’ strawberry soon after planting in 2006.

Plate 2a. The growth of small bare-rooted plants of ‘Festival’ strawberry in October 2006.

Plate 2b. The growth of large bare-rooted plants of ‘Festival’ strawberry in October 2006.

Plate 2c. The growth of containerized plants of ‘Festival’ strawberry in October 2006.

Plate 3a. The growth of bare-rooted Stanthorpe ‘Festival’ strawberry plants in October 2006.

Plate 3b. The growth of bare-rooted Toolangi ‘Festival’ strawberry plants in October 2006.

Water use in fields during establishment: a comparison between impact and micro-sprinklers

Geoff Waite and Matt Dagan

Commercial summary

Traditionally, strawberry growers in Queensland have relied on high output impact sprinklers for establishment, maintenance irrigation and frost protection. These are particularly wasteful, putting out large droplets with high physical impact over the entire cropping area. The efficiency of these sprinklers with that achieved with micro-sprinklers was compared in a strawberry field on the Sunshine Coast. Knocker sprinklers delivered 600 to 700 L per h with a 10 to 12 m wetting radius, while micro-sprinklers delivered 90 L per h (under high pressure) with a wetting radius of 2 to 3 m. There was about a 50% reduction in water use for the micro-sprinklers compared with the knockers, and a potential saving of 80% with correct water pressure. Reducing plant establishment water use by 50 to 80% would save 20 to 30% of total crop water use or 1.2 to 1.8 ML per ha.

Introduction

Irrigation is necessary for commercial strawberry production on the Sunshine Coast. Without regular watering, plant growth and yields are severely reduced. Strawberries are mostly planted as bare rooted runners with or without leaves. Leafless runners are easy to establish with little supplementary irrigation. This may be applied as trickle or from overhead sprinklers, and so long as the runners have been planted into moist soil, occasional watering during plant establishment is all that is required. On the other hand, runners with leaves intact require continuous overhead watering during the day for about a week after planting. This is to ensure that the plants and the plastic mulch remain cool. While they are establishing, the plants inevitably droop and fall onto the plastic which, if not cooled with water, will damage the plants. This practice consumes large volumes of water, and it may be counter-productive in heavy clays, which can become waterlogged and boggy, while in sands, pre-plant fertiliser is quickly leached beyond the root zone.

Most strawberry growers in southern Queensland use high output impact sprinklers for establishment, maintenance irrigation, and frost protection. These systems are particularly wasteful, putting out large droplets with high physical impact over the entire cropping area. Only a small proportion of water applied is actually used by the crop, with most of it running off the plastic-covered beds and out the ends of the rows.

Once plants establish, trickle or drip irrigation can provide adequate soil moisture in the root zone and can be used to supply fertilizer for the plants (fertigation). The traditional overhead impact sprinklers have remained the sole irrigation system for many growers, but concerns over excessive water use and run-off indicate a need for other strategies. Overhead impact sprinklers waste water, even when cycled on/off during establishment. Micro-sprinklers similar to those used in orchards could also

cool the young plants and the plastic, using a fraction of the water. Some growers use this system, although the potential benefits have not been quantified. Here we report on the relative efficiency of impact and mini-sprinklers in a strawberry field on the Sunshine Coast.

Materials and methods

An irrigated block of strawberries at Palmwoods near Nambour on the Sunshine Coast was used. The existing system consisted of impact sprinklers on 12 m x 8 m spacings. In one corner of the block, four knocker sprinklers were disconnected and micro-sprinklers linked into the existing laterals on a grid pattern (see below). Flow meters were installed in the main supply line for both sprinklers to measure the volume of water used. Catch-cans were also set up to validate the flow meter data and to include rainfall in the water use calculations. The output of the two irrigation systems was than calculated on a time basis (L per h) and on an area basis (ML per ha).

Results and discussion

The knocker sprinklers delivered 600 to 700 L per h with a 10 to 12 m wetting radius (Figure 1). This high volume was delivered as large droplets that had high impact and battered the plants, caused compaction of the inter-rows as well as splashing soil, which is undesirable in terms of local erosion and the spread of disease.

The micro-sprinklers delivered 90 L per h, which was a higher volume than required due to the high mains pressure necessary to run the other sprinklers. The micro-sprinklers had a 2 to 3 m wetting radius (Figure 2) and low impact, with no splash or soil compaction. Sprinklers with a discharge rate of 50 L per h would be adequate for the required purpose in strawberries.

The two methods of measuring water use gave similar results. Catch-cans indicated a 62% reduction in water use for the micro-sprinklers (1.13 ML per ha) compared with

the knockers (2.97 ML per ha), while the flow meters indicated a saving of 53% (82 kL versus 175 kL). On an area basis, this saving equated to 1.1 ML per ha under an operating pressure of 40 psi. Under the correct pumping pressures with a discharge of 50 L per h, the saving would be 80% or 1.8 ML per ha. There was no significant difference in plant establishment or yield between the two irrigation regimes. This indicates that the micro-sprinklers can be used successfully to establish and grow strawberries, while using much less water.

Benchmarking trials conducted in 2002 indicated that the average amount water applied to strawberry fields on the Sunshine Coast was 5.9 ML per ha. Sixty percent of the water used by the crop was used by trickle systems during cropping, and forty percent for establishment. Reducing plant establishment water use by 50 to 80% would save 20 to 30% of the total amount of water applied to the crop, in the order of 1.2 to 1.8 ML per ha for an average strawberry field.

Conclusions

The cost of converting from impact to micro-sprinklers is about $3000 per ha. There are also additional labour costs required to set up and remove the micro-sprinklers each season. Growers using knockers may have difficulty justifying the capital costs required to set up micro-sprinklers, even though they would save water. However, increasing pressure on water resources might make water savings mandatory in the future. Growers setting up new infrastructure should invest in micro-sprinklers for establishment watering, with trickle installed for the rest of the season.

This research was conducted in collaboration with Growcom. The results of these studies were presented to 130 growers at a field day in 2002, at ‘Water for profit’ workshops in 2003, and to wider industry in newsletters and a North American strawberry journal. Information from the “Water for profit financial incentive scheme” indicates that six growers immediately used the information derived and the Incentive Scheme subsidy to convert from impact to micro-sprinklers.

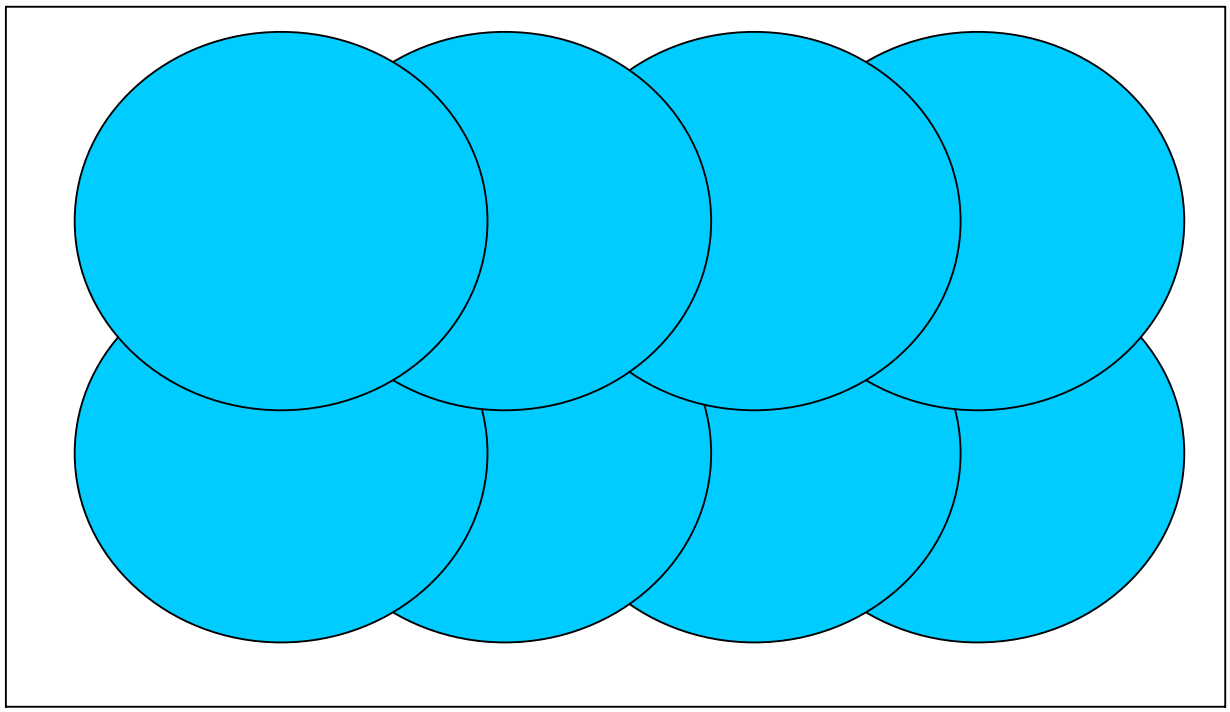

Figure 1. Sample area and sprinkler wetting pattern with impact sprinklers (knockers).

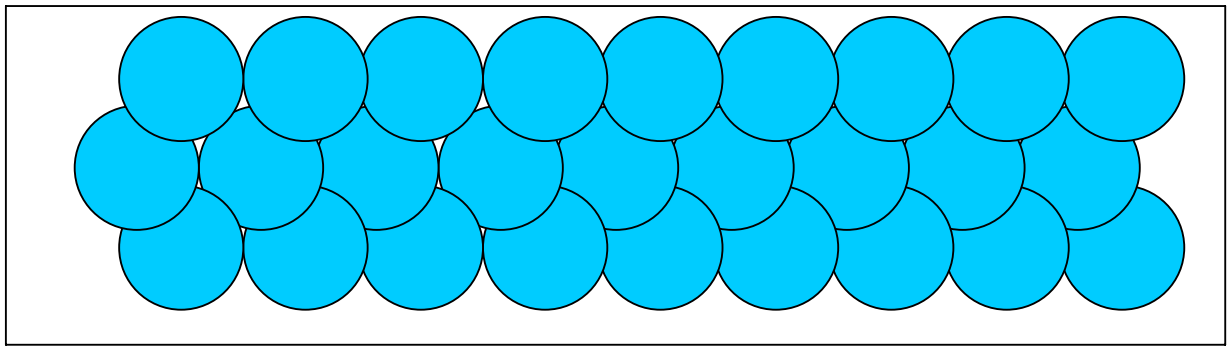

Figure 2. Sample area and sprinkler wetting pattern for micro-sprinklers.

The effect of nitrogen on the yield of different cultivars

Jenny Moisander and Dave Lyons

Commercial summary

Experiments were conducted to assess the impacts of nitrogen applications on yield and plant nitrogen status in thirteen strawberry cultivars over four years at Redlands. There was no effect of nitrogen on yield in any of the 14 experiments in the red clay loam soil, with average yield ranging from 542 to 720 g per plant. There were mixed effects of nitrogen on petiole nitrate (NO_3) concentration, with higher rates increasing plant nitrogen status in eight cases, and having no effect in six cases. The lowest petiole NO_3 concentration observed in the different treatments was considered to be the optimum level of plant nitrogen in these experiments, with mean concentrations during the season ranging from 100 mg per L for 'Festival' to 1000 mg per L for 'Harmony'.

Introduction

Nitrogen (N) is the main nutrient affecting growth, yield and quality in strawberry fields. Applications up to 150 kg N per ha have been found to increase yields, with higher rates up to 200 kg N per ha reducing yields due to a decrease in the number of inflorescences. Excessive nitrogen applications can also lead to poor quality, including pale skin colour and soft fruit. Few studies have been conducted on the response of strawberry to nitrogen in Australia, although some of the studies in Florida, which has a similar climate to southern Queensland and winter production, have application to local producers. Commercial strawberry growing in Florida is based on the injection of soluble fertilizers through the irrigation lines, production generally being best with nitrogen applications not exceeding 100 kg per ha. Applications to strawberry fields on the Sunshine Coast from flowering range from 72 to 90 kg N per ha (Vock, 1997). Nitrogen fertilizers may also be applied before planting.

The management of nutrition in horticultural crops is generally based on an assessment of leaf nutrient concentrations. Fertilizer applications are adjusted throughout the season to keep nutrient concentrations within the optimum range established for that crop. Yield and quality usually decline when leaf levels are lower or higher than the optimum range.

There is no universal standard for measuring nitrogen status in strawberry fields. Similarly, there are few studies relating yield to plant nitrogen levels. The concentration of nitrogen varies within the strawberry plant and with the season, the leaves generally having nitrogen concentrations double those of the crowns and roots, and whole leaves (blade and petiole) having higher concentrations than leaf blades, on a dry matter basis. Typically, average leaf values decline during cropping in subtropical environments such as Florida.

Several techniques have been used to assess the nitrogen status of strawberry fields, including: soil nitrogen content at planting (N_{min}); total nitrogen in the leaves or leaf blades on a dry weight basis; and petiole nitrate (NO_3) concentrations on a wet or dry weight basis.

Daugaard and Todsen (1999) found that N_{min} could be used to determine the fertilizer requirements of strawberry plantings in Denmark at the beginning of the season. This method assessed the pool of readily available nitrogen in the soil to a depth of 50 cm as indicated by the concentrations of nitrate (NO_3)- and ammonium (NH_4)-N (on a dry weight basis). Readily available soil reserves ranged from 8 to 166 kg N per ha over the three years (averages of 25 to 68 kg N per ha), indicating considerable variation across plots and years (low values after heavy rainfall). The growers applied up to 80 kg N per ha to their fields after taking into account the reserves of readily available nitrogen. Unfortunately, the principles developed by Daugaard and Todsen have not been evaluated in other environments, although they appear to provide a basis for calculating the nitrogen requirements of strawberry crops, especially to assist growers avoid over-fertilizing.

Vock (1997) provided a guide for fertilizer applications before planting for strawberry growers on the Sunshine Coast, based on soil nitrate-nitrogen concentrations from 0 to 15 cm. Suggested applications ranged from 55 kg N per ha with soil NO_3-N of 40 mg per kg, to 220 kg N per ha with soil NO_3-N lower than 10 mg per kg. Strong and Mason (1999) indicated mixed success in attempts to relate the yields of annual field crops with soil nitrate concentrations to various depths in Queensland.

The nutrient status of strawberry plantings can be assessed by monitoring the concentration of nitrogen (total nitrogen) in the leaves. Kwong and Boynton (1959) were among the first authors to report on nutrient concentrations in strawberry. Either leaf blades or whole leaves can be used, with no general agreement on which tissue is more appropriate. Many authors suggest that leaf blades should be used because the proportion of the leaf taken up by the petioles can range from 25 to 50% in different cultivars. A leaf nitrogen concentration of 3% (dry weight) is thought to be sufficient by some researchers, while others suggest a lower range of 1.8 to 2.0% is more appropriate. In a number of temperate northern hemisphere growing areas, leaf samples are taken after harvest in July. In these environments, leaf nitrogen concentrations are highest in spring and lowest at the end of harvest.

Leaf nitrogen concentrations also decline in annual production systems such as those found in Florida. Adequate ranges for nitrogen in whole leaves in Florida are 3.0 to 4.0% from October to January (northern hemisphere), 2.8 to 3.0% from February to March, and 2.5 to 3.0% in April (Hochmuth *et al*., 1991; 1996).

Lacroix and Cousin (1997) promoted the use of petiole nitrate concentrations (fresh samples) as the basis for monitoring nitrogen in strawberry plants. They found that petiole nitrate concentrations were more sensitive to changes in nitrogen supply in soilless culture than concentrations of total nitrogen in the leaf blades. A survey of 14 fields in south-west France over two years suggested that nitrogen deficiency occurred when petiole nitrate concentrations fell below 500 to 700 mg per L, and nitrogen sufficiency, with 1,000 to 1,500 mg per L. There was a poor correlation between petiole and soil nitrate concentrations (R^2 less than 0.60 in 65% of cases).

Hochmuth *et al*. (1996) investigated the relationship between yield and nitrogen applications over two years in Florida. They concluded that adequate petiole nitrate concentrations were 600 to 900 mg per L in November, decreasing to 100 to 200 mg per L in April. Petiole nitrate concentrations increased with increasing nitrogen applications (from 0.28 to 1.4 kg N per ha.day), whereas concentrations of nitrogen in the leaves was saturated at lower applications (0.56 kg N per ha.day). Presumably, there was a limit to the amount of structural nitrogen that could be fixed in the leaves, with the excess found in the sap.

Ulrich *et al*. (1980) studied the response of strawberry cultivars to nitrogen in California, and suggested a critical petiole nitrate concentration of 500 mg per kg (dry weight basis). However, the relationship between yield and petiole nitrate concentration was not presented, with values much higher than this (4000 to 5000 mg per kg) recorded for much of the season.

We report on the effects of nitrogen on the growth and performance of 13 strawberry cultivars at Redlands over four years. Different rates of nitrogen fertilizer were applied through the irrigation system, and the impacts on yield and plant nitrogen status assessed. This approach follows similar work in capsicum in southern Queensland (Olsen and Lyons, 1994). In these experiments in capsicum, petiole nitrate (fresh weight basis) was about five times more sensitive to changes in nitrogen applications than total nitrogen in the youngest mature leaf (dry weight basis). There was also a stronger relationship between yield and petiole nitrate (R^2 between 0.45 and 0.83) than between yield and leaf nitrogen (R^2 between 0.29 and 0.74).

Materials and methods

Experiments were conducted at Redlands to investigate the effects of nitrogen nutrition on the performance of thirteen strawberry cultivars planted in late March to early April over four years: 'Camarosa', 'Earlimist' and 'Sweet Charlie' in 2001; 'Adina', 'Gaviotta' and 'Lowanna' in 2002; 'Cal Giant 2', 'Cal Giant 3' and 'Festival' in 2003; and 'Camarosa', 'Harmony', 'Rubygem', 'Sugarbaby' and 'Ventana' in 2004. The soil was a red clay loam, with the plants grown on plastic in double row beds 65 cm wide and 80 cm apart. Plants along the rows were planted 40 cm apart, equivalent to a density of 33,350 plants per ha. The site was rotary hoed, and green cover crops grown for two months after the previous strawberry crop was removed. The cover crop was then mowed and the trash removed from the site before further ploughing and bed preparation. The plants were grown under commercial conditions, with standard horticultural practices (Vock, 1997).

Treatments each year were four different nitrogen rates (N1, N2, N3 and N4): 2, 4, 5 or 8 kg N per ha in 2001; 1, 3, 4 or 8 kg N per ha in 2002; 1, 3, 8 or 20 kg N per ha in 2003; and 3, 11, 2 (as slow release fertilizer) or 25 kg N per ha in 2004. The nitrogen was applied as urea, calcium nitrate and potassium nitrate in the standard treatments in eight or nine applications from first flowering in late April to early May up until the final harvest in late September. The figures do not take into account the small amounts of fertilizer applied before and just after planting. The experiment was laid out in a split-plot randomised block design, with nitrogen rates the main plots and cultivars the split plots, with three randomized blocks. The same fertilizer was

applied to all plants within a row. The plants were established by overhead irrigation, and thereafter, irrigation and fertiliser were applied through trickle tape from May. Each row had a separate point for injecting fertiliser into the trickle tape, allowing the same fertiliser treatment to be applied to all plants within the row every fortnight.

Fruit were harvested each week from the same 45 plants in each plot (n = 135). Every month or so prior to fertigation, samples of the youngest fully expanded leaves, including the petioles, were collected from each plot and bulked across replications. The sap that was expressed from the crushed petioles was analysed for NO_3 concentration as described by Vock (1997).

Cumulative yield data were analysed by split-plot analysis of variance, with nitrogen treatment the main plot, and cultivar the split plot (4 nitrogen rates x 3-5 cultivars x 3 blocks), with each year analysed separately.

To assess the impacts of nitrogen fertilizer on plant nitrogen status, the data on petiole NO_3 concentrations in 2002 and 2003 were analysed by split-plot analysis of variance, with nitrogen treatment the main plot and cultivar the split plot, and each sampling date treated as a block (4 nitrogen rates x 3 cultivars x 4-6 blocks). The data in 2001 and 2004 were analysed by one-way analysis of variance, with each cultivar analysed separately, and each sampling date treated as a block (4 nitrogen rates x 4-6 blocks). Each cultivar was treated separately because the leaf samples from the different cultivars were collected at different times.

To assess the seasonal changes in plant nitrogen status, the data on petiole NO_3 concentrations in 2002 and 2003 were analysed by repeated measure analysis of variance, with each nitrogen treatment treated as a block (3 cultivars x 5-6 sampling dates x 4 blocks). The data in 2001 and 2004 were analysed by repeated measure analysis of variance, with each cultivar analysed separately, and each nitrogen treatment treated as a block (4-6 sampling dates x 4 blocks). The relationship between yield and mean seasonal petiole NO_3 concentration in each of the cultivars was assessed by regression analysis.

Results and discussion

There was no significant effect ($P > 0.05$) of nitrogen on yield in any of the experiments (Tables 1 to 4), with average yield ranging from 542 to 720 g per plant. There were mixed effects of nitrogen on petiole NO_3 concentration (Tables 1 to 4). Higher nitrogen rates increased plant nitrogen status in eight cases (‘Earlimist’ and ‘Sweet Charlie’ in 2001, and all the cultivars in 2002 and 2003), and had no significant effect in six cases (‘Camarosa’ in 2001, and all the cultivars in 2004).

Average petiole NO_3 concentrations varied across the season (Figures 1 to 4). In most cultivars, NO_3 concentration declined as the plants began to flower and crop, but increased towards the end of the season. ‘Camarosa’ (2001), ‘Sweet Charlie’ and ‘Harmony’ displayed the greatest fluctuations, followed by ‘Earlimist’, ‘Adina’, ‘Gaviotta’, ‘Lowanna’, and then ‘Cal Giant 2’, ‘Cal Giant 3’, ‘Festival’, ‘Camarosa’ (2004) and ‘Ventana’. The changes in plant nitrogen status over the season in the

different cultivars were not sufficiently consistent to predict variations in petiole NO_3 concentrations in other locations.

There was no consistent relationship between yield and average seasonal petiole NO_3 concentration in the different cultivars (seven cases of linear relationships, four cases of quadratic relationships with a maximum, and three cases of quadratic relationships with a minimum). This information, when considered with the results of the analysis of variance (no significant effect on nitrogen on yield), suggests that the optimum plant nitrogen status for each cultivar in these experiments was the lowest petiole NO_3 concentration observed in the different nitrogen treatments.

Suggested mean optimum values during the season for the different cultivars are as follows: 500 to 700 mg per L for 'Camarosa'; 450 mg per L for 'Earlimist'; 750 mg per L for 'Sweet Charlie'; 200 mg per L for 'Adina'; 600 mg per L for 'Gaviotta'; 300 mg per L for 'Lowanna'; 200 mg per L for 'Cal Giant 2'; 150 mg per L for 'Cal Giant 3'; 100 mg per L for 'Festival'; 1000 mg per L for 'Harmony'; 700 mg per L for 'Rubygem'; 600 mg per L for 'Sugarbaby'; and 500 mg per L for 'Ventana'. Taking into account the work of Hochmuth *et al*. (1996) detailed below, optimum values early in the season are probably double mean values, while values later in the season are probably half.

Research in Florida showed that adequate petiole nitrate concentrations in subtropical strawberries were 600 to 900 mg per L in November, decreasing to 100 to 200 mg per L in April (Hochmuth *et al*., 1996). In these experiments, plant nitrogen status declined steadily (petiole nitrate or total leaf nitrogen) over the season, whereas in the experiments at Redlands, there were significant variations in seasonal trends in the different cultivars. Higher nitrogen applications increased plant nitrogen status in eight out of fourteen cases, but this did not translate into significantly higher yields. It is possible that high soil nitrogen reserves at the site masked the response to nitrogen fertilizers. Future experiments should use sites with lower nitrogen status, and a greater range of nitrogen treatments (six), and greater replication (six). The experiments on single cultivars probably need to be carried out over at least three years to take into account variations in cropping in different seasons.

Conclusions

Nitrogen applications ranging from 1 to 25 kg per ha had no significant effects on the yield of 13 strawberry cultivars growing on a red clay loam soil over four years at Redlands, probably reflecting high soil nitrogen reserves. The lowest petiole NO_3 concentration observed in the different nitrogen treatments was considered to be the optimum level of plant nitrogen in these experiments, with mean concentrations during the season ranging from 100 mg per L for 'Festival' to 1000 mg per L for 'Harmony'.

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Table 1. The effects of nitrogen applications on yield and petiole NO_3 concentration in trials in 2001. There was no interaction between cultivar and nitrogen on yield. Petiole NO_3 analysed separately for each cultivar because of different sampling dates. Data are the means of three replicates per treatment (pooled across sampling date for petiole NO_3 concentrations). See 'Methods' for details of nitrogen applications.

Treatment	Yield (g per plant)	Petiole NO_3 (mg per L)		
		Camarosa	Earlimist	Sweet Charlie
N1	590	718	451	753
N2	737	858	638	1181
N3	702	850	617	1087
N4	739	917	786	1056
LSD ($P = 0.05$)	n.s.	n.s.	141	238

Table 2. The effects of nitrogen applications on yield and petiole NO_3 concentration in trials in 2002, with 'Adina', 'Gaviotta' and 'Lowanna'. There was no interaction between cultivar and nitrogen on yield or petiole NO_3. Data are the means of three replicates per treatment (pooled across sampling date for petiole NO_3 concentrations). See 'Methods' for details of nitrogen applications.

Treatment	Yield (g per plant)	Petiole NO_3 (mg per L)
N1	519	402
N2	548	401
N3	565	552
N4	537	604
LSD ($P = 0.05$)	n.s.	150

Table 3. The effects of nitrogen applications on yield and petiole NO_3 concentration in trials in 2003, with 'Cal Giant 2', 'Cal Giant 3' and 'Festival'. There was no interaction between cultivar and nitrogen on yield or petiole NO_3. Data are the means of three replicates per treatment (pooled across sampling date for petiole NO_3 concentrations). See 'Methods' for details of nitrogen applications.

Treatment	Yield (g per plant)	Petiole NO_3 (mg per L)
N1	621	217
N2	597	227
N3	482	348
N4	668	501
LSD ($P = 0.05$)	n.s.	148

Table 4. The effects of nitrogen applications on yield and petiole NO_3 concentration in trials in 2004. There was no interaction between cultivar and nitrogen on yield. Petiole NO_3 analysed separately for each cultivar because of different sampling dates. Data are the means of three replicates per treatment (pooled across sampling date for petiole NO_3 concentrations). See 'Methods' for details of nitrogen applications.

Treatment	Yield (g per plant)	Petiole NO_3 (mg per L)				
		Camarosa	Harmony	Rubygem	Sugarbaby	Ventana
N1	770	564	1067	774	701	517
N2	724	678	1002	725	618	597
N3	725	615	1132	696	579	599
N4	661	514	1157	770	689	604
LSD ($P = 0.05$)	n.s	n.s.	n.s.	n.s.	n.s.	n.s.

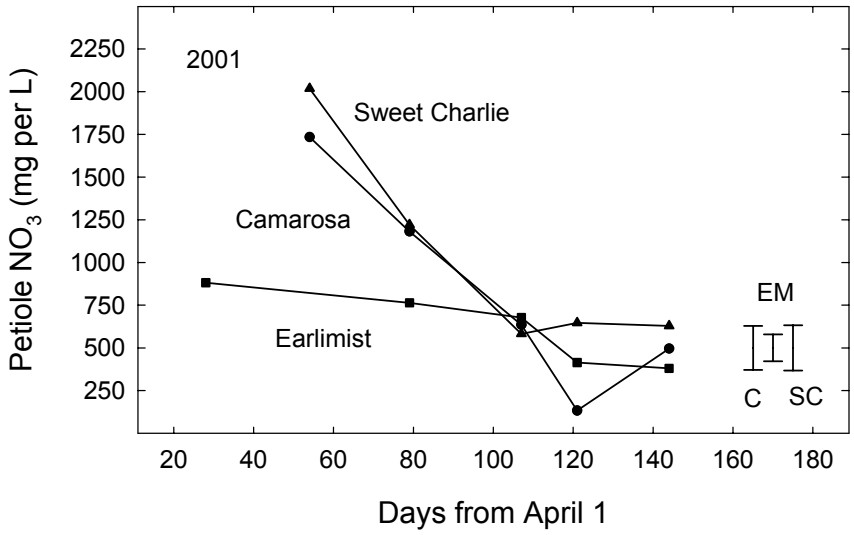


Figure 1. Seasonal changes in petiole NO_3 concentrations in 'Camarosa', 'Earlimist' and 'Sweet Charlie' strawberries at Redlands in 2001. Data are the means of twelve replicates per date, pooled across four nitrogen treatments and three plots. Bars show LSDs ($P = 0.05$).

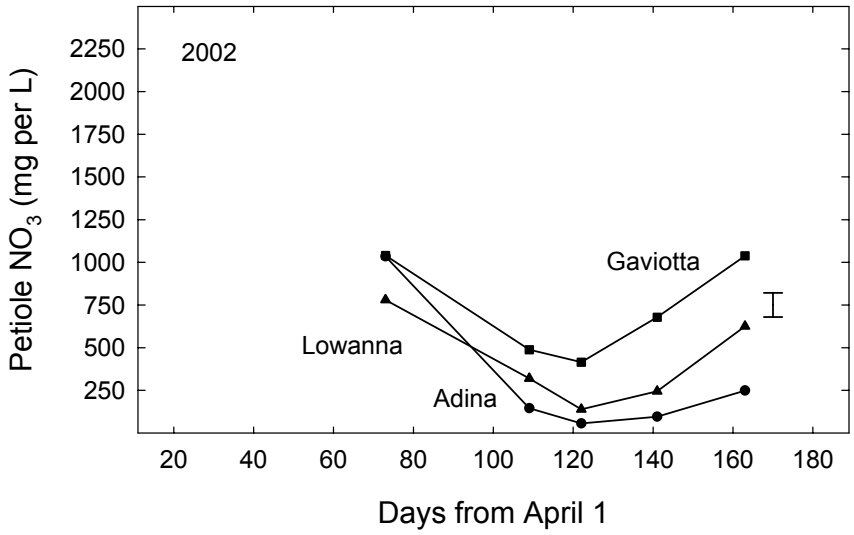


Figure 2. Seasonal changes in petiole NO_3 concentrations in 'Adina', 'Gaviotta' and 'Lowanna' strawberries at Redlands in 2002. Data are the means of twelve replicates per date, pooled across four nitrogen treatments and three plots. Bar shows LSD ($P = 0.05$).

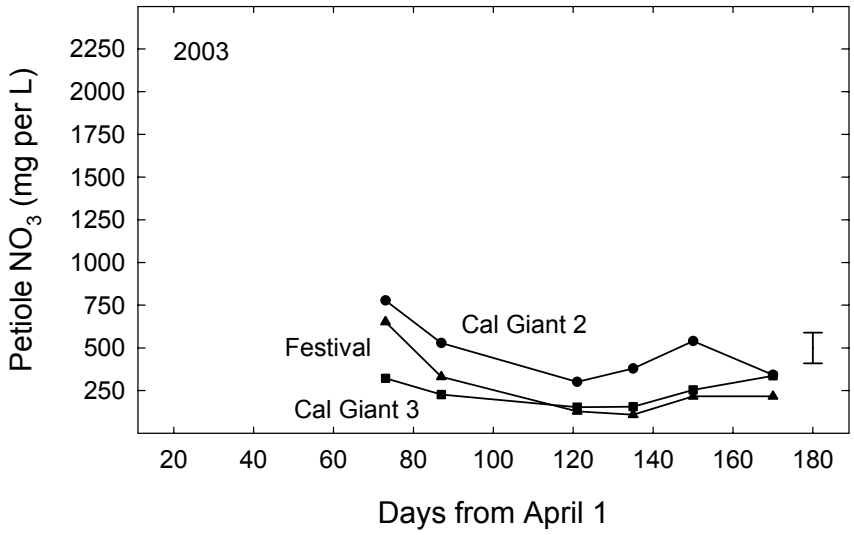


Figure 3. Seasonal changes in petiole NO_3 concentrations in 'Cal Giant 2', 'Cal Giant 3' and 'Festival' strawberries at Redlands in 2003. Data are the means of twelve replicates per date, pooled across four nitrogen treatments and three plots. Bar shows LSD ($P = 0.05$).

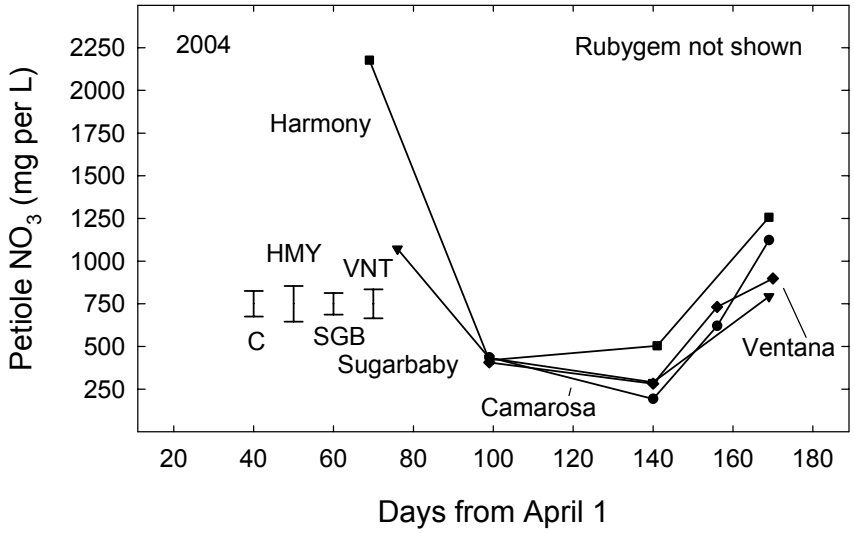


Figure 4. Seasonal changes in petiole NO_3 concentrations in 'Camarosa', 'Harmony', 'Sugarbaby and 'Ventana' strawberries at Redlands in 2004. Data are the means of twelve replicates per date, pooled across four nitrogen treatments and three plots. Bars show LSDs ($P = 0.05$).

Supplementary IPM compatible miticides

Geoff Waite

Commercial summary

Two-spotted spider mite, *Tetranychus urticae*, is the major pest of strawberries in Queensland, but is readily controlled by the predatory mite, *Phytoseiulus persimilis*. There are some situations in which total control of spider mites may be required because predatory mites have not been introduced, or because they have been introduced too late and heavy pest infestations have developed. The efficacy of bifenazate against *T. urticae*, and its effect on *P. persimilis* was assessed over three experiments on the Sunshine Coast to provide data for the future registration of the product in strawberries, increasing the number of miticides registered for such use and to reduce the risk of resistance developing to any one product. The results of these experiments indicate that bifenzate provides excellent control of spider mites and is compatible with the predatory mite. Registration of this chemical would assist growers to manage spider mites and to manage miticide resistance in their crops.

Introduction

Two-spotted spider mite, *Tetranychus urticae*, and related *Tetranychus* spp., are the major pests of strawberries throughout the world. In Queensland, *T. urticae* may infest the crop at any time, but infestations become a problem from July to October, when low humidity and moderating temperatures promote rapid multiplication. The intensity of outbreaks often increases if broad-spectrum insecticides, which disrupt natural enemies, are used. Most of the Queensland crop utilizes the predatory mite, *Phytoseiulus persimilis*, to control spider mites (Waite and Jones, 1999). This is achieved in most cases through the use of the pest-in-first or simultaneous release systems, where spider mite infestations are deliberately created early in the season to encourage the establishment of the predatory mites that are introduced with them.

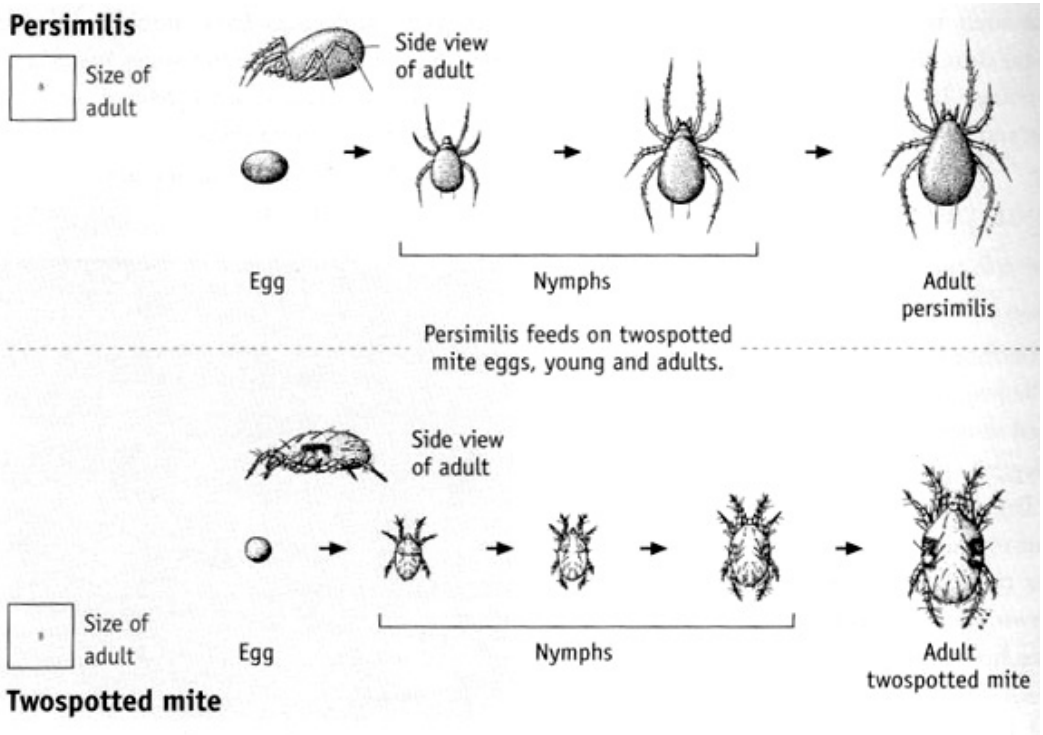
Occasionally, seasonal conditions or disruptive chemicals kill the predators, and a miticide may be required to restore the predator/prey balance. Such sprays need to be compatible with the predators, and if the predator population remains relatively healthy, a total kill of spider mites, which is seldom achieved under commercial conditions, is not required. In fact, it is not desirable since the predators require prey to survive, and should be encouraged to remain in the crop through the culture of non-damaging spider mite populations.

There are some situations in which total control of spider mites may be required because predatory mites have not been introduced, or the infestation has been allowed to progress beyond their capabilities. Thus, miticides are required to enable management under such conditions. The best approach is to use a range of miticides of different chemical structure to reduce the risk of resistance developing. This research was conducted to assess the efficacy of bifenazate against *T. urticae*, and its effect on *P. persimilis*. Three experiments were conducted over two years on strawberry fields on the Sunshine Coast.

Materials and methods

Two experiments were conducted at Maroochy Research Station in 2004, and one on a commercial farm near Nambour on the Sunshine Coast in 2005.

Spider mites and predators were counted on five randomly sampled leaves from each plot (see below), with moderate infestations of spider mites and predatory mites. Bifenazate (0.64 ml per L) and abamectin (1 ml per L) were applied on 21 June 2004 for Experiment 1, and on 31 August 2004 for Experiment 2, with a backpack power mister so that the lower leaf surfaces were well covered with the spray. Control plots were left unsprayed. In Experiments 1 and 2, a visual in-field assessment was made one day after spraying, with a detailed laboratory count six days later. In Experiment 3, mites were counted on 18 July 2005 and the treatments applied on the same day. The post-treatment assessment was done on 20 July. Data are the means of three replicates per treatment, and were analysed by one-way analysis of variance (3 treatments x 3 blocks), with each site and year analysed separately.



Results and discussion

In 2004, bifenazate and abamectin killed most of the active stages of the spider mites after one day (Table 1). However, the treatment means were not significantly different because of high variability in the control plots. As would be expected, the number of predatory mites declined because of the lack of prey on which to feed, and not necessarily because of the toxicity of the chemicals. In Experiments 2 and 3, both chemicals significantly reduced the number of spider mites (Table 1). Populations of predatory mites were universally low, and unaffected by the miticides.

Conclusions

The results of these experiments indicate that bifenzate controls spider mites in strawberries and is compatible with predatory mites. Registration of this miticide would provide growers with an effective chemical back-up, as well as reducing the likelihood of the pest developing resistance to currently registered compounds.

Reference

Waite, G.K. and Jones, P. (1999). Management of spider mites in commercial strawberry fields using *Phytoseiulus persimilis* Athios-Henriot and the 'pest in first' technique. *Advances in Strawberry Research* 18: 33-40.

Table 1. The effects of bifenazate and abamectin on the number of spider mites and predatory mites per leaf found in strawberry fields on the Sunshine Coast. Data are the means of three replicates per treatment.

Chemical	No. of spider mites before spraying	No. of predators before spraying	No. of spider mites after spraying	No. of predators after spraying
			Exp. 1	
Control	71	21	127	44
Bifenazate	57	53	2	10
Abamectin	129	21	1	22
LSD ($P = 0.05$)	n.s.	n.s.	n.s.	n.s.
			Exp. 2	
Control	175	1	139	1
Bifenazate	237	2	0	2
Abamectin	182	1	3	1
LSD ($P = 0.05$)	n.s.	n.s.	64	n.s.
			Exp. 3	
Control	26	1	28	2
Bifenazate	30	2	0	1
Abamectin	16	0	3	1
LSD ($P = 0.05$)	n.s.	n.s.	9	n.s.

Alternative non-disruptive insecticides for the control of *Helicoverpa* (*Heliothis*) and other caterpillars

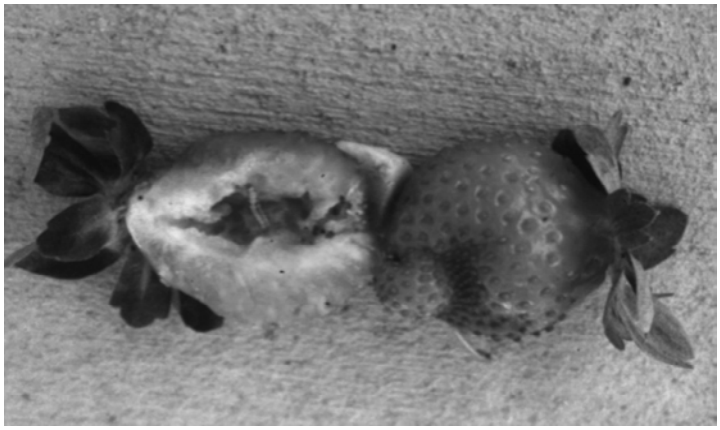
Geoff Waite

Commercial summary

Helicoverpa (*Heliothis*) and other caterpillars attack the fruit and crowns of strawberries in Queensland and elsewhere. The chemicals currently registered for control (methomyl and endosulfan) are toxic to humans and the environment, and disrupt the biological control of two-spotted spider mite by predatory mites. The potential of other chemicals to replace the current insecticides was investigated in research conducted on the Sunshine Coast over four years. Indoxacarb, emamectin and spinosad controlled the caterpillars, with little impact on predatory mites. Spinosad has been registered for use in strawberries. Indoxacarb and emamectin also need to be registered to enable a resistance management strategy to be developed.

Introduction

Helicoverpa (*Heliothis*) and other caterpillars such as *Spodoptera litura* (cluster caterpillar) and to a lesser extent *Isotenes miserana* (orange fruitborer) and *Epiphyas postvittana* (light brown apple moth) occasionally damage Queensland strawberries. Cluster caterpillar is most active during the month after planting and is easily controlled with the bacterium *Bacillus thuringiensis*. *Helicoverpa* is most active during the milder months, but may persist through winter.



Although the loss of fruit to *Helicoverpa* is not great, the young larvae tunnel into the fruit where they may remain safe from insecticide sprays and detection (see above). Growers worry that fruit with larvae inside may escape detection by pickers and packers and end up giving an unlucky consumer a surprise. Many growers also apply an insecticide to prevent potential plant damage, even if they are not worried about fruit damage! They are concerned that if larvae are allowed to develop early in the

season, irreparable damage to a plant crown may occur, which may cost two or more punnets of fruit over the season. If such concerns about caterpillars exist, sprays need to be applied to kill the larvae as they hatch and before they can burrow inside fruit or secrete themselves in the depths of the plant crown where they are relatively safe.

The only chemicals registered for caterpillars in strawberries are old chemistry – methomyl, which is toxic to range of organisms including humans, and endosulfan, for which there is a seven-day withholding period, which is clearly unacceptable in a strawberry crop that has to be picked every three to four days. In addition, endosulfan has some questionable environmental characteristics, especially its effects on aquatic life. Both insecticides can also disrupt predatory mites (*Phytoseiulus persimilis*) used to control two-spotted spider mite (*Tetranychus urticae*).

Many more effective insecticides are now available, with representatives from a number of 'new chemistry' groups exhibiting activity against certain pest groups. Three of these 'new' chemicals, spinosad (Success®), indoxacarb (Avatar ®), and emamectin (Proclaim®) are effective against lepidopterous pests in other crops, especially cotton and vegetables. Experience suggests that they are also much less disruptive of natural enemies than the old chemicals. Such a property is required to provide chemical control of caterpillars in strawberries without disrupting the biological system for spider mites and aphids. Other potential controls considered worthy of investigation and included in this research were the nuclear polyhedrosis virus of *Helicoverpa*, marketed as Gemstar® and Vivus®, and *Bacillus thuringiensis* (Bt).

Materials and methods

Trials were established in 2001, 2002 and 2003. A trial in 2004 was abandoned when no infestations were recorded. In each season, the trial area consisted of 1,500 to 2,000 plants at Maroochy Research Station on the Sunshine Coast. Bare-rooted green-leaf runners were planted in double rows in early- to mid-April, and established using mini-sprinklers. After establishment, the plants were watered and fertigated via trickle irrigation at regular intervals to maintain growth. Tolylfluanid was applied weekly to control fungal diseases. Spider mites were managed with *Phytoseiulus persimilis* under the pest-in-first system, and no specific sprays were applied for aphids, which are normally controlled by natural enemies such as the micro-hymenopteran, *Aphidius colemani*.

Treatments applied in 2001 were: indoxacarb at 0.25 g per L; emamectin at 0.15 g per L; spinosad at 0.4 ml per L; gemstar at 0.8 ml per L; *Bacillus thuringiensis* (Bt) at 2 g per L; and a control. The sprays were applied on 4 and 18 July, and 1 and 29 August.

Treatments in 2002 were: indoxacarb; emamectin; spinosad; gemstar; gemstar, plus aminofeed at 0.8 ml per L; gemstar, plus mobait at 2.5 ml per L; and a control. The plants were sprayed on 3, 17 and 31 July, and on 15 August, with additional gemstar sprays on 10 and 24 July.

Treatments in 2003 were as follows: indoxacarb; emamectin; spinosad; gemstar; gemstar plus aminofeed; and a control. The chemicals were applied on 19 June, on 2, 16 and 30 July, and on 20 August.

Gemstar® and Vivus® are commercial formulations of the *Helicoverpa* polyhedrosis virus, which is specific to *Helicoverpa*s and doesn't affect other lepidopterous larvae. Aminofeed and mobait are feeding stimulants that increase the ingestion of the virus. *Bacillus thuringiensis*, a naturally occurring bacterial disease of Lepidopterous caterpillars was applied as Dipel®.

Plots consisted of whole rows of 70 plants, with four replicates in 2001 and three replicates in 2002 and 2003. Treatments were applied via a knapsack sprayer at 1,000 L per ha. Plots were harvested once a week and the fruit assessed for caterpillar damage and the presence of larvae, and then weighed. Populations of both spider mites and aphids were monitored to assess the effect of the insecticides on the pests' population and that of their natural enemies.

Results and discussion

The infestation levels of the target caterpillars were low (Tables 1 to 3). Even so, this is probably a reasonable reflection of most commercial strawberry crops. Generally, *Helicoverpa* is a relatively minor pest. However, because of the growers' perception that it requires control, insecticides continue to be applied. Because the Queensland strawberry industry has generally adopted biological mite management, this propensity to apply unnecessary and often disruptive sprays threatens that system's integrity and its success on individual farms. While this attitude persists, and the only insecticides available for the purpose are disruptive of the predatory mites, the identification and registration of effective, compatible alternative insecticides for caterpillar control is urgent.

Despite the low infestation rates, the data indicate that several effective and IPM compatible chemicals are available for *Helicoverpa*. Indoxacarb, emamectin and spinosad all controlled the caterpillars, with less damage compared with the control and virus treated plots. Spinosad has been registered for use in strawberries, with hopefully indoxacarb and emamectin to follow.

Although *Isotenes miserana* is not regarded as a major pest in Queensland, it may occasionally be a nuisance, as does light brown apple moth, *Epiphyas postvittana*. Indications from these trials are that spinosad, indoxacarb and emamectin control these two pests, while the polyhedrosis virus will not, since it is specific to *Helicoverpa* (Tables 1 and 3).

Spinosad and emamectin suppressed populations of *Phytoseiulus persimilis* slightly, whereas indoxacarb had no affect throughout the season. Spider mites were well-controlled in all treatments (Table 4). Similarly, *Aphidius colemani* was unaffected, and aphids adequately controlled by it. There was normal activity of *P. persimilis* and *A. colemani* in the gemstar and Bt plots.

Conclusions

Registration of indoxacarb and emamectin to complement spinosad as IPM compatible caterpillar controls is desirable. These two chemicals should be registered, and used with spinosad so that a resistance management strategy can be developed and implemented, involving a rotation of chemicals throughout the season.

Observations in commercial fields suggest that the polyhedrosis virus is more effective against *Helicoverpa* when applied at low doses on a weekly schedule rather than as temporally widely-spaced sprays. This is because the virus is more effective when ingested by young larvae, which are also killed by a lower dose than that required to kill later instar larvae. Regular low dose applications place a constant and consistent source of inoculum on the foliage to be ingested by the more susceptible larval instars that hatch from eggs laid during infrequent visits by the moths.

Table 1. The number of fruit damaged by *Helicoverpa* and *Isotenes* larvae, and the number of live larvae in 2001. See text for details of treatments. Values are the means of four replicates per treatment.

Treatment	No. of fruit	No. of fruit affected by *Helicoverpa*	No. of *Helicoverpa* larvae	No. of fruit affected by *Isotenes*	No. of *Isotenes* larvae
Control	1374	93	18	13	4
Bt	1282	48	7	5	1
Gemstar	1219	66	11	8	3
Spinosad	239	7	2	9	1
Emamectin	1260	10	2	4	0
Indoxacarb	1443	4	1	4	1
LSD ($P = 0.05$)		32	4	6	n.s.

Table 2. The number of fruit damaged by *Helicoverpa* and the number of live larvae in 2002. See text for details of treatments. Values are the means of three replicates per treatment.

Treatment	No. of fruit	No. of fruit affected by *Helicoverpa*	No. of *Helicoverpa* larvae
Control	1166	40	11
Exclusion	1089	0	0
Indoxacarb	1212	2	0
Spinosad	1204	4	0
Emamectin	1153	9	2
Gemstar	1140	13	3
Gemstar/aminofeed	1082	12	2
Gemstar/mobait	1282	16	2
LSD ($P = 0.05$)		12	4

Table 3. The number of fruit damaged by *Helicoverpa* and *Isotenes*, and the number of live larvae in 2003. See text for details of treatments. Values are the means of three replicates per treatment.

Treatment	No. of fruit	No. of fruit affected by *Helicoverpa*	No. of *Helicoverpa* larvae	No. of fruit affected by *Isotenes*	No. of *Isotenes* larvae
Control	1968	89	6	8	3
Indoxacarb	2115	0	0	0	0
Emamectin	2043	8	1	1	0
Spinosad	2142	8	0	0	0
Gemstar	2113	31	0	4	1
Gemstar/aminofeed	2068	49	2	3	1
LSD ($P = 0.05$)		11	1	n.s.	1

Table 4. The number of active *Phytoseiulus persimilis* stages and eggs on 31 August, 2001, after insecticide sprays for *Helicoverpa* on 4 and 18 July, and 1 and 29 August. See text for details of treatments. Data are the means of four replicates per treatment.

Treatment	No. of active mites	No. of eggs
Control	25	19
Indoxacarb	31	18
Spinosad	8	4
Emamectin	8	3
LSD ($P = 0.05$)	20	14

Determining the susceptibility of strawberries to Queensland fruit fly

Annice Lloyd, Ed Hamacek, Thelma Peek and Geoff Waite

Commercial summary

The susceptibility of strawberries to Queensland fruit fly (*Bactrocera tryoni*) was assessed under laboratory conditions. The results indicated that 'Kabarla' is susceptible to Queensland fruit fly in cage studies, with a Host Susceptibility Index of 0.75 ± 0.07 flies per g of fruit. Queensland fruit fly infestations in commercial strawberries are extremely low and for market access, the species is considered a very low risk. This indicates that although strawberries are a moderate to good host, other factors related to fly behaviour and the nature of this crop, greatly reduce the risk of infestation in the field.

Introduction

The susceptibility of fruit and vegetables to Queensland fruit fly (Qfly) (*Bactrocera tryoni*) is determined under controlled laboratory conditions using the procedures defined by the *NZ MAF Regulatory Standard for Host Status 155.02.02.* The test was designed to determine if a commodity was a host for a particular fruit fly. Our test was specifically designed to compare the susceptibility of different citrus cultivars, which had previously been described as "least susceptible" or "most susceptible". The susceptibility of a particular cultivar is expressed as the Host Susceptibility Index (HSI) or the number of flies produced per gram of fruit when fruit is infested with one Qfly egg per g of fruit under controlled laboratory conditions. This report describes the susceptibility of 'Kabarla' strawberries.

Materials and methods

Fruit

Strawberries of the cultivar Kabarla were grown in insecticide-free plots at Maroochy Research Station on the Sunshine Coast, with a fungicide applied to the crop seven days before harvest. Fruit were harvested in the early morning and transported to Brisbane on the day of the test. Fruit were not washed, to reduce potential mould development. Organically produced, pesticide-free 'Delicious' apples were used as controls.

Oviposition test

Sixteen-day-old, sexually mature *Bactrocera tryoni* flies fed on sugar, water and protein were used for the tests. An oviposition test was carried out on the day immediately prior to the actual test to determine the number of gravid females in a particular cohort of flies that had the potential to oviposit one egg per gram of fruit

over 24 h. A hollowed out punctured apple dome was used to collect eggs from 50 gravid females over 24 h. Sugar and water but no protein, were provided to the flies during the test. After 24 h, the flies were discarded and the eggs washed from the dome and counted. There were 143 eggs deposited per female over 24 h.

Fruit infestation

Blemish-free strawberries were selected for six replicates to be infested. The replicates consisted of 40 to 44 fruit weighing 723 to 735 g. For a mean weight of 728 g, it was calculated that each sample required five females from the earlier cohort to produce one egg per g of fruit. Each strawberry sample was spread in a single layer on a plastic tray and placed in a gauze cage (30 cm x 30 cm x 30 cm) containing five female flies, and kept for 24 h in a controlled-temperature room at 25°C and a relative humidity of 65%, under natural light. Flies were provided with sugar and water during the test. A control cage containing six apples (748 g) and five females was included to ensure that flies were laying viable eggs. The recovery of flies from the control is not used to calculate the HSI, but it is an important check if the test commodity is a poor host unlikely to support fly pupae.

Fruit holding

At the end of the infestation period, the fruit were removed from the cages and placed on drip trays in gauze-topped containers with a layer of moist vermiculite. Fruit were held under controlled conditions as above, and inspected for signs of fly infestation. The vermiculite in each container was sieved 3, 6, 8, 10, 13, 15 and 27 days after infestation. Pupae that were recovered were counted, weighed and placed in Petri dishes with moist vermiculite until adult flies emerged. Days to first, maximum and last emergence were recorded.

Results

Developmental times, pupal recovery and fly emergence were consistent across the six replicates. A small percentage of fruit collapsed and went mouldy after three days. After eight days, all of the fruit collapsed and displayed the larvae (Table 1). However, because the fruit had been placed on gauze drainage containers, few larvae died.

The first pupae were recovered from five out of six replicates after eight days, and from the sixth sample after ten days (Table 1). For most replicates, the maximum number of pupae was recovered after 13 days, and the last pupae after 15 days. The mean weight of pupae recovered was 0.014 per g fruit. In comparison, the average weight of pupae from the fly colony cultured on an artificial diet was 0.013 per g fruit. The mean percentage of pupae emerging was 97.4%. An average of 13.4 pupae developed in each fruit, with 13.0 flies emerging. The HIS was 0.75 ± 0.07 flies per g of fruit.

The rate of development in the apple control was very slow, and the number of pupae recovered was much lower than in previous tests. The reason for this is not known, although fly development in apples is normally slow. Apples are used as a control

because organic pesticide-free fruit are readily available. The recovery of pupae from the control is, however, only relevant if none are recovered from the test samples. HSI is calculated on results from the test replicates.

Discussion

The results indicated that ‘Kabarla’ strawberries are susceptible to Qfly under laboratory conditions, with a HSI of 0.75 ± 0.07 flies per g of fruit. Pupal yield was comparable with that obtained under normal laboratory rearing conditions. The proportion of flies emerging from developing pupae was consistently high. These findings indicated that the strawberries were a "good" host, and that overcrowding was not an issue. By comparison, HSI was 0.002 ± 0.002 flies per g of fruit in ‘Eureka’ lemon (low susceptibility) and 0.08 ± 0.01 flies per g of fruit in ‘Murcott’ mandarin (high susceptibility).

Qfly infestations in commercial strawberries are extremely low, and for market access the species is considered a very low risk. This indicates that although strawberries are a moderate to good host for Qfly, other factors related to fly behaviour or the nature of the crop, greatly reduce the risk of infestation in strawberry fields. These factors include the close proximity of the crop to the ground, which is not a normal habitat for fruit flies, and lack of appropriate and associated higher vegetation for feeding, mating and shelter. The proximity or lack of other hosts could also affect the incidence of infestation in commercial blocks. The higher incidence of infestation in hydroponic, elevated strawberries would support this theory of fly behaviour. It is also possible that some strawberry fungicides are toxic to or repel flies.

Conclusions

These results show that ‘Kabarla’ strawberries that are susceptibility to Queensland fruit fly when assessed under laboratory conditions. In contrast, fly infestations in commercial strawberries are extremely low because crops close to the ground are not a normal habitat for fruit flies. Thus for market access, strawberry is considered a very low risk.

Table 1. The susceptibility of 'Kabarla' strawberry to Queensland fruit fly in laboratory cage experiments. Fruit were infested on 21 October 2001, with 143 eggs per fly and five *Bactrocera tryoni* flies per cage. The Host Susceptibility Index (HSI) was 0.75 ± 0.07 flies per g of fruit.

Treatment	No. of fruit per sample	Wt. of fruit per sample (g)	Days to first pupae	Days to max. pupae	Days to last pupae	No. of pupae per fruit	No. of pupae per g fruit wt.	Av. pupa wt. (g)	No. of emerged flies per fruit	Percent of pupae emerging	No. of emerged flies per g fruit wt.
Control	6	748	27	29	51	6	0.05	0.008			
Strawberry											
Range	40-44	723-735	8-10	10-13	13-15	11-19	0.59-1.12	0.012-0.015	10-18	96.3-99.6	0.58-1.08
Mean	42	728	8	12	15	13	0.77	0.013	13	97.4	0.75

Populations of Queensland fruit fly in strawberry fields in southern Queensland

Geoff Waite

Commercial summary

In recent years, Queensland fruit fly, *Bactrocera tryoni*, has been considered by other Australian states to be a pest requiring quarantine protocols for Queensland strawberries exported south in spring. Cover sprays of the crop with dimethoate are obligatory for fruit moving interstate after 20 September, jeopardizing the biological control of two-spotted spider mite (*Tetranychus urticae*) by the predatory mite (*Phytoseiulus persimilis*). Data were collected on populations of fruit fly and the number of infested fruit in a strawberry field at Nambour on the Sunshine Coast over three years. Larvae were recorded in five fruit harvested from the patch in the first week of September 2003, before the first bait was applied. No fly strikes were recorded in the other two years, even though traps indicated flies were in the vicinity. These results suggest that fruit flies are a minor issue in ground-grown strawberries in southern Queensland.

Introduction

Queensland strawberries are grown under a system of pest control that is based on the "pest-in-first technique" for the control of spider mites (*Tetranychus urticae*). This industry is the first and only one in the world to employ this technique for field-grown crops (Waite and Jones, 1999). Without it, growers would face devastating spider mite outbreaks every spring, as in the 1980s before the technique was introduced, because of the difficulty in controlling severe infestations of spider mites with sprays. Apart from the difficulty of achieving adequate spray coverage under the leaves where the mites live, the pest quickly becomes resistant to miticides, and new chemicals are redundant within two to three years.

In recent years, Queensland fruit fly, *Bactrocera tryoni*, has been targeted by other states as a pest of quarantine concern for strawberries moving south in spring. For many decades, strawberries were exported to other states without restriction, and they were not even considered a host of Queensland fruit fly. This changed in the 1990s when late maturing cultivars and the biological control of mites enabled harvesting into October, and fly infested fruit were noted. Cover sprays of the crop with dimethoate were made obligatory for fruit moving interstate after 1 September (now 20 September), which is the peak spider mite period. Under the "pest-in-first system", infestations are kept under control by the predatory mite, *Phytoseiulus persimilis*, and economic losses are rare. Thus, growers are frustrated that this effective biological control is threatened and generally ended every year, because of the requirement to spray the crop with dimethoate.

Dimethoate is very toxic to predatory mites. The predators are eliminated by the first application and the spider mites, which are unaffected by the spray, multiply

unchecked. This necessitates repeated miticide sprays that reverse the low input chemical approach, and which places more pressure on the few effective miticides available, increasing the likelihood of resistance developing. This is not a smart approach and is illogical in relation to the true pest status of Queensland fruit fly in field-grown strawberries. The growers, most of whom are now reliant on the predatory mite system, are disappointed at having to implement this insurance strategy that negates their investment in their predatory mites.

While the status of strawberries as a host of *B. tryoni* is proven, there are circumstances and processes relating to this particular association that render the threat to other states close to zero. The following facts and scenario for ground-grown strawberries are presented as the basis for the argument that dimethoate cover sprays should be abandoned in favour of fruit fly bait sprays. It is acknowledged that hydroponic strawberries grown on raised structures are a different proposition, and treatment of them with cover sprays may indeed be justified:

- The fruit fly host status of strawberries is not denied (see following chapter), however the strike rate in field-grown fruit, even in what growers would refer to as a 'bad' year, is extremely low.
- After an initial week or ten days of activity in a strawberry patch, infestation in a crop that continues to be looked after and picked, with no over-ripe fruit left in the field, drops off to virtually nothing. It might be argued that the dimethoate sprays are responsible for this. They certainly contribute, but it would also occur if a properly implemented bait spray programme was implemented.
- Fruit that have been infested stand a good chance of being noted and rejected by pickers.
- If the pickers miss infested fruit, the packers will generally pick it up.
- If the 'sting' is too recent for eggs to have hatched, the infestation may pass undetected and the fruit may be packed.
- Approximately 95% of infested fruit contain only two larvae, 4% three larvae and 1% four larvae (Waite, unpublished data 2003).
- The Queensland crop is placed in cold rooms at less than 4^{o}C usually within one hour of picking, prior to and after packing, and is refrigerated during transit to distant markets.
- Although the fruit core temperature may sometimes not reach these temperatures, fruit fly eggs, which are laid just below the fruit surface, certainly would be subject to temperatures at which development ceases. This will also apply to larvae, especially early instars.
- Eggs that survive the cold treatment will hatch slowly, so that a fruit containing eggs may be consumed before the eggs hatch. Young larvae likewise may be consumed before they cause enough damage to be noticed, resulting in rejection of that fruit – maggots are virtually invisible in the flesh as they blend with the white fibrous tissue of the fruit.
- If eggs or larvae survive in a fruit and that fruit is thrown out, the 'destination' will most likely be a domestic bin or the kitchen garden. If in a bin, it will probably end up in a tied plastic bag in land fill, with no escape for any mature larvae. If it ends up in the garden, other factors

operate, bearing in mind conditions during winter and early spring (cold and still fairly cool) in southern Australia when these fruit are arriving.

- In the garden the fruit stands a good chance of being eaten by a bird or maybe, some animal. If not, it will quickly start to desiccate or rot depending on the microenvironment. In either event, it will soon become unsuitable for the larvae to survive. If the larvae are late instars at the time (unlikely as the fruit would be mushy), they might successfully pupate. Pupation takes place in the soil, where other predators roam.
- If the pupae survive, there has to be at least two, and one of each sex for there to be any potential risk. In addition, the flies need to emerge together and probably stay together for at least a week before mating takes place, which is unlikely, as the urge is to disperse and find mates, which in this instance is also unlikely in an other-wise fly-free environment. The female fly needs to feed on protein for at least a week to mature her eggs before they will be laid. This is probably longer under the colder temperatures in the southern states at this time of the year.
- In the virtually impossible situation where all of these things occur to bring about a successful mating and maturing of eggs, the female then has to find a suitable host tree with fruit at an advanced and suitable stage of development, in which to lay her eggs in the middle of a southern winter/early spring. Fruit trees in these areas will only be flowering in September and October, and suitable oviposition sites would generally not be available until well into summer.
- Therefore, there are numerous biological and environmental pre-requisites to enable Queensland strawberries to act as a conduit for the introduction of *Bactrocera tryoni* into southern Australia. When considered logically with knowledge of the biology, ecology and behaviour of the insect, it is apparent that the risk could be considered to be zero. If a perceived risk remains, then that risk can be eliminated not through the use of disruptive chemical cover sprays, but by the use of fruit fly baits applied either to small areas of the crop or to trap crops or trees situated close to the strawberry patch, or to artificial substrates such as canite blocks. Two new fruit fly baits (Naturalure® and Amulet®) that are more effective than the protein autolysate bait sprays presently in use, are now available. They are less toxic, and are considered to be even more environmentally friendly than the old baits. Acceptance and implementation of a baiting strategy rather than OP cover sprays for fruit fly control will preserve the integrity of a unique IPM system, and will encourage growers to persist with it. In addition, consumers will be assured that the fruit they are eating is residue-free! At present, the IPM system's continued use and adoption is under threat from the unnecessary spray requirement for fruit flies.

Materials and methods

In order to acquire data to support the above argument, fruit were assessed for fruit fly infestation in two blocks of strawberries separated by 300 m and a ridge clothed in forest at Maroochy Research Station in September 2002, 2003 and 2004. In the first block, a protein autolysate bait was applied to non-crop plants around the perimeter from the first week of September, while in the second block no treatments were

applied. The fruit in each block were picked and assessed weekly over four weeks. Each harvest was in excess of 4,000 fruit. Cuelure male attracting traps were deployed adjacent to each crop to indicate general fruit fly activity.

Results and discussion

Fruit flies are common on the Sunshine Coast year round, even in winter. As temperatures warm up in September, numbers increase (Table 1) and early susceptible fruit are 'stung'.

Larvae were recorded in five fruit from the baited patch in the first week of September 2003, before the first spray was applied. Fruit fly numbers at this time were exceptionally high, much higher than in other years (Table 1). Thereafter in 2003, no flies were noted in either patch. No fly strikes were recorded in the other two years, even though the traps indicated the presence of flies. This agrees with our earlier observations. Fruit flies are a minor issue in ground-grown strawberries, so much so that meaningful data have not been obtained. In strawberry crops that are abandoned and continue to fruit, significant fly strikes can occur. While this has the potential to contribute to local fly populations, that fruit will not be marketed.

In contrast to the field grown crops, hydroponic strawberries grown one metre or more above the ground, are targets for flies, and present a significant problem. In this situation, total exclusion netting is a better option than cover sprays of dimethoate, which does not always give complete control. Once hydroponic growers commence spraying dimethoate, standard mite control becomes futile.

Conclusions

In view of the minor status and occurrence of Queensland fruit flies in field-grown strawberries, the protocol for interstate trade should be changed to allow baits to be used as legitimate alternative treatments. Such a move would provide sufficient security for the importing states as well as sustaining the integrity of mite and aphid management systems in the Queensland crop.

Reference

Waite, G.K. and Jones, P. (1999). Management of spider mites in commercial strawberry fields using *Phytoseiulus persimilis* Athios-Henriot and the 'pest in first' technique. *Advances in Strawberry Research* 18: 33-40.

Table 1. The number of male *Bactrocera tryoni* caught in one Cuelure trap each week at Maroochy Research Station in 2002 and 2003.

2002		2003	
27 August	24	12 August	97
3 September	24	19 August	4
10 September	23	26 August	16
17 September	95	3 September	227
24 September	133	10 September	585
1 October	73	17 September	67
		24 September	117

The incidence of strawberry lethal yellows in southern Queensland, and associated insect vectors

Geoff Waite and Don Hutton

Commercial summary

Strawberries grown in Queensland can be affected by a phytoplasma and a rickettsia-like organism (RLO) when infected runners are supplied by the nurseries on the Granite Belt. Research on the Granite Belt over three years showed that the disease is probably transmitted by a planthopper such as *Orosius argentatus*. Early spring rains and later dry spells encourage the movement of the vectors from weeds onto the strawberries in January. The current strategy for control is to apply insecticides to the crop to kill the vectors before they feed on the strawberry plants. However, the daily overhead irrigation needed by the crop quickly washes the chemical from the plants. In contrast, excluding the insects from the strawberry plants using fine nets over and around the blocks is very effective. In 2005, average infections in strawberry farms on the Sunshine Coast that sourced planting material from Stanthorpe ranged from 1 to 4%, with a few individual plantings having losses of 20%. The disease is of concern to the industry and especially the Queensland sector, with the development of an effective management strategy a priority.

Introduction

Strawberry runners grown on the Granite Belt are infected by lethal yellows. Research has identified the organisms responsible for SLY (Streten *et al.*, 2005ab, 2006), with a phytoplasma and a rickettsia-like organism (RLO) found in the phloem implicated.

Strawberry lethal yellows (SLY) occurs in the runner beds during summer, and frequent inspections allows roguing of infected mother plants and associated runners before the runners are dug. However, plants that are infected late and are symptomless, escape detection. When these runners are planted on the fruit farms they typically produce small, yellow leaves or virescent fruit, and fail to crop (see below). The disease is probably transmitted by a planthopper such as *Orosius argentatus* or related insects. To reduce insect populations and infections with SLY, the runner crop is sprayed frequently with insecticide. We report on attempts to identify the vector and to discover which plants might be alternative hosts and potential reservoirs for the disease in experiments conducted on the Granite Belt over three years.

Materials and methods

Incidence of SLY on runner farms

Runner production blocks at Sweet's Strawberry Runners at Stanthorpe, and at Red Jewel Strawberry Runners, Ballandean on the Granite Belt, were inspected three times during summer over three years. Plants in two runner beds on either side of the row

being walked were scanned for symptoms of lethal yellows, and infected mother and associated daughter plants rogued. Later in the season as the density of runners increased, efficient roguing became more difficult, and a few infected runners remained. These were usually picked up on a subsequent inspection. The number of infected plants marked on each occasion was recorded. A final inspection was conducted a week before digging.

Identification of causal organisms, alternative host plants and the possible insect vector

Strawberries that exhibited symptoms of SLY were sent to Charles Darwin University for PCR based diagnosis of the disease organism. Vegetation including bushland and weeds surrounding the strawberry blocks was surveyed, and plants that were yellow,

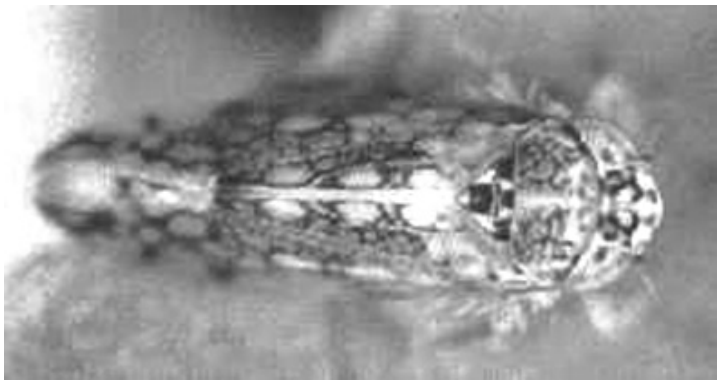
red or had symptoms of witches' broom were photographed, and samples forwarded to Darwin.

Mother plants and runners as well as weeds were sampled with a vacuum sampler and sweep net, and yellow sticky traps deployed. In 2003 and 2004, pre-plant samples were taken in spring on weeds that had germinated after early storms. Woody shrubs that had tested positive for the phytoplasma were inspected for the presence of likely insect vectors.

Results and discussion

Insects and infection in 2002

Sticky traps collected only a few planthoppers in early November, but amongst these were several specimens (five at Stanthorpe and seven at Ballandean) of the prime vector suspect, *Orosius argentatus* (see below). Suction samples yielded zero *O. argentatus* at Stanthorpe (H. Sweet), and only one at Ballandean.



Mother plants were sown in October or November, and SLY infections were first noted in January. Since the mother plants came from foundation stock grown close by during the previous summer, it is possible that some were infected with SLY but remained symptomless over winter. SLY-infected plants struggle to establish, but are easily identified and rogued at this stage. Symptoms noted later when runners are produced are most likely to be new infections.

The incidence of SLY in 2002 was much greater than in previous years. Whether this was due to the weather conditions in that season is not clear, but the incidence of SLY was higher in the next two seasons. Continuing drought conditions leading up to good but patchy summer rain may have favoured alternative host plants and the insect vectors in 2002.

Insects and infection in 2003

Spring 2003 was relatively wet in the runner growing area, with good early rain initiating a vigorous mix of weeds. Insects attuned to these plants also flourished, among them *O. argentatus*, which was very common, at least early in the season. Catches of planthoppers on sticky traps were negligible, but on 15 October, suction samples from Salvation Jane (*Echium plantagineum*) at Stanthorpe yielded 34 *O. argentatus* after two minutes.

The planthopper was also common on other weeds such as shepherd's purse (*Capsella bursa-pastoris*), verbena and white clover, with an average of 18 specimens collected from a sward of these plants over two minutes. On 16 October at Ballandean, 32 specimens were sampled from a sward of medic, white clover, shepherd's purse and other weeds growing on the bank of a drainage channel. In a drier patch of weeds including medic, mallow, thistles and various grasses, an average of 20 *O. argentatus* were collected in two minutes.

The increase in planthopper activity was associated with a higher incidence of SLY (Tables 1 and 2). Mean infection rate in the runner beds increased from below 0.2% to 1.1%. There were no consistent differences in infection rates between different cultivars on each property, but there were differences in infection rates between properties.

Insects and infection in 2004

Early rains again brought on the weeds in spring, but populations of *O. argentatus* remained relatively low, averaging only three to five specimens in vacuum samples from various non-crop situations on the runner properties. An exception was the 'Bush Hill' block at Stanthorpe, where 15 specimens were collected. Vacuum samples were also taken from the strawberry runner crop. No *O. argentatus* were collected, even when the planthopper was common in adjacent weeds, suggesting that strawberries are either not a favoured host of the vector or that the insecticides suppress insect populations.

The weather and weed growth in 2003 and 2004 provided an opportunity to formulate a theory as to how and when the strawberries become infected with the lethal yellow organisms. Whether *Orosius* or some other leafhopper is confirmed as the vector, the early spring rain is implicated as a key factor in infections that are manifest in summer. By late October in 2003, several species of planthopper, including *Orosius*, were common in weeds, and their numbers increased over the next weeks. Frequent rain maintained vigorous weed growth and populations of *Orosius*. As the weeds matured and seeded, hot, dry weather in December hastened senescence and made the weeds unattractive and unsuitable for planthoppers. This may have initiated a mass migration of the insects that had relied on those plants for survival.

An inviting green strawberry crop would undoubtedly attract many insects, at least initially in the search for suitable hosts. Even though strawberries might not be a suitable breeding host, initial 'tasting' of the strawberry plants by the insect may be sufficient to transmit the disease before the insect moves on. Such an event would

usually occur about late December when the strawberry mother plants are starting to produce runners.

The identification of the vector would help explain the dynamics and epidemiology of SLY. As suggested above, the vector could be one that normally doesn't feed on strawberries, and infection occurs through random feeding and probing by the insect until it discovers that the strawberry plant is not a suitable host. Only a few of the potential vectors might carry the infective organisms, but if large numbers of insects are involved, a low infective rate might translate into significant levels of lethal yellows.

Records from the runner farms indicate that the time frame for the manifestation of disease symptoms matches this scenario. The hypothesis is strongly supported by the incidence of infection at Springfields (Stanthorpe), where the growth of *Echium* in particular and the association of *Orosius* with it, indicate a close link between those two. This is not to suggest that the disease originates in the *Echium*, as no symptoms have been noted in that plant. The connection is merely with the seasonal abundance of that particular insect and the hosts that support it and contribute to its overall abundance in the area. The more insects per unit area, the greater the chance that some of them will encounter infected alternative hosts that they can utilise, and in so doing, can acquire the disease organisms and become infective.

Figure 1 illustrates the dynamics of the leafhopper population in the areas adjacent to the runner beds at Stanthorpe.

Incidence of SLY in foundation bed grown under insect-proof netting

In 2004, exclusion netting was erected over the Foundation Plant Nursery at Ballandean. The netting is sufficiently fine to exclude small insects such as aphids. Planthoppers, which are suspected SLY vectors, are certainly excluded (see below).

The tissue cultured plants grown under the net had not been exposed to SLY or insect vectors. At the final inspection of commercial runners on 15 March 2005, no symptoms of SLY were visible inside or outside the netted area, but three weeks later, significant numbers of lethal yellow plants were found in the unprotected area outside (Table 5).

Interestingly, the intensity of infection in that block decreased as the distance from the northern wall of the netted compound increased (Table 5). It may be that the vectors arrived on site on a north-easterly wind that swept them against the vertical net wall. On impact, they may have dropped to the ground and gradually made their way via normal localised flights, into the runner crop. The first plants encountered would thus be subject to the most intense attention from the insects. If the vector does not prefer strawberries as a host, they would have gradually dispersed away from the net. There may also have been a loss of potential infections because some insects would probably have emigrated from the block immediately and directly, without working their way through the remainder of the crop.

Why don't frequent insecticide sprays control SLY?

The current strategy is to apply insecticides to the crop to kill the vectors before they feed on the strawberry plant. However, the daily overhead irrigation needed by the crop quickly dilutes the chemical.

Identification of the planthoppers

Phytoplasmas in other crops are transmitted by members of the planthopper families, Cicadellidae and Cixiidae. The numerous species collected from weeds adjacent to the runners were identified by Dr. Murray Fletcher, NSW Department of Primary Industries, Orange (Table 6). *Orosius argentatus* remains the firm favourite as the vector of strawberry lethal yellows by virtue of its previous form, and its abundance on the runner farms. While the other species listed in Table 6 are vectors of various diseases in various plant species, most of these diseases are caused by viruses.

Phytoplasma vectors can readily acquire, incubate and transmit these organisms. One feature considered essential for successful SLY transmission is that the vectors must feed from the plant's phloem, where the phytoplasma resides. Other phloem feeders listed in Table 6 are known grass feeders and for this reason have been considered unlikely to be vectors of the disease. Two such species, *Sogatella kolophon* (Kirkaldy) and *Toya dryope* (Kirkaldy) (Delphacidae) were collected on sticky traps on a fruit farm on the Sunshine Coast in 2005, where there was a significant amount of 'green petal'. However, Dr Fletcher suggests that it is highly unlikely that these insects can transmit the disease through probing. The phloem feeders also feed on xylem fluid.

Recent research in the USA has shown that the xylem and phloem feeders regularly penetrate the other type of vessel and this can also happen with parenchyma feeders. This has been called 'cell rupture feeding', because the injected saliva dissolves the cells into a liquid, which can then be ingested. Phytoplasmas are entirely phloem resident, but xylem feeders and parenchyma feeders can penetrate the phloem and extract fluid and inject saliva in the process. Whether they do this often is unknown. Since Delphacids are grass feeders,

they are unlikely to feed on strawberries, but this does not preclude probing sufficient to transmit diseases. This might explain the distribution of Australian Grapevine Yellows (AGY) caused by *Candidatus* Phytoplasma australiense, which suggests that the vector arrives, tastes, moves, tastes again, and some time later, leaves the vineyard. A vector that does not like feeding on grape such as a grass feeder, may nonetheless transmit phytoplasmas in a vineyard.

Alternative host plants

Surveys of vegetation in Stanthorpe and Ballandean revealed numerous plants with symptoms similar to those infected with *Candidatus* Phytoplasma australiense. These included small, yellow or distorted leaves, witches' broom and malformed shoots. Suspect specimens were subjected to PCR tests to determine if the relevant disease organisms were present. The results of these tests are detailed in the following chapters.

Conclusions

Future research will attempt to identify the vector of SLY. Even though the phytoplasma is transmitted by an insect, probably a planthopper, some authorities consider identification of the vector not critical for the development of control strategies. These authors suggest that the chemicals applied for control will be effective across all potential candidate species. While this is probably true, the continuous application of chemicals that have minimal effect due to frequent dilution from overhead irrigation as explained above, becomes very expensive, as well as facilitating the development of resistance to those chemicals in the insect population. If the actual vector can be identified, targeted management strategies might be developed. Therefore, efforts to confirm the vector's identity and the most likely alternative host plant for it and the phytoplasma will continue.

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Streten, C., Herrington, M.E., Hutton, D.G., Persley, D.M., Waite, G.K. and Gibb, K.S. (2005a). Plant hosts of the phytoplasmas and Rickettsia-like-organisms associated with strawberry lethal yellows and green petal diseases. *Australasian Plant Pathology* 34: 165-73.

Streten, C., Hutton, D., Waite, G., Persley, D., Herrington, M. and Gibb, K.S. (2006). Distribution and significance of pathogens associated with Australian strawberry lethal yellows and green petal diseases. *Fifth International Strawberry Symposium,* Coolum, Australia.

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Table 1. The incidence of strawberry lethal yellows (SLY) in the runner beds at Stanthorpe at the final inspection in 2004.

Cultivar	No. of mother plants	No. of infected plants	Percent of plants infected
Cal Giant No. 3	5782	74	1.2
Adina	4074	25	0.6
Lowana	1050	13	1.2
Tallara	1428	21	1.5
Jewel	1722	17	1.0
Festival	4620	17	0.4
Kabarla	1008	8	0.8
Sweet Charlie	1036	12	1.2
Flame	980	3	0.3
Joy	2352	18	0.8
Earliblush	3528	86	2.4
Rubygem	4704	53	1.1
Total	32284	347	1.1

Table 2. The incidence of strawberry lethal yellows (SLY) in 'Festival and 'Kabarla' in different blocks on two runner farms at Stanthorpe at the final inspection in 2004.

Block	Festival			Kabarla			Both cultivars		
	No. of mothers	No. of mothers infected	Percent infection	No. of mothers	No. of mothers infected	Percent infection	No. of mothers	No. of mothers infected	Percent infection
Farm 1a	12600	244		8484	21				
Farm 1b	10080	244							
Farm 1c	7292	135							
Farm 1d	3024	9							
Total	32998	632	1.9	8484	21	0.3			
Farm 2a	1176	0		5544	32				
Farm 2b	4032	3		15120	22				
Farm 2c	4242	7							
Total	9450	10	0.1	20664	54	0.3			
Total for farm 1							60158	820	
Total for farm 2							46214	244	
Average for farm 1									1.4
Average for farm 2									0.5

Table 3. The incidence of strawberry lethal yellows (SLY) in the runner beds at Ballandean at the final inspection in 2005.

Block	No. of mother plants	No. of mother plants infected	Percent of plants infected
Rubygem (1)	14400	182	1.3
Festival (1)	11520	72	1.0
Cal Giant No. 3	2304	46	2.0
Sweet Charlie	1152	7	0.6
Jewel	720	6	0.8
Joy	960	12	1.3
Cal Giant No. 4	1200	4	0.3
Sugarbaby	480	0	0
Earliblush	480	5	1.0
Rubygem (2)	14784	244	1.4
Festival (2)	17280	95	0.6
Festival (3)	20160	99	0.5
Lowana	14112	43	0.3
Festival (4)	13824	72	0.5
Rubygem (3)	11520	41	0.4
Festival (5)	18432	88	0.5
Kabarla	12096	26	0.2
Festival (6)	29952	42	0.1
Festival (7)	39168	494	1.3
Festival (8)	14400	317	2.2
Festival (9)	28800	364	1.3
Total	275040	2259	
Average			0.8

Table 4. The incidence of strawberry lethal yellows (SLY) in the runner beds at Stanthorpe and on fruit farms on the Sunshine Coast in 2005. Maximum values for the fruit farms are shown in parenthesis.

Runner farm	Percent of plants infected on March 8	Percent of plants infected on March 15 after roguing.	Percent of plants infected 6 to 8 weeks after planting on fruit farms
1	0.5	< 0.1	< 1 (1.5)
2	0.1	< 0.1	<1
3	0.8	< 0.1	4 (20)

Table 5. The percent of runners with strawberry lethal yellows (SLY) inside and outside the nets at Ballandean on 5 April 2005. There were no infections on 15 March.

Zone	
Inside net	0
Outside net	
Four rows adjacent to net	18.0
Next 10 rows from net	9.7
Next 10 rows from net	7.8
Next 10 rows from net	3.4

Table 6. Leafhoppers collected in the strawberry runner farms at Stanthorpe and Ballandean. Information for *Recilia hospes* from "The search for the vector of strawberry lethal yellows (SLY) in New Zealand" by Charles, J.G., Allan, D.J., Anderson, M.T., Langford, G. and Mossop, D. (2002) Proceedings of 55th Conference of The New Zealand Plant Pathology Society, pp. 385-9. New Zealand species that have tested positive for *P. australiense* include *Arawa variegata* and *Recilia hospes*. Species collected on Sunshine Coast fruit farm with high incidence of 'green petal' include *Sogatella kolophon* (Kirkaldy) and *Toya dryope* (Kirkaldy) (Delphacidae).

Orosius argentatus	A vector of several phytoplasma diseases, including legume little leaf , tomato big bud, lucerne witches broom, potato purple top wilt and pawpaw yellow crinkle. It has also been implicated as a possible vector of grapevine yellows and pawpaw yellows and strawberry lethal yellows
Orosius canberrensis	Although not recorded as a vector of phytoplasma diseases, it is close phylogenetically and geographically to O. argentatus.
Austroasca viridigrisea	A pest of leafy vegetables in Australia, attacking bean, carrot, potato, non-irrigated tomato, lucerne and many broadleaf weeds
Recilia hospes	Very common on several grass species. In New Zealand, *P. australiense* found in specimens collected from ryegrass pasture and weeds
Balclutha incisa	Medicago (Fabaceae), Poaceae, Cyperaceae, Apiaceae, Convolvulaceae
Nesoclutha pallida	Apparently is restricted to grasses. In Australia, it is the vector of cereal chlorotic mottle rhabdovirus, chloris striate mosaic geminivirus, paspalum striate mosaic geminivirus and maize wallaby ear
Zygina honiloa	No data
Austrogallia torrida	Vector of rugose leaf curl virus of vegetables
Recilia zealandica	Very wide host range.
Cicadulina bimaculata	It was described from lucerne by Evans (1940) but is probably a grass feeder as are its congeners. It is recorded as the vector of cereal chlorotic mottle rhabdovirus and the phytoplasma, maize wallaby ear in Australia, and maize streak geminivirus overseas
Balclutha saltuella	Agrostis (Poaceae), Gossypium (Malvaceae)
Zygina zealandica	Very wide host range.
Bactromorphus sp.	No data.
Balclutha sp.	No data.
Limatettix encyrta	No data.
Cofana sp.	Strict xylem-feeders.
Austroasca spp.	*A. alfalfae* and *A. viridigrisea* feed on broadleaf weeds, clovers and lucerne.

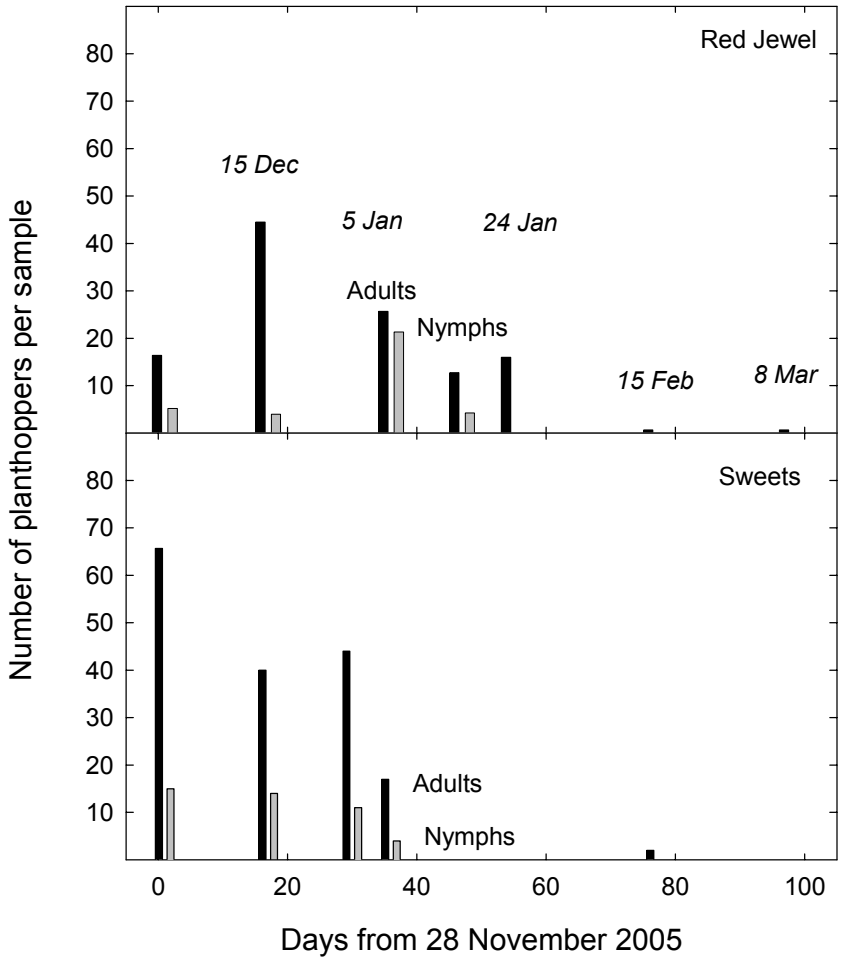

Figure 1. The changes in the population of leafhopper adults and nymphs (*Orosius argentatus*) next to the runner beds at the two runner farms near Stanthorpe over 2005/06. Insects collected using vacuum samples over the weeds and other plants.

Rickettsia-like-organisms and phytoplasmas associated with diseases in strawberries

Claire Streten, Geoff Waite, Mark Herrington, Don Hutton , Denis Persley and Karen Gibb

Commercial summary

Strawberry lethal yellows (SLY) disease in Australia is associated with the phytoplasmas *Candidatus* Phytoplasma australiense and tomato big bud, and a rickettsia-like-organism (RLO). *Ca*. P. australiense is also associated with strawberry green petal (SGP) disease. This study investigated the association of the different agents with SLY. Of the 363 SLY samples, 117 tested positive for the RLO, 67 tested positive for *Ca*. P. australiense AGY strain and 11 plants tested positive for *Ca*. P. australiense PYL variant strain. On runner production farms at Stanthorpe, the RLO was detected in SLY plants more frequently than for the phytoplasmas. On fruit production farms on the Sunshine Coast, *Ca*. P. australiense was detected in SLY plants more frequently than the RLO.

Introduction

Strawberry plants grown on runner and fruit production farms in southern Queensland are affected by a range of diseases such as strawberry lethal yellows (SLY), strawberry green petal (SGP), yellow edge (SYE), strawberry crinkle (SC), Fusarium wilt and crown rot (Broadley *et al*. 1988). Of these diseases, SLY and SGP are caused by intracellular bacteria-like pathogens that can have a significant impact on productivity because flowering and fruit set are inhibited, and infected plants frequently die (Greber and Gowanlock 1979). These diseases can be transmitted from mother plants to runners and so can be passed in planting material from runner production farms to fruit production areas (Greber 1987). To prevent this, plants exhibiting symptoms are rogued from runner beds during frequent disease inspections. However, it can take up to 8 weeks for the plants to exhibit SLY or SGP symptoms (Greber and Gowanlock 1979) making it possible for affected runners to be unintentionally sent to fruit production farms.

Two types of lethal yellows symptoms have been reported in Australian strawberry plants. Bronze discoloration of older leaves, stunted petioles and interveinal chlorosis on younger leaves are symptoms associated with a rickettsia-like-organism (RLO) (Greber and Gowanlock 1979). Purple discoloration of older leaves, and stunted younger leaves with shortened petioles and marginal chlorosis are associated with *Candidatus* Phytoplasma australiense (Padovan *et al*. 2000; Greber and Gowanlock 1979). The symptoms associated with both these organisms are collectively referred to as SLY disease. However, another disease syndrome called SGP has also been associated with *Ca*. P. australiense. This disease is characterised by severe phyllody where floral structures become leaf-like. In addition, a mixed phytoplasma association of an uncharacterised phytoplasma and *Ca*. P. australiense has also been identified in association with SLY symptoms (Padovan *et al*. 2000).

The relationship between these different organisms and SLY disease is poorly understood because it is difficult to differentiate the symptoms associated with an RLO from those associated with a phytoplasma (Greber and Gowanlock 1979). Although SLY diseased samples could be tested using PCR primers specific for the phytoplasma 16S rRNA gene or the Tu elongation factor (*tuf*) gene (Padovan *et al*. 2000), a diagnostic test for the SLY RLO has not been available. The recent characterisation of the flavoprotein subunit succinate dehydrogenase gene of the RLO associated with papaya bunchy top (PBT) disease and the development of PCR primers to detect this RLO (Davis *et al*. 1998) may provide the tools to investigate the significance of each of the causal agents associated with SLY (Streten *et al*., unpublished data). This study aimed to investigate the relationship between phytoplasmas, RLOs and SLY disease, and the distribution of these organisms in the runner and fruit production areas.

Materials and methods

Plant sample collection sites

Asymptomatic and symptomatic strawberry plants were collected from various locations in Queensland and South Australia between March 2000 and October 2002 (Table 1). Diseased plants were collected if they exhibited abnormal growth or discoloration compared with healthy plants.

Reference phytoplasma samples

The reference sample for tomato big bud phytoplasma was extracted from a symptomatic periwinkle plant and the reference strain for *Candidatus* Phytoplasma australiense Australian grapevine yellows (AGY) was extracted from a papaya plant with dieback symptoms. Both were collected in Darwin. The *Candidatus* Phytoplasma australiense Phormium yellow leaf (PYL) reference strain DNA was provided by Mark Andersen (HortResearch, Auckland, New Zealand).

Screening for phytoplasmas and RLOs

Approximately 10 mm of the strawberry petioles was used as source material for DNA extraction. The petioles were cut into 1-mm sections and total DNA extracted according to the Doyle and Doyle (1990) CTAB protocol with the modification that the CTAB extraction buffer (2% CTAB, 1.4 M NaCl, 20 mM EDTA, 1% PVP) contained 1 M Tris-HCl (Padovan *et al*. 1995). Extracted DNA was separated on a 1% agarose gel stained with ethidium bromide and visualised by UV trans-illumination to provide an indication of DNA quality.

Symptomatic samples were initially tested using the fP1/rP7 (Schneider *et al*. 1995; Deng and Hiruki 1991) primer pair, which amplifies the 16S rRNA gene and 16S–23S spacer region of most phytoplasmas. Samples that tested negative using these primers were tested again in a single round PCR using the primer pair fU5/m23sr (Lorenz *et al*. 1995; Padovan *et al*. 1995). This primer pair amplifies a smaller region of the phytoplasma 16S rRNA gene and can be more suitable than P1/P7 for amplifying phytoplasmas from difficult hosts (Schneider and Gibb 1997). The PCR reactions

were according to Schneider *et al*. (1997), with 35 cycles of 95°C/1 min; 55°C/1 min and 72°C/1.5 min. One µL of undiluted DNA, 1:10 diluted DNA or 1:50 diluted DNA was used in PCR reactions.

Samples were also screened using the fTufAy/rTufAy primers, which amplify the Tu elongation factor (*tuf*) gene of *Ca*. P. australiense (Schneider *et al*. 1997). PCR reactions were according to Schneider *et al*. (1997) with 35 cycles of 95°C/1 min; 50°C/1 min; 72°C/1.5 min.

Diseased strawberry samples were also tested using PCR primers (PBTF1 and PBTR1), which amplify the flavoprotein subunit of the succinate dehydrogenase (*sdhA*) gene of the RLO associated with papaya bunchy top disease (Davis *et al*. 1998). PCR reactions were according to Davis *et al*. (1998) with 40 cycles of 94°C/1 min; 52°C/1.5 min and 72°C/1 min. Deoxyribonucleic acid from healthy strawberry plants was included as a negative control. The PCR products amplified from two SLY diseased samples using the PBTF1/PBTR1 primers were purified using QIAquick PCR purification kit. All steps were performed according to the manufacturer's protocol (Qiagen, Brisbane, Australia). Deoxyribonucleic acid quantity was determined by comparing purified products to a DNA mass ladder (Invitrogen, Mount Waverley, Victoria). The PCR products were sequenced using the big dye terminator sequencing kit version 3.1 and sequencing reactions were separated at Australian Genomic Research Facility (AGRF) (Brisbane, Australia).

Nucleotide sequences were aligned using AssemblyLIGN (Eastman Kodak Co., New Haven, CT, USA). The BlastN search engine (Altschul *et al*. 1997) was used to identify homologous sequences in the GenBank main database which was accessed through the Biomanager website (Entigen Corporation, http://www.entigen.com, Sydney, Australia).

Identification of phytoplasmas and RLOs

The PCR products amplified using primers specific for the phytoplasma 16S rRNA gene were digested with restriction enzymes *Alu*I and *Rsa*I, and the *tuf* gene PCR products were digested with *Hpa*II and *Hind*III (Schneider *et al*. 1997). PCR products of samples previously identified as being associated with *Ca*. P. australiense or the TBB phytoplasma were used as references for restriction fragment length polymorphic (RFLP) analysis. The PCR products amplified using the primers specific for the RLO *sdhA* gene were digested with *Alu*I, *Rsa*I, *Hpa*II and *Mse*I. A SLY diseased sample that was identified as RLO positive by sequence analysis was used as the reference strain for RLO *sdhA* gene RFLP analysis. Digestion reactions were performed according to the manufacturer's specifications (Promega, Sydney, Australia). The digested products were separated on a 12% polyacrylamide gel, which was then stained with ethidium bromide and bands visualised under UV illumination.

Relationship between the presence of phytoplasmas or RLO

The relationship between phytoplasmas or RLO and SLY diseased plants was analysed using Fisher's exact test. Statistical analysis was performed using JMP software version 5.0.1 (SAS Institute Inc., North Carolina, USA).

Results

The nucleotide sequences of the PCR product amplified from the two representative SLY samples using the PBTF1 and PBTR1 primers were homologous to each other and shared 96% homology with the *sdhA* gene of the RLO associated with papaya bunchy top disease (AY423625).

Strawberry plants exhibited a range of disease symptoms, lethal yellows (SLY), green petal (SGP), fruit distortion (SFD) and leaves emerging from fruit (SLF) (Table 2). Of these diseases, SLY occurred most frequently. SLY diseased plants exhibited bronze, red and purple discoloration on older leaves, and stunted younger leaves with shortened petioles, marginal and interveinal chlorosis.

Of the 363 SLY plants tested, 211 were PCR positive and of these, 117 were RLO positive, 83 were phytoplasma positive and 11 were positive for both (Table 2). All samples that tested positive for an RLO had the same RFLP pattern as the reference RLO when digested with RsaI, HpaI, AluI or MseI (Fig. 1).

The 83 phytoplasmas detected by the universal PCR test were subjected to the *Ca*. P. australiense specific PCR test using the *tuf* gene primer pair. This product was subjected to RFLP analysis which showed that two strains were present; one was indistinguishable from the *Ca*. P. australiense Australia grapevine yellows (AGY) strain reference sample and the other indistinguishable from *Ca*. P. australiense Phormium yellow leaf (PYL) strain reference sample based on *Hpa*II digestion but differed based on *Hind*II banding patterns (data not shown). RFLP analysis of the 16S rRNA gene showed that the TBB phytoplasma was also associated with SLY disease (data not shown). Of the 83 samples positive for phytoplasma, *Ca*. P. australiense was detected most often (Table 2). Some mixed infections were detected; RLO with *Ca*. P. australiense AGY strain and TBB phytoplasma with *Ca*. P. australiense AGY strain (Table 2). The PYL variant strain of *Ca*. P. australiense was detected in 11 plants (Table 2). There was a significant relationship between all agents and SLY diseased plants ($P < 0.0001$). The relationship between SLY disease and the RLO was significant ($P = 0.002$) as was the relationship between SLY disease and the phytoplasmas ($P < 0.0001$). Only 12 plants were observed with symptoms of both SLY and SGP and all these were positive for *Ca*. P. australiense AGY strain (Table 2). This phytoplasma was also detected in the two plants observed with SGP disease (Table 2).

Discussion

Testing of PBT RLO sdhA PCR primers on SLY samples

The nucleotide sequence of the product amplified from SLY diseased samples using the PBTF1 and PBTR1 primers shared 96% similarity with the *sdhA* gene of the PBT RLO which indicates that the corresponding gene was amplified from SLY diseased samples. This suggests that the primers designed by Davis *et al*. 1998 should be suitable for screening SLY diseased plants for an RLO. However, only one gene was characterised so it was not possible to confirm that the bacterium associated with SLY

is definitely of Rickettsiae origin and future studies may show that a bacterium-like-organism is associated with SLY disease.

SLY and SGP diseases

Greber and Gowanlock (1979) previously reported the occurrence of RLO-associated SLY symptoms and phytoplasma-associated SLY symptoms. Bronze discoloration of older leaves, stunted petioles and interveinal chlorosis on younger leaves are symptoms associated with a rickettsia-like-organism (RLO) (Greber and Gowanlock 1979). Purple discoloration of older leaves, stunted younger leaves with shortened petioles and marginal chlorosis are associated with a phytoplasma. The SLY diseased plants collected during this study exhibited a combination of these two SLY symptom types. Due to this, the diseased strawberry samples collected during this study could not be classified into either RLO or phytoplasma associated SLY symptoms. These findings suggest that the type of SLY symptoms exhibited by the strawberry plant may be influenced by soil type or cultivar instead of the presence or absence of a pathogen.

In this study, the majority of diseased strawberry plants had lethal yellows symptoms, a few had green petal disease, and strawberry plants with both lethal yellows and green petal diseases were observed in fruit production areas for the first time. All strawberry plants with SGP disease alone or in combination with SLY disease were positive for *Ca*. P. australiense AGY strain which suggests that SGP symptoms are always indicative of a phytoplasma association. For SLY disease, there was a significant association between putative causal agents and disease and, as reported previously, *Ca.* P. australiense (AGY strain), *Ca*. P. australiense (PYL variant strain), the tomato big bud (TBB) phytoplasma and a RLO were associated with SLY disease (Padovan *et al*. 2000).

Although there was a significant association between SLY disease and RLO or phytoplasmas, not every plant with SLY disease was positive for these organisms.

A major factor may have been low titre and uneven distribution of the phytoplasmas and RLO in the host plant (Constable *et al*. 2003; Gibb *et al*. 1999). Furthermore, another organism, which has not yet been characterised, may be associated with SLY disease.

The *tuf* gene amplified from 11 plants with SLY disease collected from Caboolture in 2001 had the same RFLP banding pattern as the PYL phytoplasma when digested with *Hpa*II but had a unique banding pattern when digested with *Hind*III. This phytoplasma was designated *Ca*. P. australiense PYL variant strain. The PYL phytoplasma is associated with New Zealand strawberry lethal yellows and Phormium yellow leaf (PYL) diseases (Andersen *et al*. 1998*a* , 1998*b*). Although the phytoplasma associated with PYL disease can be differentiated from the Australian SLY phytoplasma by *tuf* gene analysis (Schneider *et al*. 1997), these two phytoplasmas are considered identical based on 16S rRNA gene analysis and, therefore, both are designated *Ca*. P. australiense (Padovan *et al*. 2000; Liefting *et al*. 1998). The *Ca*. P. australiense PYL variant strain was associated only with SLY diseased samples collected at Caboolture on the same day and from the same farm. Its absence from other farms in the Caboolture area may indicate that the vector was not

present throughout the region to transmit the phytoplasma more widely or an itinerant vector carrying *Ca*. P. australiense PYL variant strain from another region and/or another host made a brief stop to feed on a limited number of plants in the area (Lee *et al*. 2003, 1998). Disease surveys of alternative host plants in the strawberry growing areas may provide insight into the movement of the vector for this phytoplasma and the distribution of the phytoplasma which would indicate whether this farm represents an isolated ecological niche for the *Ca*. P. australiense PYL variant strain.

Few plants with SLY disease were positive for multiple agents. One explanation is that the frequency of multiple 'infections' may have been greater than the results showed with the limitation being PCR, which preferentially amplifies the dominant species (Lee *et al*. 2000). Mixed 'infections' are more frequently revealed when samples are screened using nested PCR (Alma *et al*. 1996; Lee *et al*. 1995) but this has other drawbacks such as risk of contamination and expense.

It is unlikely that strawberry cultivar had an effect on symptom expression because plants of the same cultivar exhibited green petal, lethal yellows, and a combination of both symptoms. Green petal disease was observed only at the fruit production farms; therefore, the age of the plant at the time of inoculation or soil type may influence symptom expression. In addition, plants for runner production do not flower, which limits the opportunity for SGP disease expression in the runner region. This study did not resolve the issue of why the same phytoplasma is associated with two different symptoms, green petal and lethal yellows.

New strawberry disease symptoms

Two previously unreported strawberry disease symptoms, severe fruit distortion (SFD) and strawberry leaves on fruit (SLF) were observed during the study. Unlike lethal yellows symptoms, which were observed over the 3 year study, the SFD and SLF diseases were recorded only once during the study. Of the seven samples with SFD, one was positive for *Ca*. P. australiense AGY strain and of the 20 SLF samples, four were positive for the TBB phytoplasma. The sample size was too small to make inferences about disease and phytoplasma association but it was interesting to observe the range of symptoms in the field. The SFD and SLF symptoms may have been caused by other factors such as nutritional deficiencies, poor pollination, inherited characteristics, spray drift or another pathogen that was not detected. The plants that tested positive for phytoplasma may have shown symptoms of SLY or SGP disease if they had been sampled later.

Causal agent and locality of diseased strawberry plants

SLY disease is the only RLO-associated disease identified in Australia. An RLO is also associated with papaya bunchy top disease in North America (Davis *et al*. 1998) and carrot proliferation disease in the Czech Republic (Franova *et al*. 2000). Very little is known about the distribution and occurrence of RLO-associated plant diseases. In this study, the RLO was detected most often in plants with SLY disease in the runner production area while at the fruit production farms, the proportion of disease associated with phytoplasmas increased from 2000, until by 2002, phytoplasmas were much more common than RLOs. This finding suggests that although the RLO-associated SLY disease is distributed throughout Queensland

strawberry growing districts, this organism is more frequently identified in the runner production area. Based on RFLP analysis of the *sdhA* gene amplified from the SLY diseased samples collected at both runner and fruit production farms, the same RLO strain was present in the different strawberry growing regions. However, it is not known whether the *sdhA* gene is suitable for differentiating RLOs. The characterisation of the SLY RLO 16S rRNA gene that has variable and non-variable regions may facilitate the differentiation of the RLOs associated with SLY disease.

In Australia, the vector for the SLY RLO has not yet been identified whereas in North America the leafhopper, *Empoasca papayae*, is known to transmit the RLO associated with papaya bunchy top disease. The only species of *Empoasca sensu stricto* from Australia is *Empoasca smithi* (Murray Fletcher, personal communication); this leafhopper may be a possible vector of the SLY RLO. However, other leafhopper genera may also transmit the SLY RLO. Identification of other host plants for the SLY RLO may provide insight into the nature of insect vectors for this organism and indicate reasons why RLO-associated SLY disease is more common in the runner production area.

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Table 1. Collection data for strawberry plant samples collected between March 2000 and October 2002.

Collection area	Farm type	Location	Date	Presence or absence of symptoms (+/−)	Number collected
1	Runner	Stanthorpe, Queensland (28°S, 151°E)	Mar-00	+ (SLY)	36
			Feb-01	−	34
				+ (SLY)	5
			Mar-01	+ (SLY)	64
			May-01	+ (SLY)	10
			Jun-01	+ (SLF)	20
			Feb-02	+ (SLY)	25
			Mar-02	+ (SLY)	20
2	Fruit	Caboolture, Queensland (27°S, 152°E)	May-00	+ (SLY)	25
			Jul-00	+ (SLY)	8
			May-01	+ (SLY)	52
			May-02	+ (SLY)	14
			Jun-02	+ (SLY)	3
			Aug-02	+ (SLY)	46
				+ (SLY + SGP)	4
		Nambour, Queensland (26°S, 152°E)	Jul-00	+ (SLY)	5
			Aug-00	+ (SLY)	23
			Apr-01	−	74
			Jul-01	−	3
				+ (SGP)	2
			May-02	+ (SLY)	4
			Jun-02	+ (SLY)	1
			Aug-02	+ (SLY)	9
				+ (SLY + SGP)	4
		Beenleigh, Queensland (27°S, 153°E)	Aug-00	+ (SLY)	2
			Jul-01	+ (SLY)	1
			Jun-02	+ (SLY)	5
				+ (SLY + SGP)	2
		Brisbane, Queensland (27°S, 153°E)	Sep-00	+ (SFD)	6
				−	3
		Atherton, Queensland (17°S, 145°E)	Jun-01	+ (SFD)	1
		Adelaide, South Australia (34°S, 138°E)	Dec-01	+ (SLY)	5

Table 2. The relationship between symptoms expressed by strawberry plants collected between March 2000 and October 2002 and the associated agents.

Symptoms	Number plants tested	Number PCR positive	Number of plants positive for each organism/s categorised by symptoms					
			RLO[A]	*Ca.* P. australiense AGY[B] strain	*Ca.* P. australiense PYL[C] variant strain	RLO and *Ca.* P. australiense AGY strain	TBB and *Ca.* P. australiense AGY strain	TBB[D]
SLY[E]	363	211	117	67	11	11	3	2
SLY & SGP[F]	12	12	–	12	–	–	–	–
SGP	2	2	–	2	–	–	–	–
SFD[G]	7	1	–	1	–	–	–	–
SLF[H]	20	4	–	–	–	–	–	4
Asym[I]	114	20	20	–	–	–	–	–

[A]RLO, Rickettsia-like-organism. [B]AGY, Australian grapevine yellows. [C]PYL, Phormium yellow leaf. [D]TBB, Tomato big bud. [E]SLY, strawberry lethal yellows. [F]SGP, strawberry green petal. [G]SFD, strawberry fruit distortion. [H]SLF, strawberry leaves from fruit. [I]Asym, Asymptomatic.

Table 3. Strawberry cultivar, location, symptoms and pathogen for collection areas 1 and 2.

Collection[A] area	Location	Strawberry cultivar	Symptoms[B]	Number of plants tested	Number of samples positive for each organism(s)					
					RLO	*Ca*. P. australiense AGY strain	*Ca*. P. australiense PYL variant strain	RLO and *Ca*. P. australiense AGY strain	TBB and *Ca*. P. australiense AGY strain	TBB
1	Stanthorpe	Kabarla	SLY	132	69	–	–	–	3	2
		Kabarla	Asym	34	4	–	–	–	–	–
		Sweet Charlie	SLY	11	1	1	–	–	–	–
		Joy	SLY	4	2					
		Blush	SLY	4	–	–	–	–	–	–
		Flame	SLY	3	1	–	–	–	–	–
		Adina	SLY	3	2	–	–	–	–	–
		Jewel	SLY	1	–		–	–	–	–
		Earlimist	SLY	1	–	–	–	–	–	–
		Unknown	SLY	1	1	–	–	–	–	–
		Cartuno	SLF	20	–	–	–	–	–	4
2	Caboolture	Camarosa	SLY	50	7	26	2	1	–	–
		Karbarla	SLY	48	21	10	–	1	–	–
		Selva	SLY	22	–	6	9	–	–	–
		Adina	SLY	16	5	5	–	5	–	–
		Sweet Charlie	SLY	10	2	2	–	–	–	–
		Camarosa	SLY + SGP	3	–	3	–	–	–	–
		Joy	SLY	2	–	–	–	–		–
		Adina	SLY + SGP	1	–	1	–	–	–	–
2	Nambour	Adina	SLY + SGP	2	–	2	–	–	–	–
		Adina	SLY	5	–	4	–	1	–	–
		Camarosa	SLY	1	–	1	–	–	–	–
		Camarosa	SLY + SGP	2	–	2	–	–	–	–
		Flame	SLY	1	–	–	–	–	–	–
		Joy	SLY	3	–	–	–	–	–	–
		Kabarla	SLY	16	3	1	–	–	–	–
		Kabarla	Asym	77	16	–	–	–	–	–
		Sweet Charlie	SLY	15	3	3	–	1	–	–
		Unknown	SGP	2	–	2	–	–	–	–
		Unknown	SLY	2	–	2	–	–		–
		Jewel	SLY + SGP	1	–	1	–	–	–	–
2	Beenleigh	Camarosa	SLY	3	–	2	–	–	–	–
		Camarosa	SLY + SGP	2	–	2	–	–	–	–
		Sweet Charlie	SLY	1	–	1	–	–	–	–
		Kabarla	SLY	4	–	4	–	–	–	–
2	Brisbane	Sweet Charlie	Asym	3	–	–	–	–	–	–
		Sweet Charlie	SFD	6	–	1	–	–	–	–
2	Atherton	Camarosa	SFD	1	–	–	–	–	–	–
2	Adelaide	Selva	SLY	5	–	1	–	–	–	–

[A]Collection areas 1 and 2 are the runner and fruit production areas, respectively.
[B]Abbreviations as in Table 2.

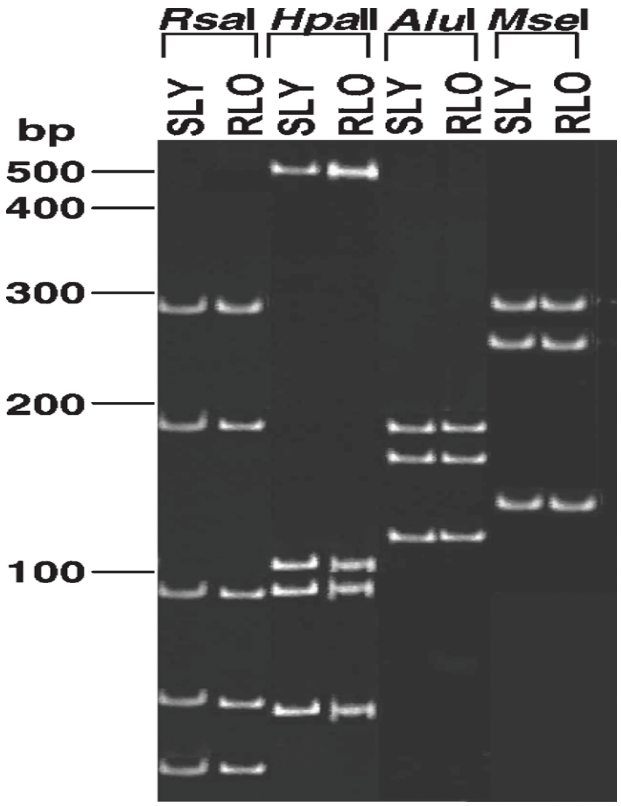

Figure 1. RFLP analysis of PCR products of a representative sample amplified with the PBTF1/PBTR1 primers specific for the *sdhA* gene of the RLO associated with strawberry lethal yellows disease. SLY, strawberry lethal yellows; RLO, the *sdhA* gene of an RLO associated with strawberry lethal yellows that shared 96% homology with the corresponding gene of the papaya bunchy top RLO.

Figure 2. Strawberry plants affected by the disorder where leaves emerge from the fruit (SLF).

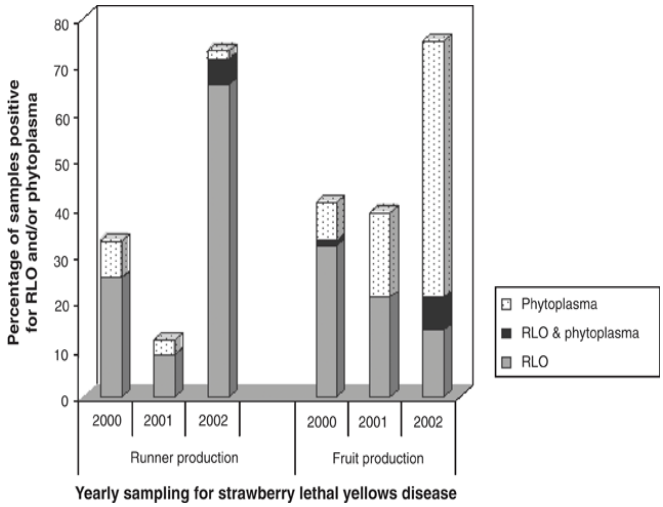

Figure 3. The association of RLO and phytoplasmas with strawberry lethal yellows diseases between March 2000 and October 2002.

Plant hosts of the phytoplasmas and rickettsia-like-organisms associated with strawberry lethal yellows and green petal

Claire Streten, Mark Herrington, Don Hutton, Denis Persley, Geoff Waite and Karen Gibb

Commercial summary

Candidatus Phytoplasma australiense (*Ca*. P. australiense) is associated with strawberry lethal yellows (SLY) and strawberry green petal (SGP). SLY is also associated with a rickettsia-like-organism (RLO) or infrequently with the tomato big bud (TBB) phytoplasma, the latter being associated with a wide range of plant diseases throughout Australia. In contrast, the RLO has been identified only in association with SLY disease, and *Ca*. P. australiense has been detected only in a limited number of plant host species. The aim of this study was to identify plant hosts that are possible reservoirs of *Ca*. P. australiense and the SLY RLO. Thirty-one plant species from south-east Queensland were observed with disease between 2001 and 2003 and, of these, 18 species tested positive for the phytoplasma. These results indicated that the vector(s) of *Ca*. P. australiense are distributed throughout south-east Queensland and the diversity of phytoplasmas detected in balloon cottonbush suggests it is a feeding source for phytoplasma insect vectors or it has a broad susceptibility to a range of phytoplasmas.

Introduction

The tomato big bud (TBB) phytoplasma is infrequently detected in strawberry plants with lethal yellows (SLY) disease while *Candidatus* Phytoplasma australiense (*Ca*. P. australiense; Davis *et al*. 1997) is consistently associated with SLY disease (Padovan *et al.* 1998; Padovan *et al*. 2000*b*). In Australia, *Ca.* P. australiense is also associated with the diseases strawberry green petal (SGP) (Padovan *et al*. 2000*b*), papaya dieback (PDB; Gibb *et al*. 1996; Liu *et al*. 1996), Australian grapevine yellows (AGY; Padovan *et al*. 1996) and mung bean witches' broom (MBWB; Schneider *et al*. 1999). More recently, *Ca.* P. australiense has been implicated as a causal agent of pumpkin yellow leaf curl (PYLC; Streten *et al*. 2005*a*) and periwinkle phyllody (Davis *et al*. 2003). *Ca.* P. australiense is also associated with plant diseases in New Zealand including strawberry lethal yellows (SLY; Andersen *et al*. 1998), *Phormium* yellow leaf (PYL; Liefting *et al*. 1998), *Cordyline australis* (cabbage tree) sudden decline (CSD; Andersen *et al*. 2001) and *Coprosma* lethal decline (CLD; Andersen *et al*. 2001).

Although *Ca*. P. australiense has been consistently associated with a range of crop species, only a few non-crop host species have been identified during phytoplasma disease surveys in Australia (Davis *et al*. 1997, 2003; Schneider *et al*. 1999). The plant host range of a phytoplasma generally reflects the number of natural vector species that are capable of transmitting the organism and their feeding behaviour (Lee *et al*. 2000). Results to date suggest that the vector of *Ca*. P. australiense has a narrow

host range or a limited number of species are susceptible to this phytoplasma. In Australia, no vectors have been identified for *Ca*. P. australiense whereas in New Zealand, the planthopper, *Oliarus atkinsoni* transmits this phytoplasma (Boyce and Newhook 1953; Liefting *et al*. 1997). *O. atkinsoni* is a monophagous species that feeds on *Phormium* sp. and is essentially limited to New Zealand (Liefting *et al*. 1998; Andersen *et al*. 2001), which means that it is unlikely to transmit *Ca*. P. australiense in Australia. Identification of possible alternative hosts of *Ca*. P. australiense may provide insight into the identity of its vectors in Australia. Furthermore, the detection of phytoplasmas in plants in the vicinity of strawberry farms would implicate these plant species as possible reservoirs of *Ca*. P. australiense when strawberry plants are not being grown in the field.

In contrast to *Ca*. P. australiense, the TBB phytoplasma has a wide host range including native and introduced plant species (Davis *et al*. 1997; Schneider *et al*. 1999; Padovan and Gibb 2001; Davis *et al*. 2003). These TBB phytoplasma-associated diseases occur throughout Australia (Davis *et al*. 1997, 2003; Schneider *et al*. 1999; Padovan and Gibb 2001). The TBB phytoplasma has provisionally been assigned the Candidate species name, *Candidatus* Phytoplasma australasia (White *et al*. 1998). The wide host range of the TBB phytoplasma possibly reflects the feeding habits of its insect vector, the common brown leafhopper, *Orosius argentatus*, which is widely distributed throughout Australia (Hill 1943).

A rickettsia-like-organism (RLO) is also associated with SLY disease (Greber and Gowanlock 1979). Little is known about this RLO, as until recently there was no diagnostic test. The development of a PCR diagnostic test, which amplifies the flavoprotein subunit succinate dehydrogenase (*sdhA*) gene of the SLY RLO (Streten *et al*. 2005*b*) and the papaya bunchy top (PBT) RLO, has facilitated the identification of other hosts and possible vectors for this organism. The only known vector of an RLO is the leafhopper, *Empoasca papayae*, which transmits the PBT RLO (Davis *et al*. 1998). The identification of alternative hosts for the SLY RLO may indicate its host range and provide a focus for subsequent vector studies.

This study aimed to identify other host plants of *Ca*. P. australiense by conducting disease surveys near strawberry farms where SLY disease has been recorded. To determine whether the phytoplasmas or RLO associated with SLY disease are limited to the strawberry growing districts, diseased plant host species were also collected 50–200 km from any strawberry farm.

Materials and methods

Source and location of samples

Diseased and asymptomatic plants were collected on, or within, 50–100 m of strawberry runner beds in the Nambour and Stanthorpe districts of south-east Queensland, between March 2001 and January 2003 (Table 1). Diseased plants were also collected in Allora, Gatton, Toowoomba and Warwick districts of south-east Queensland, which are located 50–200 km from any strawberry farm (Table 1). A single collection was made from Adelaide in South Australia (Table 1).

Screening for phytoplasmas and rickettsia-like-organisms

Total DNA was extracted from plant samples according to Doyle and Doyle (1990) using a modified CTAB buffer (Padovan *et al*. 1995). Deoxyribonucleic acid quality was determined by subjecting the samples to electrophoresis in a 1% agarose gel, which was then stained with ethidium bromide and viewed by UV trans-illumination.

Plant samples were screened for phytoplasmas using the primer pairs fP1 / rP7 (Deng and Hiruki 1991; Schneider *et al*. 1995) and fU5 / m23sr (Lorenz *et al*. 1995; Padovan *et al*. 1995), which amplify the phytoplasma 16S rRNA gene and 16S-23S spacer region. The PCR reactions were prepared according to Schneider *et al*. (1997) and subjected to 35 cycles of 95°C/1 min; 55°C/1 min and 72°C/1.5 min. One microlitre of undiluted DNA or DNA diluted 1:10 or 1:50 in water was used as DNA template in PCR.

Symptomatic and asymptomatic samples were also screened using the fTufAy and rTufAy primers according to Schneider *et al*. (1997). These primers amplify the Tu elongation factor (*tuf*) gene of phytoplasmas assigned to the aster yellows and stolbur groups, which includes *Ca*. P. australiense but not the TBB phytoplasma.

Deoxyribonucleic acid samples were also tested using the PCR primers that amplify the flavoprotein subunit of succinate dehydrogenase (*sdhA*) gene (PBTF1 and PBTR1) of the RLO associated with lethal yellows (Streten *et al*. 2005*b*) and PBT disease (Davis *et al*. 1998). PCR reactions were prepared according to Davis *et al*. (1998). Amplification conditions used for the PBTF1 and PBTR1 primers were 94°C/1 min, 52°C/1.5 min and 72°C/1 min for 40 cycles.

Identification of phytoplasmas and rickettsia-like-organisms

PCR products amplified from diseased and asymptomatic plants using primers specific for the phytoplasma 16S rRNA gene or the RLO *sdhA* gene were digested with the restriction enzymes *Alu*I and *Rsa*I. *Tuf* genes were digested with *Hpa*II and *Hind*III (Schneider *et al*. 1997). All digestions were in buffer supplied by the manufacturer, 1 U enzyme (Promega, Sydney, Australia), 5 µL of PCR product and sterile distilled water. Reactions were incubated overnight at the specified temperature and subsequently separated in a 12% polyacrylamide gel. The gels were then stained with ethidium bromide and visualised on a UV trans-illuminator.

Results

Rickettsia-like-organism detection in plant host species

The RLO was detected in only one diseased *Jacksonia scoparia* sample and one diseased *Modiola caroliniana* sample; both were collected at Stanthorpe (Tables 1 and 3). The *sdh*A gene amplified from these diseased plants all had the same restriction banding patterns as the reference RLO associated with SLY disease (data not shown).

Phytoplasma detection in plant host species

Eighteen out of 34 diseased plant host species tested positive using phytoplasma specific primers (Tables 1–4). The *Ca*. P. australiense Australian grapevine yellows (AGY) strain was detected in 25 plants collected from Nambour, Gatton, Stanthorpe and Allora districts of south-east Queensland. The 25 plants represented six different plant species (Tables 1–4). The *tuf* gene amplified from *Hexham* sp. (Table 1), and *G. physocarpus* from Toowoomba and Nambour (Table 2 and Fig. 1) had the same RFLP banding pattern as the *Phormium* yellow leaf phytoplasma when digested with *Hpa*II and a different banding pattern when digested with *Hind*III (data not shown). This phytoplasma was designated *Ca*. P. australiense PYL variant strain.

The TBB phytoplasma was detected in 33 plants from Stanthorpe, Brisbane, Warwick and Nambour (Tables 1–4) in Queensland and in one plant from Adelaide, South Australia (Table 1). These 34 diseased samples represented 15 plant species, some of which are also hosts for *Ca*. P. australiense. A *Ca*. P. australiense and the TBB phytoplasma mixed 'infection', was detected in only one *G. physocarpus* plant. The SPLL-V4 phytoplasma was detected in single *G. physocarpus* plants from Allora and Nambour (Table 2).

Association between phytoplasma, rickettsia-like-organism and disease

All pumpkin (*Cucurbita maxima*) plants exhibiting yellow leaf curl were positive for *Ca*. P. australiense AGY strain and all asymptomatic pumpkin plants were phytoplasma negative (Table 1). All native cherry (*E. cupressiformis*) samples with small leaf symptoms were phytoplasma positive (Table 1).

Ca. P. australiense PYL variant strain was detected in all four *G. physocarpus* plants with yellowing and little leaf or clumping of leaves along the stem. *G. physocarpus* plants with symptoms of yellowing, little leaf and bunching along the stem and also without symptoms tested positive for the SPLL-V4 phytoplasma (Table 2). The TBB phytoplasma was detected in a single *G. physocarpus* plant with symptoms of reduced yellow leaves, green petal and clumping of growth at terminal ends, and in a plant exhibiting yellow mottling of leaves (Table 2). *Ca*. P. australiense AGY strain and the TBB phytoplasma were detected in one *G. physocarpus* plant with symptoms of little leaf and proliferation of leaves at terminal ends (Table 4). *Ca*. P. australiense AGY strain was also detected in *G. physocarpus* plants exhibiting witches' broom or narrow red/yellow leaves (Table 2). Eleven *G. physocarpus* plants exhibiting disease symptoms tested negative for phytoplasmas or RLOs (Table 2).

Phytoplasmas were detected more commonly in diseased *J. scoparia* exhibiting an abnormal branching pattern (Fig. 1) than in plants exhibiting other phytoplasma-type symptoms (Tables 1 and 3). An RLO was also detected in *J. scoparia* plants with abnormal branching symptoms (Table 3). *M. polymorpha* plants with symptoms of reddening and curling of leaves or stunted growth and little leaf tested positive for the TBB phytoplasma (Table 4). *Ca*. P. australiense AGY strain was amplified from diseased *M. polymorpha* plants with symptoms of reddened reduced leaves or symptoms of yellow and red leaves (Table 4).

Amaranthus sp., *Araujia sericifera*, *Chenopodium carinatum*, *Erimophyla* sp., *Hibiscus trionum* and *Plantago lanceolata* were rarely observed with disease so few samples were collected (Table 1). Asymptomatic samples from each of these plant species tested positive for TBB phytoplasma (Table 1). Diseased and asymptomatic *Acacia melanoxylon*, *Acacia* sp., *Asclepias curassavica*, *Echinochloa colona*, *Malva parviflora*, *Medicago sativa*, *Osothamnus diosmifolius*, *Plantago cunninghamii* and *Sonchus* sp. were also sampled during the study (Table 5). No RLO or phytoplasma was detected in these plant species (Table 5).

Discussion

In Queensland, strawberry growers producing runners are located in the Stanthorpe region while fruit is produced in the areas surrounding Nambour, Caboolture, Beenleigh and Brisbane. Strawberry plants are not grown all year round, which suggests that non-crop plant species growing near strawberry fields may be reservoirs for phytoplasmas or RLO associated with SLY disease. However, growers remove weeds growing among strawberry plants on fruit production farms and south-east Queensland was experiencing a drought during the study, reducing the number of plant hosts growing on and near strawberry runner and fruit production farms. Therefore, during the survey, the only plant species with symptoms of yellows disease at fruit production farms, where *Ca*. P. australiense is often detected in SLY or SGP diseased strawberry plants (Padovan *et al*. 2000*b*), were *Gomphocarpus physocarpus* and *Acacia melanoxylon*. Diseased *G*. *physocarpus* were also observed at locations 50–200 km away from fruit production farms.

Ca. P. australiense AGY strain, *Ca*. P. australiense PYL variant strain, TBB and SPLL-V4 phytoplasmas were all detected in diseased *G. physocarpus* plants, which suggests that these plants are a food source for the insect vectors or this species is susceptible to a range of phytoplasmas. Diseases of *Gomphocarpus* sp. have also been reported in Italy (D'Aquilio *et al*. 2002) and the stolbur and European aster yellows phytoplasmas were detected in these plants. Symptomatic *G*. *physocarpus* plants were collected at different locations in south-east Queensland, which suggests that these phytoplasmas are not confined to a single location and their insect vectors are distributed throughout south-east Queensland. Based on frequency of phytoplasma detection, the symptoms of green petal, little leaf, and reduced leaves appear to be a phytoplasma disease in *G*. *physocarpus* plants. The other symptoms observed for *G*. *physocarpus* plants may have been due to nutritional deficiencies, lack of water or another pathogen being present.

In this study, diseased *G*. *physocarpus*, *M*. *polymorpha* and *J*. *scoparia* were most frequently observed but other plant species with phytoplasma-type symptoms were also collected. Pumpkin plants with yellow leaf curl were observed at Gatton and *Ca*. P. australiense AGY strain was detected in these samples, thus confirming this previously reported phytoplasma associated disease (Streten *et al*. 2005*a*).

Ca. P. australiense or the TBB phytoplasma were detected in diseased *M*. *polymorpha*, *E. cupressiformis*, *J. scoparia* and no mixed phytoplasma 'infections' were detected for these samples. Although *Ca*. P. australiense and the TBB phytoplasma were identified as having these common host plants, *Ca*. P. australiense

and TBB are unlikely to have the same vector because they only shared a limited number of host plant species and host range generally reflects the feeding habits of the vector (Lee *et al*. 2000). Therefore *M*. *polymorpha*, *E*. *cupressiformis* and *J*. *scoparia* are possibly food sources for a range of insect vectors.

The TBB phytoplasma was detected in diseased *Amaranthus* sp., *C. baileyi, C. carinatum*, *Conzya* sp., *D*. *stramonium*, *E. cupressiformis, Erimophyla* sp*., H. trionum, J*. *scoparia*, *M*. *polymorpha*, *Plantago lanceolata* and *S. nigrum* plants that were located near runner production farms in the Stanthorpe district. Therefore, there is an abundant supply of TBB phytoplasma inoculum in the vicinity of runner production farms. Despite this, the TBB phytoplasma is infrequently detected in plants with SLY disease (Padovan *et al*. 2000*b*). The low occurrence of TBB phytoplasma-associated strawberry disease in Stanthorpe where there is a range of sources of inoculum in the surrounding area suggests that the vector, *O*. *argentatus*, is either not prevalent in the region, or strawberry plants are not a preferred food source for this leafhopper species, or strawberry plants are not highly susceptible to the TBB phytoplasma.

The SPLL-V4 phytoplasma, which is closely related to the TBB phytoplasma (Padovan *et al*. 2000*a*), was only detected in diseased *G*. *physocarpus* plants collected at Allora. This is in contrast to previous disease surveys in northern Australia, which showed that the SPLL-V4 phytoplasma is associated with diseases that occur in a wide range of plant species (Davis *et al*. 1997, 2003; Schneider *et al*. 1999; Padovan and Gibb 2001). The identification of a single plant species positive for the SPLL-V4 phytoplasma compared with the TBB phytoplasma (16 species) suggests that in south-east Queensland, these phytoplasmas may not have a common vector and that the vector for the SPLL-V4 phytoplasma is not prevalent. If the vector for the SPLL-V4 phytoplasma and incidence of the disease is not abundant in south-east Queensland, it is unlikely that strawberry plants will be inoculated with the SPLL-V4 phytoplasma.

The TBB and SPLL-V4 phytoplasmas were detected more frequently in non-crop plants growing in or near Stanthorpe than were the *Ca*. P. australiense AGY or PYL variant strains. *Ca*. P. australiense AGY and PYL variant strains were detected in different *G*. *physocarpus* plants collected at Nambour and these plants were growing within 100 m of SLY diseased plants that tested positive for *Ca*. P. australiense AGY strain (Streten *et al*. 2005*b*). *Ca*. P. australiense PYL variant strain has previously been identified as being associated with SLY diseased at Caboolture and it was thought that this strain represented an isolated population within Australia (Streten *et al*. 2005*b*). The detection of *Ca*. P. australiense New Zealand strain at Nambour, Toowoomba and Caboolture in *G*. *physocarpus* and *Hexham* sp. plants showed that this phytoplasma is more widespread than previously thought. These plant species may be reservoirs for this phytoplasma and they may also be a source of inoculum for SLY disease if its vector is present.

The vector of the Australian RLOs is still unknown and this study provided limited insight into the nature of the insect that transmits these organisms. RLO-associated disease was only identified in two non-crop plant hosts in the area surrounding runner production farms where this organism is the most common agent associated with SLY disease (Streten *et al*. 2005*b*). This suggests that the vector has a limited host range or only a limited number of plants are susceptible to the RLO (Lee *et al*. 1998; Lee *et al*.

2000). *G. physocarpus* plants could not be screened for an RLO because, after PCR amplification, all samples including healthy controls gave a band the same size as the reference RLO strain. We, therefore, do not know if the RLO is associated with this host species.

In conclusion, results from this study suggest that *G. physocarpus* is a food source for insect vectors of phytoplasmas and, therefore, a possible source of phytoplasma for SLY disease. Diseased pumpkin is also a possible source of *Ca*. P. australiense for strawberry plants. *Ca*. P. australiense AGY strain was also detected in diseased *M. polymorpha* plants that were collected on runner production farms and these plants are likely to be a reservoir of phytoplasmas for strawberry plants because they are located in the strawberry growing region and on strawberry farms. Although nine plant species collected on or near runner production farms were positive for the TBB phytoplasma, this may not be significant because this phytoplasma is detected only occasionally in SLY diseased plants. The Australian RLO was detected in diseased *M. caroliniana* and *J. scoparia* plants, which were growing on runner production farms in the Stanthorpe district. Thus, these plants may act as reservoirs of the RLO if the insects that feed on these species can acquire and transmit the RLO, and use strawberry as a food source.

This study of phytoplasma and RLO host range, while not intended as a systematic survey of all other host plants in the 200 km area surrounding commercial strawberry farms, has identified some key non-crop species that are hosts for the RLO and a range of phytoplasmas. Future studies should focus on these species and candidate insect vectors.

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Figure 1. *Gomphocarpus physocarpus* infected with *Candidatus* Phytoplasma australiense *Phormium* yellow leaf strain (left) and *Jacksonia scoparia* infected with tomato big bud (TBB) phytoplasma (right).

Table 1. Plant species in which phytoplasmas and rickettsia-like-organisms were detected.

Scientific name	Common name	Location	Symptoms	P.australiense[A]	TBB[A]	RLO[A]	SPLL-V4[A]	Number of plants tested
Amaranthus sp.		Stanthorpe	Yellowing of leaves		2			2
Araujia sericifera		Gatton	Asymptomatic					3
		Gatton	Yellowing of leaves with red margins		1			1
		Warwick	Witches' broom		1			1
Callitris baileyi		Stanthorpe	Yellowing of branches					1
		Stanthorpe	Asymptomatic		1			1
Chenopodium carinatum		Stanthorpe	Shortening and clumping of petioles		2			2
Conzya sp.	Fleabane	Stanthorpe	Leaf distortion		3			3
		Stanthorpe	Asymptomatic					1
		Stanthorpe	Reduced leaves					1
Cucurbita maxima	Pumpkin	Stanthorpe	Asymptomatic					5
		Stanthorpe	Yellow leaf curl	3				3
		Gatton	Yellow leaf curl	10				10
		Stanthorpe	Yellowing at vine tips					1
Datura stramonium	Thornapple	Stanthorpe	Yellowing of plant		1			3
		Stanthorpe	Asymptomatic					1
Erimophyla		Stanthorpe	Leaf distortion		1			1
Exocarpus cupressiformis	Native cherry	Stanthorpe	Reduced yellow leaves	1	5			6
Gomphocarpus physocarpus	Cottonbush	In Table 2	Refer to Table 2	8	3		3	33
Hexham sp.		Toowoomba	Witches' broom, stunting	2[B]				2
Hibiscus trionum	Bladder ketmia	Stanthorpe	Yellowing of leaves		1			1
Jacksonia scoparia		Stanthorpe	Refer to Table 3	2	4	1		23
Medicago polymorpha		Stanthorpe	Refer to Table 4	4	5			16
Modiola caroliniana	Carolina mallow	Stanthorpe	Leaf distortion, yellowing and stunting			1		1
Plantago lanceolata	Ribwort	Stanthorpe	Yellow and white leaves		1			1
		Brisbane	Yellowing and smaller plant		1			1
		Stanthorpe	Crimped and cupped leaves					3
		Stanthorpe	Asymptomatic					2
		Stanthorpe	New leathery growth					1
		Stanthorpe	Branched leaves and deformed new leaves					1
Solanum nigrum	Nightshade	Stanthorpe	Leaf tip clumping					1
		Stanthorpe	Proliferation of tips and buds					1
Trifolium sp.	Clover	Stanthorpe	Reddening/yellowing of leaves and clumping of plant	1				1
		Adelaide	Red and yellow leaves					3
		Adelaide	Green flowers and phyllody		1			1
Total				31	34	2	3	138

[A]Number of samples positive for the specified pathogen. P. australiense, *Candidatus* Phytoplasma australiense; TBB, tomato big bud phytoplasma (Candidatus Phytoplasma australasia); RLO, rickettsia-like-organism; SPLL-V4, sweet potato little leaf strain V4.
[B]*Candidatus* Phytoplasma australiense *Phormium* yellow leaf (PYL) variant strain.

Table 2. Phytoplasmas detected in *Gomphocarpus physocarpus* (balloon cottonbush).

Location	Symptoms	P.australiense[A]	TBB[A]	SPLL-V4[A]	Total num of plants te
Allora	Yellowing, little leaf, bunching along stem			2	2
	Asymptomatic			1	1
	Witches' broom	1			1
Gatton	Narrow red and yellow leaves	1			1
Nambour	Asymptomatic	1			4
	Reddening and yellows of stems and leaves				2
	Little leaf, proliferation of leaves at terminal ends of branches and yellowing	1	1		1
	Yellow mottling on leaves		1		3
	Yellowing and leaf distortion				5
	Clumping of leaves along stem and yellow reduced leaves	1[B]			1
	Small mottled leaves clumped along stem				2
	Older leaves with yellow mottling, young leaves reduced and yellow, curling of leaves, green petals on very reduced flowers, leaves clumping at terminal ends and leaves protruding from flowers		1		1
Stanthorpe	Asymptomatic				1
	Yellow distorted leaves				1
Toowoomba	Asymptomatic				3
	Yellowing and reduced leaves	3[B]			3
	Green plant with wilted and distorted terminals				1
Total		8	3	3	33

[A]Number of samples positive for the specified pathogen. Abbreviations as in Table 1.
[B]*Candidatus* Phytoplasma australiense *Phormium* yellow leaf (PYL) variant strain.

Table 3. Phytoplasmas and RLOs detected in *Jacksonia scoparia* (dogwood).

Location	Symptoms	P. australiense[A]	TBB[A]	RLO[A]	Total number of plants tested
Stanthorpe	Abnormal growth at tips		1	1	7
	Abnormal branching and growth	2	1		3
	Asymptomatic				6
	Proliferation of growth at branch ends		2		4
	Wilting at branch tips				1
	Witches broom				3
Total		2	4	1	24

[A]Number of samples positive for the specified pathogen. Abbreviations as in Table 1.

Table 4. Phytoplasmas detected in *Medicago polymorpha* (burr trefoil).

Location	Symptoms	P. australiense[A]	TBB[A]	Total number of plants tested
Stanthorpe	Reduced leaves with reddening	2		3
	Asymptomatic	1	2	5
	Reddening and curling of leaves		2	2
	Red leaf margins			1
	Reduced leaves with curling of leaf margins			1
	Yellow and red leaves	1		3
	Stunted growth with reduced leaves		1	1
Total		4	5	16

[A]Number of samples positive for the specified pathogen. Abbreviations as in Table 1.

Table 5. Plant species in which phytoplasma and rickettsia-like-organisms (RLO) were not detected.

Scientific name	Common name	Location	Symptoms	Total number of plants tested
Acacia melanoxylon	Blackwood	Nambour	Proliferation of deformed undifferentiated tissue at buds	1
			Asymptomatic	1
			Interveinal yellowing	1
Acacia sp.		Stanthorpe	Yellow young leaves with red leaf margins	1
Asclepias curassavica	Red Cottonbush	Stanthorpe	Young leaves distorted	1
Echinochloa colona	Swamp grass	Stanthorpe	White striping on leaves	1
			Asymptomatic	1
Glycine max	Soybean	Toowoomba	Proliferation of flowers and seeds. Yellow seed pods, necrosis of mid vein, yellowing of leaves	15
Glycine sp.		Stanthorpe	Yellowing leaves	1
			Asymptomatic	1
			Clumping of plant growth	1
Lycopersicon esculentum	Tomato	Stanthorpe	Asymptomatic	1
			Reduced leaves, yellowing along leaf veins	1
Malva parviflora	Marshmallow	Stanthorpe	Yellowing	1
Medicago sativa	Lucerne	Toowoomba	Asymptomatic	3
			Shortened internodes, smaller leaves with clumping and elongation of leaves and yellowing	2
Melaleuca sp.	Ti tree	Stanthorpe	Chlorotic terminal	1
Osothamnus diosmifolius	Sago flower	Stanthorpe	Yellowing of leaves	1
Plantago cunninghamii	Sago weed	Stanthorpe	Yellowing	1
Plantago sp.		Stanthorpe	Distorted growth	1
Solanum mauritianum	Wild tobacco	Stanthorpe	Yellowing of branch tips	1
Sonchus sp.	Milk thistle	Stanthorpe	Yellowing and reddening of leaves	2
Total				40

The control of Colletotrichum crown rot

Don Hutton and Apollo Gomez

Commercial Summary

One of the major diseases affecting strawberries in Queensland is crown rot caused by *Colletotrichum gloeosporioides* (*Cg*). The fungus is present in a small number of plants in the commercial runner beds, but can cause serious losses in commercial fruit farms on the Sunshine Coast where it is probably introduced with the planting material. We report on the incidence of *Cg* in various stages of the runner production system, with samples collected from different strawberry nurseries across Australia. Losses due to crown rot on commercial fruit farms on the Sunshine Coast were also assessed. In other experiments, we collected samples of rotting petioles and crowns and determined the level of resistance of *Cg* to prochloraz, the main fungicide used to control crown rot in runner beds, and screened a range of fungicides for their effects on the disease. There was generally a low level of infection in the strawberry nurseries, with an average of only 0.06% of symptomless petioles testing positive for the presence of *Cg* over five years. Visual symptoms of crown rot, including lesions on the petioles and stolons and wilting plants were relatively rare in the nurseries, with plant losses ranging from 0 to 0.5%. Losses on fruit farms were highly variable (up to 30%), but generally low and below 0.1%. There was no evidence of resistance to prochloraz. A fungicide based on cyprodininil plus fludioxinil offers promise for inclusion in a resistance management program with prochloraz.

Introduction

Colletotrichum crown, stolon and petiole rot, as well as leaf spot caused by *Colletotrichum gloeosporioides* (*Cg*) are important diseases affecting the commercial strawberry industry in Queensland. These diseases were first identified in runners growing at Crows Nest near Toowoomba in 1989, with stolon lesions appearing annually from 1991 to 1998 in runners grown at Esk, Cooroy, Cottonvale and Stanthorpe. Impacts on coastal fruit farms have been less apparent, although there were major losses of plants in 1994, and minor losses in 2004 and 2005.

From 1990 to 1995, we observed lesions on stolons of plants from the tissue culture growing-on area at Gatton. *Colletotrichum gloeosporioides* was also present in symptomless nucleus plants held at Indooroopilly, while pathogenic strains of *Cg* were isolated from symptomless strawberry plants and alternative weed hosts on runner and fruit farms (Hutton, 1997). Fungicide trials in 1993 showed that prochloraz at 2 g per L reduced the recovery of *Cg* from symptomless petioles, and gave reliable control in the runner beds. Subsequent laboratory tests in 1994 confirmed these results. Detached symptomless petioles with known high levels of *Cg* were dipped in spray-strength fungicide suspensions, with prochloraz superior to all the other chemicals tested.

These detached petiole tests in the laboratory provided a simple and reliable way of screening fungicides for use in a resistance management strategy with prochloraz.

The test was adapted and used as the basis for subsequent monitoring. With the registration of prochloraz, only plants grown in tissue culture were allowed onto runner farms, with plants at all levels of the scheme sprayed every 7 to 14 days. All the nursery areas were monitored annually for symptoms of *Cg* and symptomless *Cg* using the detached petiole test. Using this strategy, there was an immediate reduction in the number of plants showing symptoms of *Cg*, and in the recovery of *Cg* from symptomless petioles.

Prochloraz is one of the demethylation inhibitor (DMI) group of fungicides (FRAC Group 3) to which resistance in a range of organisms is common. This type of resistance is quantitative, meaning isolates of a particular pathogen exhibit a range in sensitivity to a DMI depending on the number of genes involved. Isolates of a particular pathogen also exhibit varying responses to different DMIs depending on their activity. Resistance to prochloraz has been reported in *Tapesia* sp., the cause of foot rot and take-all disease in wheat (Anonymous, 2004). Resistance to prochloraz has not been identified in *Cg* across a range of crops, but it is essential we identify a suitable companion fungicide to use with prochloraz.

Anthracnose crown rot was first identified in the USA in 1931, when Brooks reported serious losses due to *C. fragariae*. Runners could no longer be grown in Florida because of the impact of this disease. Howard and Albregts first described a crown rot caused by *C. gloeosporioides* in 1984. *C. gloeosporioides* is the organism most commonly associated with Colletotrichum crown rot in Florida (Urena-Padilla *et al.,* 2002). *C. acutatum* has also increased in importance as a cause of crown rot. All three organisms are disseminated on infected transplants from runner nurseries (Maas, 1998). The incidence of crown rot in Florida has been largely overcome by sourcing runners from nurseries at high latitudes in Canada. The use of chemicals on the fruit farm at planting has also reduced the incidence of this disease (Peres, personal communication).

We report on the incidence of *Cg* in various stages of runner production, with samples collected from different strawberry nurseries across Australia. The level of losses due to crown rot on commercial fruit farms on the Sunshine Coast was also assessed. In other experiments, we collected samples of rotting petioles and crowns and determined the level of resistance of *Cg* to prochloraz, and screened a range of fungicides for their effects on crown rot in an attempt to provide a companion for prochloraz in a resistance management program.

Materials and methods

The presence of Colletotrichum gloeosporioides (Cg) in strawberry nurseries

Samples of petioles without symptoms were collected from the strawberry tissue culture nursery at Indooroopilly in Brisbane (2001/02–2005/06), mother plants on the two runner farms at Stanthorpe (2004/05 and 2005/06), and commercial plants on the two runner farms at Stanthorpe (2001/02–2005/06). The tissue culture laboratory supplied a petiole from every fifth plantlet in the growing-on area three weeks before the plants were despatched to the runner growers. Runner growers supplied petioles

from the older leaves of every tenth mother plant. There were no obvious symptoms of crown rot on the runner farms initially, with symptoms appearing only from 2004.

A laboratory based petiole test was used to assess for the presence of *Colletotrichum gloeosporioides* (*Cg*) in the different nurseries and runner farms. Petioles were sterilised with 0.5% sodium hypochlorite for 5 min and rinsed twice in sterilized water. A one centimetre length of petiole from just above the stipule was placed on quarter strength PDA media (Anonymous, 1968), with 50 mg per L streptomycin sulphate in a petri dish (n = 8 petioles per dish). The percentage of petioles with *Cg* in each dish was recorded after 14 days.

Visual symptoms of crown rot in strawberry nurseries and commercial fruit farms

The two commercial runner farms at Stanthorpe and 10 to 15 fruit farms on the Sunshine Coast were monitored for symptoms of *Cg* from 2001/02 to 2005/06 (n > 40 sites). Visual symptoms included wilted plants along with lesions on the stolons and petioles.

Resistance to prochloraz

Each time in 2004/05 and 2005/06 that *Cg* was implicated with wilting or dying plants, or isolated from symptomless petioles (n = 1061), we tested for resistance to prochloraz by subbing the isolate onto quarter strength PDA media (plus 50 mg streptomycin sulphate per L and 0.1 mg prochloraz per L). Growth of the isolate on this media indicated resistance to the fungicide.

Screening of fungicides to be used with prochloraz – laboratory experiments

Strawberry plants at Nambour with high levels of latent *Cg* in symptomless petioles were identified using the detached petiole test. Petioles were collected from the field and placed in plastic food containers, with each container representing one plot (n = 30), and four replicates per treatment. Petioles were dipped in fungicide suspensions in each container for 30 min, and allowed to dry overnight. Two 1 cm long sections were isolated from each petiole after sterilisation with 0.05% sodium hypochlorite as described above. The percentage of petioles with *Cg* in each container was recorded after ten days.

In the first experiment, the following treatments were used: untreated control; tolylfluanid (1 g per L); prochloraz (0.92 g per L); propiconazole (0.1 g per L); azoxystrobin (0.2 g per L); trifloxystrobin (0.2 g per L); kresoxim-methyl (0.2 g per L); pyraclostrobin (0.2 g per L); boscalid (0.08 g per L) plus pyroclostrobin (0.04 g per L); spiroxamine (0.2 g per L); and quinoxyfen (0.2 g per L).

In the second experiment, the treatments used were: control; tolylfluanid (1 g per L); captan (1.6 g per L); prochloraz (0.92 g per L); propiconazole (0.1 g per L); carbendazim (0.25 g per L); azoxystrobin (0.2 or 0.3 g per L); fludioxinil (0.05 or 0.1 g per L); cyprodinil (0.3 g per L) plus fludioxinil (0.2 g per L); trifloxystrobin (0.2 or 0.3 g per L); pyroclostrobin (0.1 or 0.2 g per L); boscalid (0.6 g per L); boscalid (0.2 g per L) plus pyroclostrobin (0.1 g per L); and boscalid (0.3 g per L) plus pyroclostrobin (0.15 g per L).

Data were analysed by one-way analysis of variance (11 or 18 treatments x 4 blocks), with each experiment analysed separately.

Screening of fungicides to be used with prochloraz – field experiment

Tolylfluanid (1 g per L); captan (1.6 g per L); prochloraz (0.92 g per L); propiconazole (0.125 g per L); fludioxinil (0.07 g per L); pyroclostrobin (0.3 g per L); cyprodinil (0.3 g per L) plus fludioxinil (0.2 g per L); and boscalid (0.2 g per L) plus pyroclostrobin (0.1 g per L) were compared with untreated control plots in runner beds at Nambour. Three sprays were applied weekly from 29 March, and four sprays from 30 May in 2006, with samples of petiole collected a week after the last sprays, and assessed for the presence of *Cg* as described above (without dipping in fungicides). The plants initially had high levels of latent *Cg* in symptomless petioles. Data are the means of four blocks per treatment, and were analysed by one-way analysis of variance (9 treatments x 4 blocks), with each sampling period analysed separately.

Results

The presence of Cg

Colletotrichum gloeosporioides was not isolated from samples collected from the nurseries from 2001/02 to 2004/05, with a low incidence of recovery (0.17% of samples) in 2005/06 (Table 1).

Visual symptoms of Cg

Wilting and plant deaths occurred at one runner farm in 2005 (2004/05 season) and on both properties in 2006 (Table 2). *Colletotrichum gloeosporioides* was more frequently associated with crown rots on the first farm (in 2006) than on the second farm, while *Macrophomina phaseolina* was more common on the second farm. Crown rot (*Cg*) was detected in commercial fruit fields from 2002 (2001/02 season) to 2006 (Table 3). While serious losses occurred in some fields, overall losses were usually less than 1%.

Resistance to prochloraz

We did not detect resistance to prochloraz in *Cg* from crown rots on fruit farms on the Sunshine Coast, with 692 samples collected in 2005 and 369 samples collected in 2006.

Screening of fungicides

In the first laboratory experiment, propiconazole, trifloxystrobin, pyraclostrobin, and boscalid plus pyroclostrobin were the best treatments along with the prochloraz standard (Table 4). These chemicals were followed by tolylfluanid, kresoxim-methyl, spiroxamine and quinoxyfen which were still better than the control. In the second laboratory experiment, *Cg* was not detected after dipping with prochloraz, fludioxinil or cyprodininil plus fludioxinil (Table 5). Tolylfluanid and pyroclostrobin (0.2 g per

L) gave less than 10% recovery, with all the other chemicals still better than the untreated group. In the field trial, cyprodininil plus fludioxinil eliminated *Cg* by the end of the first set of sprays (Table 6). This treatment was also successful in the second round of spraying, along with prochloraz, fludioxinil and pyroclostrobin. These treatments were followed by tolylfluanid, captan, and boscalid plus pyroclostrobin, all better than the control.

Discussion

The presence of Colletotrichum gloeosporioides (Cg) in strawberry nurseries

We showed that monitoring for the presence of *Cg* and testing for resistance is working. *Colletotrichum gloeosporioides* was not detected in symptomless petioles at the current tissue culture growing-on area. The disease was not seen on the current farms at Stanthorpe until 2004/05. In 2005/06, it was detected at low levels in one paddock on one runner farm. Constant vigilance is required to acquire and maintain a crown rot-free status.

Crown rot on fruit farms

Certified plants were virtually free of *Cg* crown rot in 2001/02 and 2002/03, with the few losses probably due to local infections on the affected farms. Overall losses from 2003/04 to 2005/06 were no more than 1%. This experience differs from 1994 before prochloraz was applied to the runner beds, when major losses sometimes occurred on the fruit farms. The literature suggests that the fungus is spread via the runners (Maas, 1998; Smith, 2006), although the possibility of local sources of infection should not be completely ignored. In Florida, plots given captan or thiram early in the season prior to infection with *Cg*, had fewer crown rots, higher yields and better quality later in the season than unsprayed plots (Mertely and Peres, 2006). *Colletotrichum acutatum* is frequently reported as a cause of crown rot in strawberries in the USA (Freeman and Katan, 1997; Howard *et al.,* 1992; Smith and Black, 1986). However, the involvement of this pathogen in crown rot in Australia is not known.

Resistance to prochloraz and potential candidate fungicides to be used in resistance management

Israel is possibly the only other country able to use prochloraz for the control of *Cg* crown rot (Freeman *et al.,* 1997). Their experience matches the results here where resistance has not been detected despite many isolates being tested (Freeman, personal communication).

Despite the lack of resistance in the current local *Cg* genepool, it is highly desirable to identify a fungicide to use in a resistance management program with prochloraz. The laboratory experiments (Tables 4 and 5) showed that cyprodininil plus fludioxinil, fludioxinil, pyroclostrobin, and boscalid plus pyroclostrobin are as effective as prochloraz in reducing the recovery of *Cg* from symptomless petioles. These four chemicals were more effective than prochloraz in the first assessment of the field experiment (Table 6). The equivalent efficacy of these fungicides with prochloraz in the second part of the field trial supports their nomination as potential partners in a

resistance management program. "Cyprodininil plus fludioxinil" was particularly impressive.

The excellent efficacy of the strobilurin formulations of pyroclostrobins, and boscalid plus pyroclostrobin is also encouraging. However, the use of a strobilurin for control of *Cg* on runner farms is not desirable as trifloxystrobin, another strobilurin, has recently been registered in strawberries for the control of powdery mildew. The use of any other strobilurin in the strawberry system increases the risk of the powdery mildew pathogen becoming resistant to the chemical. It is fortunate that this work has shown that there is at least one alternative (cyprodininil plus fludioxinil) that can be used with prochloraz. Fludioxinil alone is registered as a treatment for seeds and will not be considered for use as a field spray.

The poor performance of prochloraz in the first assessment of the field experiment is puzzling. This chemical is used on a routine basis in the commercial runner nurseries, from the tissue culture growing-on area through to runner harvest. This appears to keep the incidence of *Cg* below levels that can be detected with current sampling and laboratory methods. Cyprodininil plus fludioxinil apparently move through plant tissue more efficiently than prochloraz, making them more effective in controlling *Cg* present in infected petioles.

Future work should investigate whether the presence of *Colletotrichum acutatum* in samples affects the identification of *Cg* in rotting petioles and crowns. Further research is also required to acquire relevant data comparing the efficacy of the promising fungicides in strategies with prochloraz, enabling an application to be made to APVMA for registration.

Conclusions

A program for controlling *Cg* crown rot based on regular use of prochloraz in the runner beds and vigilance in monitoring for symptoms, as well as isolating *Cg* from symptomless petioles appears to keep the incidence of the disease below 0.1% most seasons across the strawberry industry on the Sunshine Coast. However, there are occasions when higher levels of infection occur, sometimes in the absence of visual symptoms of the disease in the runner beds or detection of the pathogen in symptomless petioles. These results suggest that crown rot can still be a significant problem on commercial fruit farms on the Sunshine Coast even when it is a relatively minor pathogen and relatively rare in the runner beds. Further work is required to better understand the biology and etiology of crown rot, particularly on the source of infection in the runner beds and fruit farms.

A permit for the use of "cyprodininil plus fludioxinil" (Switch®), with prochloraz for the control of *Cg* in runner nurseries has been submitted to APVMA for registration.

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Table 1. The recovery of *Colletotrichum gloeosporioides* (*Cg*) from symptomless petioles in the Queensland runner scheme. Data show the number of isolates per sample of petioles assessed.

Production area	2001/02	2002/03	2003/04	2004/05	2005/06
Tissue culture nursery	nil/1998	nil/4970	nil/4553	nil/5403	nil/7304
Mother plants on runner farm 1	na	na	na	nil/1224	1/1628
Mother plants on runner farm 2	na	na	na	nil/1440	nil/1276
Commercial plants on runner farm 1	nil/1024	nil/1640	nil/2848	nil/4660	30/6403
Commercial plants on runner farm 2	nil/1880	nil/1900	nil/2942	nil/11416	16/11745

Table 2. The recovery of *Colletotrichum gloeosporioides* (*Cg*) from plots with visible symptoms in petioles, stolons or plants in the Queensland runner scheme. Data show the number of isolates per sample of petioles assessed. There were no visible symptoms of *Cg* from 2001/02 to 2003/04. In 2004/05, there were <0.1% wilted plants (*Macrophomina* also) in commercial blocks at runner farm 2. In 2005/06, *Cg* was isolated from only one paddock (0.5% wilted plants) from commercial plants of runner farm 1. In 2005/06, *Macrophomina* was mainly associated with crown rots in commercial plants of runner farm 2.

Production area	Plant part affected	2004/05	2005/06
Tissue culture nursery	petioles	no symptoms	no symptoms
Mother plants on runner farm 1	stolons, petioles or wilted plant	no symptoms	nil/12
Mother plants on runner farm 2	stolons, petioles or wilted plant	no symptoms	no symptoms
Commercial plants on runner farm 1	stolons	nil/15	no symptoms
Commercial plants on runner farm1	wilted plants	nil/30	106/147
Commercial plants on runner farm 2	stolons	nil/60	no symptoms
Commercial plants on runner farm 2	wilted plants	10/140	nil/73

Table 3. The incidence of crown rot with recovery of *Colletotrichum gloeosporioides* (*Cg*) on fruit farms on the Sunshine Coast, with material supplied from different strawberry nurseries in Australia. There was no crown rot in material supplied from nurseries in Tasmania (2001/02 to 2005/06) and Canberra (2004/05).

Runner production area	2001/02	2002/03	2003/04	2004/05	2005/06
Stanthorpe farm 1	1 site with < 1%	1 site with < 0.1%	3 sites with < 0.1%	1 site with 28%; and 5 other sites with <1%	1 site with 15%; 3 sites with 5%; 1 site with 4%; and 1 site with 3.5%
Stanthorpe farm 2	2 sites with <0.01%	2 sites with < 0.01%	1 site with < 1%; and 3 sites with < 0.1%	2 site with 30%; 2 sites with 3%; and 8 other sites with <1%	several sites with < 0.1%
Victoria	nil	nil	2 sites < 0.1%	5 sites with <0.01%	1 site with < 1%

Table 4. The effect of fungicides on the recovery of *Colletotrichum gloeosporioides* (*Cg*) in detached petioles (percent of petioles in a sample) from field-grown plants at Nambour. Chemicals applied to the petioles in the laboratory (first experiment). The plants in the field had high levels of latent *Cg* in symptomless petioles. Data are the means of four replicates per treatment.

Treatment	
Control	68
Tolylfluanid (1 g per L)	23
Prochloraz (0.92 g per L)	4
Propiconazole (0.1 g per L)	0
Azoxystrobin (0.2 g per L)	28
Trifloxystrobin (0.2 g per L)	11
Kresoxim-methyl (0.2 g per L)	29
Pyraclostrobin (0.2 g per L)	3
Boscalid (0.08 g per L) + pyroclostrobin (0.04 g per L)	2
Spiroxamine (0.2 g per L)	35
Quinoxyfen (0.2 g per L)	37
LSD ($P = 0.05$)	13

Table 5. The effect of fungicides on the recovery of *Colletotrichum gloeosporioides* (*Cg*) in detached petioles (percent of petioles in a sample) from field-grown plants at Nambour. Chemicals applied to the petioles in the laboratory (second experiment). The plants in the field had high levels of latent *Cg* in symptomless petioles. Data are the means of four replicates per treatment.

Treatment	
Control	91
Tolylfluanid (1 g per L)	9
Captan (1.6 g per L)	44
Prochloraz (0.92 g per L)	0
Propiconazole (0.1 g per L)	35
Carbendazim (0.25 g per L)	55
Azoxystrobin (0.2 g per L)	40
Azoxystrobin (0.3 g per L)	32
Cyprodinil + fludioxinil	0
Fludioxinil (0.05 g per L)	0
Fludioxinil (0.1 g per L)	0
Trifloxystrobin (0.2 g per L)	28
Trifloxystrobin (0.3 g per L)	23
Pyroclostrobin (0.1 g per L)	24
Pyroclostrobin (0.2 g per L)	10
Boscalid (0.6 g per L)	55
Boscalid (0.2 g per L) + pyroclostrobin (0.1 g per L)	13
Boscalid (0.3 g per L) + pyroclostrobin (0.15 g per L)	22
LSD ($P = 0.05$)	20

Table 6. The effect of fungicides on the recovery of *Colletotrichum gloeosporioides* (*Cg*) in detached petioles (percent of petioles in a sample) from runner beds at Nambour (field experiment). Chemicals applied to the plants in the field. The plants had high levels of latent *Cg* in symptomless petioles. Data are the means of four replicates per treatment.

Treatment	Assessment 1	Assessment 2
Control	72	78
Tolylfluanid (1 g per L)	65	21
Captan (1.6 g per L)	60	24
Prochloraz (0.92 g per L)	51	5
Propiconazole (0.125 g per L)	60	61
Fludioxinil (0.07 g per L)	30	4
Pyroclostrobin (0.3 g per L)	33	4
Cyprodinil (0.3 g per L) + fludioxinil (0.2 g per L)	0	0
Boscalid (0.2 g per L) + pyroclostrobin (0.1 g per L)	28	18
LSD ($P = 0.05$)	20	18

The control of fruit rots

Don Hutton and Apollo Gomez

Commercial summary

Several fungicides and other compounds were assessed over two years for their efficacy against powdery mildew and grey mould in strawberry crops at Nambour on the Sunshine Coast. The incidence of these diseases in a range of cultivars was also examined. A strategy based on regular applications of tolylfluanid applied from soon after plant establishment gave the best control of powdery mildew and grey mould, and the best yields. When powdery mildew pressure increased, the use of trifloxystrobin gave excellent control. This work contributed to a national registration for trifloxystrobin for the control of powdery mildew in strawberries. Several biological compounds including Ecocarb, synetrol oil, soap, milk and ti-tree oil offered some control of these diseases; however, none of these compounds matched the performance of the standard crop protectant.

Introduction

Black spot (*Colletotrichum acutatum*), grey mould (*Botrytis cinerea*), and powdery mildew (*Sphaerotheca macularis*) are the most important fruit diseases affecting strawberries in southern Queensland. These diseases are also important in other strawberry growing areas such as Florida (Chandler *et al*., 2006). Environmental conditions usually favour grey mould for most of the strawberry season in Queensland and Florida, whereas black spot is more sporadic.

Previous research in Queensland identified tolylfluanid and captan as effective protectants against black spot and grey mould; iprodione, pyrimethanil and fenhexamid for grey mould; and myclobutanil for powdery mildew (Hutton, 1998; 2001). Yield and quality data from commercial fruit fields on the Sunshine Coast confirm the efficacy of regular tolylfluanid sprays from soon after establishment. The use of tolylfluanid in this way provides a strong platform for the effective use of specific grey mould and powdery mildew fungicides at times of higher disease pressure. The most obvious weakness with this strategy is that myclobutanil does not perform adequately under high powdery mildew pressure. This project sought to address that need.

A new group of crop protectants, the strobilurins, are effective against a wide range of fungi, including the three main strawberry fruit pathogens in Queensland. Other prospective fungicides for the control of these major diseases have also become available. Here we report on the efficacy of several fungicides in controlling fruit diseases in strawberries growing on the Sunshine Coast. In some trials, standard fungicides were compared with the biological control formulation of *Trichoderma viride* and *T. harzianun*, as well as ti-tree oil and similar compounds.

The last ten years in Australia have seen the release of at least fifty new strawberry cultivars from overseas, and as many from local breeding programs. This has resulted

in significant changes in the mix of cultivars grown. It has also contributed to changes in the range and severity of common diseases. In the second part of this work, we studied the relative susceptibility of the major cultivars to fruit pathogens found in strawberry fields in southern Queensland.

Materials and methods

Comparison of conventional and experimental fungicides

The performance of conventional and experimental fungicides was studied over two years at Nambour on the Sunshine Coast. The cultivar 'Adina' was planted in two row beds on a loam soil that was not fumigated, with 30 cm between the rows and plants in the rows. 'Adina' was selected because of its susceptibility to powdery mildew and because of the presence of high levels of this disease in the runners from the nursery. The plants were grown in a similar fashion to commercial crops with respect to strawberry agronomy (Vock, 1997).

Treatments in 2002 were as follows: untreated control; tolylfluanid at 1 g per L weekly or fortnightly after establishment or weekly from July (plus powdery mildew and grey mould fungicides when there were two days of cloud or rain); two applications of myclobutanil after establishment, one week apart, followed by tolylfluanid weekly; two applications (weekly intervals) of trifloxystrobin at 0.062 g per L in rotation with two applications of tolylfluanid (weekly intervals) after establishment; trifloxystrobin at 0.062, 0.125 or 0.2 g per L weekly from July; azoxystrobin at 0.2 g per L weekly from July; acibenzolar-S-methyl at 0.05 or 0.2 g per L weekly from July; quinoxyfen at 0.05 or 0.075 g per L weekly from July; and spiroxamine at 0.062 or 0.125 g per L weekly from July. The runners were planted on 17 April.

Treatments in 2003 were: control; tolylfluanid at 1 g per L weekly or fortnightly after establishment or weekly from July as above; myclobutanil at 0.048 g per L weekly after the start of flowering; trifloxystrobin at 0.05, 0.1, 0.125 or 0.2 g per L weekly after the start of flowering; two sprays of trifloxystrobin at 0.1 g per L from July, then two sprays of tolylfluanid a week later (trifloxystrobin when there were two days of cloud or rain); or a system of two sprays of myclobutanil followed by two sprays of tolylfluanid from July. The runners were planted on 14 April, with flowering commencing in May.

Fruit were harvested weekly and counted, weighed and assessed for diseases. Data on the incidence of the main diseases are presented as the percentage of fruit affected. The treatments were replicated in four randomised blocks, with thirty plants per plot. The data were analysed by one-way analysis of variance (11 or 16 treatments x 4 blocks), with the disease data subjected to angular transformations before analysis.

Comparison of conventional fungicides and organic compounds

The effects of conventional fungicides and biological or organic compounds were studied over two years at Nambour, with a similar set-up as above.

Treatments in 2003 were as follows: control; tolylfluanid at 1 g per L weekly from establishment as above; sulphur at 2 g per L weekly from flowering; Ecocarb (85.6% $KHCO_3$) at 4 g per L plus synetrol oil at 2.5 ml per L weekly from flowering; as with the previous treatment, but with Ecocarb at 2 g per L; synetrol oil at 2.5 ml per L weekly from flowering; *Trichoderma viride* plus *T. harzianun* (1×10^9 spores per g) at 5 g per L weekly from flowering; full cream powdered milk at 10 g per L weekly from flowering; ti-tree oil A (1.5% 1.8 cineol and 42% terpinene-4-ol) at 3 ml per L weekly from flowering; or ti-tree oil B (22% 1.8 cineol and 28% terpinene-4-ol) at 3 ml per L weekly from flowering. The runners were planted on April 10, with flowering commencing in May.

Treatments in 2004 were: control; tolylfluanid at 1 g per L weekly from establishment as above; same as the previous treatment, but fortnightly tolylfluanid; OCP soft soap at 20 ml per L weekly from flowering; EcoCarb at 3 g per L plus soap weekly from flowering; EcoCarb plus synetrol at 2.5 ml per L weekly from flowering; sulphur at 2 g per L weekly from flowering; mono-potassium phosphate at 3 g per L weekly from flowering; milk at 10 g per L weekly from flowering; molasses at 50 ml per L weekly from flowering; milk plus molasses weekly from flowering; ti-tree oil B at 3 ml per L weekly from flowering; or ti-tree oil B plus molasses weekly from flowering. The runners were planted on 19 April, with flowering commencing in May.

Data were collected as above, with the treatments replicated in four randomised blocks, using thirty plants per plot. The data were analysed by one-way analysis of variance (10 or 13 treatments x 4 blocks), with the disease data transformed by angular before analysis, and are presented as the percentage of fruit affected. Even though grey mould data are reported, the control of powdery mildew was the primary reason for doing this work.

Fruit diseases in different cultivars

The incidence of fruit diseases was assessed in 16 strawberry lines in 2002, and 20 lines in 2003 at Nambour (Table 1), with a similar set-up as above. Each line was replicated in four randomised blocks, with 14 plants per plot. In 2002, twenty plants of each cultivar were planted in two row beds in each plot on 16 April. In 2003, the eastern row in each plot was planted with ten 'Adina' plants infected with powdery mildew acting as source plants, and ten test cultivars were planted in the western row of each plot. Both eastern and western rows were planted on 10 April. Fungicides were not applied.

Fruit were harvested weekly and rots categorised according to the causal disease, with the data presented as cumulative totals up to selected harvest dates. Data were subjected to angular transformation before one-way analysis of variance (16 or 20 cultivars x 4 blocks), and are presented as the percentage of fruit affected.

Results

Comparison of fungicides

Powdery mildew levels were high in both trials, while grey mould was virtually absent in 2002, and moderate in 2003.

Experiment in 2002. The trifloxystrobin (0.062 g per L) plus tolylfluanid rotation applied weekly from establishment, tolylfluanid weekly and fortnightly from establishment, and myclobutanil from establishment controlled powdery mildew and gave the best yields (Table 2). Trifloxystrobin sprays applied from July were also effective. Spiroxamine applied from July was better than the control in terms of disease incidence, but had similar yields. Tolylfluanid from July, azoxystrobin, acibenzolar-S-methyl, and quinoxyfen all applied from July were ineffective in controlling disease or maintaining yield (Table 2).

Experiment in 2003. The data up to the end of July showed that trifloxystrobin, tolylfluanid applied weekly or fortnightly from establishment and myclobutanil controlled powdery mildew (Table 3). Tolylfluanid applied weekly from establishment was the most effective treatment for grey mould, and when applied fortnightly was also more effective than the other treatments including the control. The tolylfluanid treatments applied weekly or fortnightly from establishment, and the myclobutanil and trifloxystrobin treatments applied from July had higher yields than the controls (Table 3).

Sprays first applied in July, such as tolylfluanid, trifloxystrobin and myclobutanil controlled powdery mildew from 30 August to 10 September, along with tolylfluanid given earlier (Table 4). There were no significant differences ($P > 0.05$) in the control of grey mould at this time between the treatments applied late. Yield during this period was better in all treatments than the control, except for myclobutanil, and trifloxystrobin plus myclobutanil (Table 4).

Comparison of fungicides and organic compounds

The incidence of powdery mildew was high in both trials, whereas grey mould infection was moderate in 2003 and low in 2004.

Experiment in 2003. Tolylfluanid, the industry standard, was unchallenged as the most effective chemical in terms of low disease levels and high yields (Table 5). Sulphur was equivalent to tolylfluanid in controlling powdery mildew. This resulted in sulphur giving relatively high yields. It was ineffective against grey mould. Ecocarb plus synetrol, milk and ti-tree oil gave some control of powdery mildew, followed by synetrol oil alone. Trichoderma was ineffective. Only tolylfluanid applied weekly from establishment was effective against grey mould (Table 5). Tolylfluanid weekly from establishment gave the highest yield, followed by Ecocarb plus synetrol, ti-tree oil, sulphur and synetrol oil alone (Table 5).

Experiment in 2004. All treatments gave better powdery mildew control than the controls (Table 6). The tolylfluanid treatments and sulphur gave the best control; EcoCarb plus soap, and Ecocarb plus synetrol were equivalent to the fortnightly

standard. There were no significant differences between treatments in grey mould control, which only affected a small proportion of the crop (data not presented). The standard treatments along with EcoCarb plus soap gave the best yields (Table 6).

Fruit diseases in different cultivars

Experiment in 2002. Early in the season, 'Adina' was more severely affected by powdery mildew than the other cultivars (Table 7); 'Lowanna' and 'Sweet Charlie' were intermediate, and the other lines low. Later in the season 'Adina' was the worst, while 'Camarosa', 'Sweet Charlie', 'Selva' and 'Crimson Glow' (56% - 34% of fruit affected) were significantly worse than other cultivars. 'Kabarla', 'Oso Grande', 'Gaviotta' and 'Aromas' were the best of the cultivars tested (19% - 23% of fruit affected).

'Tallara' and 'Camarosa' suffered more damage from grey mould early in the season than the other cultivars (Table 7). Later in the season, there was a low incidence of the disease, which ranged from 11% in 'Adina' to 22% in 'Harmony'. These results suggest that there is limited resistance to grey mould in the local strawberry genotypes.

Experiment in 2003. In a year with a high incidence of powdery mildew, 'Diamante' and 'Pajaro' had lower levels of disease than the other cultivars on the first sampling date (Table 8). At the second assessment, 'Diamante' was also better (16% of fruit affected) than the other cultivars (39% - 62% of fruit affected). 'Pajaro' had a low incidence of grey mould early in the season (5% of fruit affected) compared with the other cultivars (15% - 48% of fruit affected). In the later harvest, there was less variation, with most cultivars having 20 to 40% of fruit affected ('Selva' and 'Gaviotta' had less than 20% of fruit affected).

Discussion

Conventional fungicides

Powdery mildew was severe in 2002, providing confidence in the results obtained for the candidate chemicals. The outstanding results for tolylfluanid applied weekly or fortnightly from establishment must be highlighted. Trifloxystrobin was also an effective fungicide, with curative action. The known risk of resistance development to strobilurins means that good management strategies need to be recommended and put into place commercially. The regular use of tolylfluanid, together with the use of trifloxystrobin up to three times in a season, is recommended.

Other chemicals did not perform well in 2002. This should not be taken as an absolute measure of the usefulness of these products against powdery mildew. Under less severe disease pressure, it is probable that the treatments would have given better control. The decision was taken to give the candidate fungicides a severe test in the hope that we would uncover a very effective chemical. This decision appears to have been vindicated by the results with trifloxystrobin.

Trifloxystrobin has been registered as Flint™ by Bayer Crop Science. It is suggested that strawberry producers apply tolylfluanid to their crops every seven to ten days from early in the season. When powdery mildew is first seen, it is recommended to use trifloxystrobin and tolylfluanid, followed up with tolylfluanid one week later. An extra spray of tolylfluanid and myclobutanil may be necessary for complete control. Growers can then revert to regular tolylfluanid sprays.

Biological compounds

The results from the two trials showed that Ecocarb plus synetrol oil, EcoCarb plus soap, milk, and ti-tree oil offered some control of fruit diseases in strawberries. When combined with other management practices it is possible that these products could be used in organic or minimal chemical systems. However, overall these alternatives cannot provide the level of disease control given by the tolylfluanid standard and which is required for most commercial situations.

Fruit diseases in different cultivars

The successful control of fruit rots in strawberries requires their early identification and careful management. The strawberry industry in Australia is most fortunate in that it has an array of chemicals to control the three main fruit diseases. The results of experiments conducted in 2003 show that there are useful levels of resistance to powdery mildew in the genotypes tested, whereas the results for grey mould suggest that there are few, if any, differences between cultivars. The information provided here would assist growers to decide which cultivars to plant. For instance, 'Cal Giant 3' is very susceptible to grey mould, while 'Camarosa', 'Adina' and 'Festival' are susceptible to powdery mildew.

Conclusions

A program based on tolylfluanid with trifloxystrobin can provide good control of powdery mildew in strawberries grown in southern Queensland. Trifloxystrobin plus tolylfluanid also gave the best control of grey mould, although the incidence of this disease was low to moderate in the experiments on the Sunshine Coast. The evaluation of different cultivars shows wide variation in the incidence of powdery mildew, which should be exploited in future strawberry breeding programs.

References

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Table 1. The sources of the cultivar using in the screening trials.

Cultivar	2002	2003	Cultivar	2002	2003
Adina	Stanthorpe	Stanthorpe	Crimson Glow	Nambour	Nambour
Aromas	Toolangi	Toolangi	Harmony	Nambour	Nambour
Camarosa	Toolangi	Toolangi	Bright Eyes	Nambour	Nambour
Gaviotta	Toolangi	Toolangi	Hope		Stanthorpe
Jewel	Stanthorpe	Stanthorpe	Flame		Stanthorpe
Joy	Stanthorpe	Stanthorpe	Earliblush		Stanthorpe
Kabarla	Stanthorpe	Stanthorpe	2000-430		Stanthorpe
Lowanna	Stanthorpe	Stanthorpe	Cal Giant 2		Stanthorpe
Oso Grande	Toolangi	Toolangi	Cal Giant 3		Stanthorpe
Selva	Toolangi	Toolangi	Festival		Stanthorpe
Sweet Charlie	Stanthorpe	Stanthorpe	Diamante		Toolangi
Tallara	Stanthorpe	Stanthorpe	Pajaro		Toolangi
96-033	Nambour	Nambour			

Table 2. The effects of fungicides on the incidence of powdery mildew and cumulative fruit yield up to early August in 2002 (comparison of conventional and experimental fungicides). See the text for details. Trifloxystrobin, azoxystrobin, acibenzolar-5-methyl, quinoxyfen and spiroxamine applied from July. Data are the means (angular transformations for percent data) of four replicates per treatment, with 30 plants per plot. There was a low incidence of grey mould in the trial.

Treatment	Percent of fruit with powdery mildew	Yield (g per plot)
Control	51	525
Tolylfluanid weekly from establishment	6	1717
Tolylfluanid f/n from establishment	4	1924
Tolylfluanid weekly from July	45	916
Myclobutanil from establishment	2	1821
Trifloxystrobin (0.062 g per L) + tolylfluanid	4	2111
Trifloxystrobin (0.062 g per L)	15	2045
Trifloxystrobin (0.125 g per L)	10	1776
Trifloxystrobin (0.2 g per L)	13	1584
Azoxystrobin	43	833
Acibenzolar-5-methyl (0.05 g per L)	44	756
Acibenzolar-5-methyl (0.2 g per L)	47	741
Quinoxyfen (0.05 g per L)	43	938
Quinoxyfen (0.075 g per L)	42	905
Spiroxamine (0.062 g per L)	32	776
Spiroxamine (0.125 g at L)	36	865
LSD (P = 0.05)	10	532

Table 3. The effects of fungicides on the incidence of powdery mildew and grey mould and cumulative fruit yield up to late July in 2003 (comparison of conventional and experimental fungicides). See the text for details. Trifloxystrobin alone treatments applied from the start of flowering in May. Data are the means (angular transformations for percent data) of four replicates per treatment, with 30 plants per plot.

Treatment	Percent of fruit with powdery mildew	Percent of fruit with grey mould	Yield (g per plot)
Control	51	23	585
Tolylfluanid weekly from establishment	1	1	2440
Tolylfluanid f/n from establishment	13	6	1878
Tolylfluanid weekly from July	51	23	516
Myclobutanil from establishment	5	19	1836
Trifloxystrobin (0.05 g per L)	0	15	2154
Trifloxystrobin (0.1 g per L)	1	15	2285
Trifloxystrobin (0.125 g per L)	0	16	2122
Trifloxystrobin (0.2 g per L)	1	14	2480
Tolylfluanid + trifloxystrobin from July	39	23	932
Trifloxystrobin + myclobutanil from July	43	25	704
LSD ($P = 0.05$)	8	5	600

Table 4. The effects of fungicides on the incidence of powdery mildew and grey mould and cumulative fruit yield from late August to mid-September in 2003 (comparison of conventional and experimental fungicides). See the text for details. Data are the means (angular transformations for percent data) of four replicates per treatment, with 30 plants per plot.

Treatment	Percent of fruit with powdery mildew	Percent of fruit with grey mould	Yield (g per plot)
Control	19	10	519
Tolylfluanid weekly from establishment	0	1	1077
Tolylfluanid f/n from establishment	0	3	959
Tolylfluanid weekly from July	4	4	940
Myclobutanil from establishment	0	9	843
Trifloxystrobin (0.05 g per L)	10	6	916
Trifloxystrobin (0.1 g per L)	0	9	1343
Trifloxystrobin (0.125 g per L)	0	9	1363
Trifloxystrobin (0.2 g per L)	0	6	1015
Tolylfluanid + trifloxystrobin from July	0	7	957
Trifloxystrobin + myclobutanil from July	0	8	740
LSD ($P = 0.05$)	6	7	405

Table 5. The effects of fungicides on the incidence of powdery mildew and grey mould and cumulative fruit yield up to late August in 2003 (comparison of fungicides and organic compounds). See the text for details. Data are the means (angular transformations for percent data) of four replicates per treatment, with 30 plants per plot.

Treatment	Percent of fruit with powdery mildew	Percent of fruit with grey mould	Yield (g per plot)
Control	51	28	637
Tolylfluanid weekly from establishment	9	7	3325
Sulphur	13	27	2104
Ecocarb (4 g per L) + synetrol oil	19	24	2388
Ecocarb (2 g per L) + synetrol oil	23	28	2001
Synetrol oil	33	22	1917
Trichoderma	46	23	952
Milk	27	33	1330
Ti-tree oil A	20	30	2352
Ti-tree oil B	19	23	2501
LSD ($P = 0.05$)	9	5	615

Table 6. The effects of fungicides on the incidence of powdery mildew and cumulative fruit yield up to late August in 2004 (comparison of fungicides and organic compounds). See the text for details. Data are the means (angular transformations for percent data) of four replicates per treatment, with 30 plants per plot. There was a low incidence of grey mould in the trial.

Treatment	Percent of fruit with powdery mildew	Yield (g per plot)
Control	45	1772
Tolylfluanid weekly from establishment	10	3568
Tolylfluanid f/n from establishment	15	3704
Soap	25	2942
EcoCarb + soap	21	3150
EcoCarb + synetrol oil	19	2921
Sulphur	16	2674
Mono-potassium phosphate	30	2328
Milk	29	2294
Molasses	30	2424
Milk + molasses	24	2417
Ti tree oil	26	2708
Ti tree oil + molasses	26	3070
LSD ($P = 0.05$)	8	594

Table 7. The incidence of powdery mildew and grey mould in strawberry cultivars in 2002 (fruit diseases in different cultivars). See Table 1 for cultivar details. Data are the means (angular transformations) of four replicates per treatment, with 30 plants per plot.

Cultivar	Percent of fruit with powdery mildew		Percent of fruit with grey mould	
	26 June	2 September	26 June	2 September
Adina	60	56	0	11
Aromas	0	24	0	15
Camarosa	0	44	43	20
Gaviotta	5	24	6	17
Jewel	0	30	0	18
Joy	9	33	0	15
Kabarla	10	20	4	14
Lowanna	21	45	5	12
Oso Grande	0	23	1	15
Selva	2	35	15	12
Sweet Charlie	31	39	0	18
Tallara	9	30	92	19
96-033	11	29	9	15
Crimson Glow	0	34	0	15
Harmony	11	25	12	22
Bright Eyes	11	30	12	20
LSD ($P = 0.05$)	20	8	10	5

Table 8. The incidence of powdery mildew and grey mould in strawberry cultivars in 2003 (fruit diseases in different cultivars). See Table 1 for cultivar details. Data are the means (angular transformations) of four replicates per treatment, with 30 plants per plot.

Cultivar	Percent of fruit with powdery mildew		Percent of fruit with grey mould	
	16 July	20 August	16 July	20 August
Kabarla	73	54	26	27
Joy	84	57	28	28
Hope	65	45	23	23
Flame	93	55	15	24
Earliblush	77	53	19	22
Crimson Glow	97	62	23	24
Harmony	71	43	27	30
Bright Eyes	100	47	22	24
2000-430	86	51	21	31
Sweet Charlie	64	45	26	27
Cal Giant 2	65	49	31	32
Cal Giant 3	80	48	48	39
Festival	95	55	19	22
Adina	81	59	35	29
Selva	47	40	22	18
Camarosa	91	60	22	24
Gaviotta	78	48	21	17
Diamante	28	16	22	31
Pajaro	23	39	5	31
Jewel	72	50	30	30
LSD ($P = 0.05$)	28	8	12	7

An evaluation of several fumigants as potential replacements for methyl bromide

Don Hutton, Apollo Gomez and Scott Mattner

Commercial summary

Strawberry plants in southern Queensland are affected by a range of soil-borne diseases and weeds that are normally controlled by methyl bromide. We investigated the efficiency of several chemicals as potential replacements for this fumigant in light of the phasing out of the use of substances that deplete the earth's ozone layer. In the first series of experiments over three years, the effects of Telone C35, methyl bromide plus chloropicrin, chloropicrin, and metham sodium or metham potassium, all applied by tractor-drawn tynes, were studied. In the second experiment over a single season, the use of some of these fumigants applied via the irrigation system was assessed. In the third experiment conducted over three years, we compared the performance of strawberry plants grown in soil treated with Telone C35, chloropicrin, and methyl bromide plus chloropicrin, from runner production in Victoria to fruit production in Queensland. The results showed that Telone C35 and chloropicrin could replace methyl bromide used for strawberry runner and fruit production. In contrast, metham potassium and metham sodium were less effective and would not be suitable replacements.

Introduction

Strawberry plants in southern Queensland are affected by a range of soil-borne diseases, including Fusarium wilt (*Fusarium oxysporum* f. sp. *Fragariae*), Verticillium wilt (*Verticillium dahliae*) and Phytophthora crown rots (*Phytophthora nicotianae and P. cactorum*). Plants that are affected by these diseases can wilt and die, with a reduction in fruit production and quality. Nutgrass, *Cyperus rotundus* is the major weed affecting fruit production, but a range of grass and other weeds can also be a problem. Typically, the yields of strawberry fields contaminated by weeds are lower than those of fields where weeds have been controlled (Pritts and Kelly, 2001). Grass and broad leaf weeds can be a problem in runner production but have traditionally been controlled by methyl bromide.

For many years, soil fumigation with chemicals such as methyl bromide has been the standard approach to control soil-borne diseases such as Fusarium and Verticillium wilts, nematodes and weeds. Under the terms of The Montreal Protocol, it was agreed to phase out the use of such substances because of their impact on the ozone layer which protects the earth's surface from harmful ultraviolet (UV) rays. For most industries, the accepted deadline was 2005, although there has been limited use of methyl bromide since that date for those sectors that have been granted "critical use exemption". However, it has generally been accepted that the wide use of chemicals that deplete the ozone layer is a thing of the past, with most industries moving to other chemicals and technologies.

Here we report on the efficiency of several chemicals as potential replacements for methyl bromide in strawberry production. These studies follow earlier research on strawberries conducted in Victoria by Porter *et al*. (1998, 1999), and in southern Queensland by Hutton *et al*. (2001).

In the first series of experiments, the effects of Telone C35, methyl bromide plus chloropicrin, chloropicrin and metham sodium or metham potassium applied by tractor drawn tynes were studied. Information was collected on the health and yield of two strawberry fields under the different chemical regimes on the Sunshine Coast over three years.

In the second part of the research, the use of fumigants injected through the irrigation system was assessed. The chemicals evaluated included Telone C35 as a gas injected by tractor tynes, and Telone C35 EC (an emulsifiable formulation) and metham potassium or metham sodium applied via the irrigation. The impacts of these fumigants on weed infestation and fruit yield were monitored over a single season at Nambour.

Finally, experiments running from 2001 to 2004 compared the performance of strawberry plants grown under Telone C35, chloropicrin, and methyl bromide plus chloropicrin, from runner to fruit production. Each year, runners produced under the different chemicals in Toolangi, Victoria, were transported to Nambour, Queensland, for experiments conducted on fruit crops grown under the same fumigation regimes.

Materials and methods

Comparison of fumigants applied by tractor drawn tynes

Experiments were conduced over three years at Bli Bli, and over two at Wamuran on the Sunshine Coast to assess the effects of various soil fumigants on the health and yield of strawberries. Both fields were affected by Fusarium wilt, *Fusarium oxysporum* f. sp. *fragariae*. The plants were grown as standard commercial crops (Vock, 1997), with a commercial operator fumigating the trial plots.

Treatments at Bli Bli were: nonfumigated control; Telone C35 at 500 kg per ha; methyl bromide plus chloropicrin (50:50 or 70:30) at 500 kg per ha; chloropicrin at 500 kg per ha; metham sodium at 300 or 500 L per ha; and metham potassium at 200, 500 or 650 L per ha. Treatments at Wamuran were: Telone C35 at 500 kg per ha; methyl bromide plus chloropicrin (50:50 or 98:2) at 500 kg per ha; and chloropicrin at 500 kg per ha. The treatments were laid out in randomised blocks, with four replicates per treatment (see below).

At Bli Bli, data were collected on crown (2002) or plant diameter (2003) in the middle of the season (see below), fruit yield weekly, and the percentage of plants dead in each plot at the end of the season (n = 20). Laboratory isolations from crown rots and discoloured vascular tissue were carried out to determine the presence of *F. oxysporum* or other soil pathogens. At Wamuran, only data on plant health were recorded. The data were analysed by one-way analysis of variance (4 or 10 treatments

x 4 blocks), with each year and site analysed separately. The data on the percentage of plants dying were subject to angular transformation before analysis.

Comparison of fumigants applied via trickle irrigation

An experiment was conducted in a strawberry field (cultivar Jewel), at Nambour on the Sunshine Coast in 2002 to examine the effects of fumigants applied via trickle irrigation, with a particular emphasis on the effects of the chemicals on nutgrass, *Cyperus rotundus*. Data were also collected on fruit production and survival of the strawberry plants.

Treatments were: nonfumigated control; Telone C35 gas at 450 kg per ha injected by tractor tynes on 26 March; Telone C35 EC at 450 or 650 kg per ha applied via the trickle irrigation on 30 May; metham potassium or metham sodium at 600 L per ha applied via the trickle irrigation on 3 June. The trickle fumigants were applied in three bursts after the soil had been irrigated, with the treatments replicated in four randomised blocks. The runners were planted on 24 June, 21 days after the metham was applied, and 25 days after the Telone C35 EC was applied.

The number of nutgrass sedges in the centre of each control plot and the Telone C35 gas plot was counted on 25 May to assess the initial impact of the gassing. All the plots were assessed on 17 June and 18 July to determine the impact of the other treatments applied via irrigation. Fruit were harvested weekly, and weighed ($n = 20$ per plot). We also collected data on the number of strawberry plants that were dead in each plot in December. Data were analysed by one-way analysis of variance (2 or 6 treatments x 4 blocks), with each sampling period analysed separately. Data on the number of nutgrass plants per plot were transformed by $\log_e + 1$ before analysis, with backtransformed means presented in the text.

Runner and fruit farm fumigation

Experiments were conducted at Toolangi, Victoria, and at Nambour in southern Queensland over three years to assess the impacts of fumigation on the growth of strawberry runners and on subsequent fruit production. Various fumigants were applied to the runner beds at Toolangi, and the nursery plants transported to Queensland, where the same treatments were applied to the fruiting beds. Data were recorded on weed infestations and the growth of the daughter and mother plants in the runner beds, and on weed infestations, plant growth and yield in the fruiting fields. The cultivar Camarosa was used in 2001/02 and 2002/03, and cultivar Gaviota in 2003/04.

Treatments each year were: nonfumigated control; fumigated with Telone C35 at 500 kg per ha for the runner and fruit experiments; fumigated with chloropicrin at 500 kg per ha for the runner experiments and at 350 kg per ha fruit experiments, or fumigated with methyl bromide plus chloropicrin at 500 kg per ha for the runner and fruit experiments. The runner beds were fumigated on 5 January 2001, 6 February 2002, and 5 March 2003, while the fruiting beds were fumigated on 3 February 2002, 4 March 2003, and 3 April 2004.

The mother plants were planted 50 cm apart along the rows at the runner production site in Toolangi, three months or more after fumigation and grown using standard industry practices. The runners were dug by hand, and the leaves removed before being consigned to Queensland for the fruit experiments. The soil at Nambour was

bedded up, fumigated, and the plastic mulch and trickle tape laid. The runners were then planted in two row beds with 40 cm between the plants in the rows.

The number of weeds emerging per m² of each runner bed plot was assessed, along with the number of leaves and stolons per mother plant two to three months after planting (in 2001/02 and 2003/04), as indicators of plant establishment. The number of runners per linear metre of row was also counted at digging (2001/02, 2002/03 and 2003/04). In the fruiting experiments, the number of weeds emerging per plot was determined (2001/02, 2002/03 and 2003/04), along with the number of leaves per strawberry plant (2001/02 and 2002/03), diameter of the plants and fruit yield and average fruit weight (2001/02, 2002/03 and 2003/04). The percentage of plants dying in each plot was also determined in 2002/03 and 2003/04.

The experiments were laid out in randomised blocks, with five replicates per treatment and 30 plants per plot. Data were analysed by one-way analysis of variance (4 treatments x 5 blocks), with each location and year analysed separately.

Results and discussion

Fumigants applied by tractor drawn tynes

Bli Bli. The plots fumigated with Telone C35 had higher yields than the control plots and the plots fumigated with metham sodium or potassium in 2003 and 2004 (Table 1). The methyl bromide plus chloropicrin treatments were as effective as the Telone C35 treatment in these two years. Chloropicrin alone was applied as a treatment in 2004, and was as effective. The results for 2005 showed that the plots treated with Telone C35 had higher yields than the control plots, while fumigation with metham potassium was ineffective (Table 1).

Telone C35, and methyl bromide plus chloropicrin increased crown diameter compared with the control plots and the plots treated with metham potassium in 2003 (Table 2). Data collected on plant diameter in 2004 showed that Telone C35, methyl bromide plus chloropicrin, and chloropicrin alone were the best treatments (Table 2). These treatments (Telone C35, chloropicrin and methyl bromide plus chloropicrin) also gave the best response in terms of plant health over the three years (Table 3)

Wamuran. There were no significant ($P > 0.05$) differences amongst the fumigation treatments (Telone C35, chloropicrin, and methyl bromide plus chloropicrin at 50:50 or 98:2) in terms of plant health in either year (data not presented), with plant losses below 12%.

Overall, these results showed that Telone C35 was as effective as methyl bromide in terms of shoot growth, plant health and yield. Generally, the data were consistent with earlier research conducted on the Sunshine Coast by Hutton *et al*. (2001). Metham sodium is cheaper than Telone C35, but is only partially effective as a fumigant for soil-borne diseases such as Fusarium wilt.

Trickle irrigation fumigation

There was no evidence of phytotoxicity, even though we applied the trickle fumigants much later than standard commercial practice. Plots treated with Telone C35 gas in March (4 plants per plot) had significantly ($P = 0.05$) fewer nutgrass plants than the untreated plots (42 plants per plot) when assessed on 25 May. On 17 June, the best treatment was Telone C35 gas (5 plants per plot), with Telone C35 EC at 450 or 650 kg per ha (15 and 13 plants per plot), metham sodium and metham potassium (21 and 31 plants per plot) similar to the controls (44 plants per plot) ($P < 0.05$). The assessment made on 18 July showed that the blocks were highly variable, with no significant ($P > 0.05$) effect of fumigation on the number of nutgrass plants per plot (31 to 167 plants per plot).

The plots treated with Telone C35 EC had higher yields than the control plots (Table 4). In contrast, the other treatments were similar to the controls. Fumigation had no significant ($P > 0.05$) effect on plant health, with 13 to 16 dead plants in each plot in December. These results are possibly due to the uneven distribution of fungal spores in the soil.

It can be concluded that Telone C35 gas was the best fumigant for controlling nutgrass, whereas the equivalent EC treatments gave the best yield. Obviously there was a benefit with the EC form in terms of better plant growth even in the presence of greater populations of nutgrass. It is possible that the effectiveness of the trickle applied treatments was related to the capacity of the irrigation system to disperse the fumigant laterally through the soil. Metham potassium and metham sodium were similar to the untreated plots in terms of nutgrass control and yield. Both chemicals were applied much later than would normally be recommended for commercial strawberry production.

Runner and fruit farm fumigation

Experiments in 2001/02. The fumigants reduced weed emergence in the runner beds to less than 12% of that observed in the control plots, with no significant difference amongst the chemicals (Table 5). Soil disinfestation also increased early plant establishment by 0.5 to 3 fold, and the number of runners dug at harvest by more than 16 fold compared with the rates observed in the control plots (Table 5).

The fumigated plots had less nutgrass, the main weed in the fruiting beds, than the control plots in early July, with 37 weeds per control plot, 13 weeds per chloropicrin plot, 10 weeds per methyl bromide plus chloropicrin plot and 11 weeds per Telone C35 plot (LSD $P = 0.05$, 13). In contrast, there were no significant effects ($P > 0.05$) of the treatments on weed control later in the season when the field was assessed on 21 August and 16 September (37 to 75 weeds per plot).

Plants in the fruiting beds treated with Telone C35 and chloropicrin had higher yields than the controls on 15 July, while these two treatments and methyl bromide plus chloropicrin had higher yields than the controls on 12 August (Table 6). In contrast, there was no effect of the fumigants in early September. The effect of the treatments on average fruit weight was small or not significant (Table 6). The higher yields in

the fumigated plots were associated with greater plant growth compared with that observed in the control plots (Table 7).

Experiments in 2002/03. Disinfestation with chloropicrin (60 runners per m), methyl bromide plus chloropicrin (128 runners per m), and Telone C35 (103 runners per m) increased daughter plant yields compared with the control plots at Toolangi (13 runners per m) (LSD $P = 0.05$, 37).

Fruiting blocks fumigated with the chemicals had fewer nutgrass plants (1 to 3 plants per plot versus 18 plants per plot) (LSD $P = 0.05$, 14), and broad-leafed weeds than the blocks that were not fumigated (2 to 13 plants per plot versus 39 plants per plot) (LSD $P = 0.05$, 25). Disinfested plots had higher yield compared with the control plots in the fruiting experiment, with no differences between the fumigants up until mid-September, when the plots treated with chloropicrin had higher yields than those treated with Telone C35 (Table 8). Fruit from fumigated plots were also generally larger than those from nonfumigated plots (Table 8).

Higher yields with fumigation were associated with greater shoot growth (Table 9), but not with better plant health. Less than 10% of the plants died, with *Fusarium oxysporum* and *Macrophomina phaseolina* accounting for most of the losses.

Experiments in 2003/04. In the runner experiment, the fumigated plots had less than 20% of the weed population that was observed in the control plots (Table 10). Better weed control resulted in higher runner yields (three times higher than those recorded by the control plots), even though plant establishment rates were similar (Table 10).

Fumigation reduced the number of nutgrass specimens counted in early May in the fruiting fields compared with values recorded in the control plots, whereas there were no differences amongst the treatments at later assessments (Table 11). The effect of the chemicals on the emergence of broad-leafed species was inconsistent (Table 11). Plants in fumigated soils had larger fruit and higher yields than those recorded for plants in control soils (Table 12). Within the fumigation treatments, yields on soils treated with Telone C35 and chloropicrin tended to be higher than those on soils treated with methyl bromide plus chloropicrin.

Higher yields with fumigation were associated with greater shoot growth, but not better plant health. The diameter of the control plants on 9 August was 277 mm compared with 324 mm for the chloropicrin plots, 336 mm for the Telone C35 plots, and 317 mm for the methyl bromide plus chloropicrin plots (LSD $P = 0.05$, 9). Plant losses were below 2%.

These experiments clearly demonstrate the benefits of soil disinfestation for strawberry production, even in sites that contain low levels of pathogens. In the runner fields, fumigation increased daughter plant production by up to 16-fold, while in the fruit fields, it increased yields by up to 90%. The effects of the chemicals were more marked in runner production than in fruit production, because runners are produced in open fields without plastic mulch, where runners suffer more competition from weeds than fruiting plants grown on plastic (Pritts and Kelly, 2001).
There was a strong response to fumigation, and differences between individual chemicals, but no evidence of carry-over from the runner beds to the fruiting fields.

This response agrees with the results of earlier research conducted with chloropicrin, methyl bromide, methyl iodide, metham sodium and dazomet in Victoria (Porter *et al*., 1998), Florida (Gilreath *et al*., 2002) and California (Fennimore *et al*., 2004).

Overall, disinfestation with chloropicrin produced yields equivalent to fumigation with methyl bromide plus chloropicrin. It was only in 2001/02 that plants grown with chloropicrin produced fewer runners than those with methyl bromide plus chloropicrin. This was probably due to the inferior weed control given by chloropicrin compared with the mixed product. Despite this, lower daughter plant yields with chloropicrin did not translate in to lower crop yields on the fruit farm. This suggests that chloropicrin can be combined with herbicides as an effective alternative to methyl bromide plus chloropicrin for commercial strawberry production.

Telone C35 produced runner and fruit yields equivalent to or better than those with methyl bromide plus chloropicrin. This is in contrast to our experiments conducted on runner farms, where Telone C35 was phytotoxic. Our results demonstrate that Telone C35 is an effective alternative to methyl bromide plus chloropicrin for strawberry production, provided it is applied under appropriate environmental conditions and not too close to planting.

Conclusion

It can be concluded that Telone C35 and chloropicrin can be used for strawberry runner and fruit production as possible replacement fumigants for methyl bromide. In contrast, metham potassium and metham sodium were less effective and would not be suitable replacements. Generally, the data are consistent with earlier research conducted on the Sunshine Coast by Hutton *et al*. (2001).

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Table 1. The effect of soil fumigation on cumulative yields of 'Gaviotta' strawberries (g per plot) at Bli Bli on the Sunshine Coast from 2003 to 2005 (tractor tyne applications). Data are the means of four replicates per treatment, with 20 plants per plot.

Treatment	2003	2004	2005
Control	4311	7406	6943
Telone C35 (500 kg per ha)	8321	9424	11401
Chloropicrin (500 kg per ha)		9893	
Methyl bromide + chloropicrin (50:50) (500 kg per ha)	7576		
Methyl bromide + chloropicrin (70:30) (500 kg per ha)		8806	
Metham sodium (300 L per ha)		6524	
Metham sodium (500 L per ha)	5537	7370	
Metham potassium (200 L per ha)	5154		
Metham potassium (500 L per ha)	4974		8589
Metham potassium (650 L per ha)			8304
LSD ($P = 0.05$)	1609	1185	2654

Table 2. The effect of soil fumigation on crown diameter in 2003 and plant diameter in 2004 (mm) in 'Gaviotta' strawberries at Bli Bli on the Sunshine Coast (tractor tyne applications). Data are the means of four replicates per treatment.

Treatment	2003	2004
Control	32	380
Telone C35 (500 kg per ha)	46	402
Chloropicrin (500 kg per ha)		418
Methyl bromide + chloropicrin (50:50) (500 kg per ha)	40	
Methyl bromide + chloropicrin (70:30) (500 kg per ha)		404
Metham sodium (300 L per ha)		384
Metham sodium (500 L per ha)	35	368
Metham potassium (200 L per ha)	35	
Metham potassium (500 L per ha)	35	
Metham potassium (650 L per ha)		
LSD ($P = 0.05$)	3	17

Table 3. The effect of soil fumigation on the percentage of 'Gaviotta' strawberry plants dying at Bli Bli on the Sunshine Coast from 2003 to 2005 (tractor tyne applications). Data are the means (with angular transformations) of four replicates per treatment.

Treatment	2003	2004	2005
Control	7	1	11
Telone C35 (500 kg per ha)	3	0	4
Chloropicrin (500 kg per ha)		0	
Methyl bromide + chloropicrin (50:50) (500 kg per ha)	2		
Methyl bromide + chloropicrin (70:30) (500 kg per ha)		1	
Metham sodium (300 L per ha)		1	
Metham sodium (500 L per ha)	10	1	
Metham potassium (200 L per ha)	8		
Metham potassium (500 L per ha)	9		8
Metham potassium (650 L per ha)			7
LSD ($P = 0.05$)	4	1	3

Table 4. The effect of soil fumigation on the yield of 'Jewel' strawberries (g per plant) growing at Nambour on the Sunshine Coast in 2002 (trickle irrigation applications). Data are the means of four replicates per treatment.

Treatment	30 September	7 October	14 October
Control	48	59	78
Telone C35 gas (450 kg per ha)	56	64	86
Telone C35 EC (450 kg per ha)	63	83	112
Telone C35 EC (650 kg per ha)	71	94	129
Metham potassium (600 L per ha)	52	62	83
Metham sodium (600 L per ha)	59	69	91
LSD ($P = 0.05$)	13	14	20

Table 5. The effects of soil fumigation on weed infestation, and the growth of 'Camarosa' strawberry mother plants and runners at Toolangi in 2001/02 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The runners from the various treatments were later grown at Nambour using the same fumigants in the fruiting beds.

Treatment	No. of weeds per m²	No. of stolons per plant	No. of leaves per plant	No. of runners per m
Control	942	0.6	4.4	6
Chloropicrin	104	1.9	6.8	104
Methyl bromide + chloropicrin	98	1.7	6.4	119
Telone C35	31	2.3	7.0	125
LSD (P = 0.05)	243	0.6	0.4	41

Table 6. The effects of soil fumigation on cumulative yield and mean fruit weight of 'Camarosa' strawberries at Nambour in 2001/02 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The treatments had no significant (P > 0.05) effect on average fruit weight on 12 August and 9 September. The runners for this experiment were produced at Toolangi, using the same fumigants in the runner beds.

Treatment	Yield (g per plant)			Average fruit f. wt (g)
	15 July	12 August	9 September	on 15 July
Control	14	71	172	17.8
Telone C35	24	102	201	17.3
Chloropicrin	28	105	218	18.8
Methyl bromide + chloropicrin	20	102	199	20.5
LSD (P = 0.05)	8	25	n.s.	2.0

Table 7. The effects of soil fumigation on the growth of 'Camarosa' strawberries at Nambour in 2002/03 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The runners for this experiment were produced at Toolangi using the same fumigants in the runner beds.

Treatment	No. of leaves per plant		Diameter of plant (mm)
	4 June	2 July	on 2 July
Control	3.0	4.1	238
Telone C35	3.7	6.6	249
Chloropicrin	3.7	6.4	263
Methyl bromide + chloropicrin	3.6	6.4	257
LSD (P = 0.05)	0.4	0.4	12

Table 8. The effects of soil fumigation on cumulative yield and average fruit weight of 'Camarosa' strawberries at Nambour in 2002/03 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The runners for this experiment were produced at Toolangi using the same fumigants in the runner beds.

Treatment	7 July	4 August	1 September	15 September
		Yield (g per plant)		
Control	23	107	203	252
Telone C35	53	157	285	389
Chloropicrin	51	179	339	480
Methyl bromide + chloropicrin	61	155	297	415
LSD ($P = 0.05$)	18	34	56	67
		Average fruit weight (g)		
Control	15.6	14.1	15.8	15.6
Telone C35	18.3	17.6	19.2	19.4
Chloropicrin	16.6	18.1	21.0	20.6
Methyl bromide + chloropicrin	15.7	16.0	19.1	19.4
LSD ($P = 0.05$)	n.s.	1.9	1.3	1.5

Table 9. The effect of soil fumigation on the growth of 'Camarosa' strawberry plants at Nambour in 2002/03 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The runners for this experiment were produced at Toolangi using the same fumigants in the runner beds.

Treatment	Diameter of plant (mm) on 11 July	Plant d. wt. (g) on 19 August
Control	192	108
Telone C35	278	134
Chloropicrin	267	179
Methyl bromide + chloropicrin	267	139
LSD ($P = 0.05$)	61	24

Table 10. The effects of soil fumigation on weed infestation and on the growth of 'Gaviota' strawberry mother plants and runners at Toolangi in 2003/04 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The runners from the various treatments were later grown at Nambour using the same fumigants used in the runner beds.

Treatment	No. of weeds per m²	No. of stolons per plant	No. of leaves per plant	No. of runners per m
Control	103	0.6	5.7	18
Chloropicrin	13	1.4	6.0	52
Methyl bromide + chloropicrin	7	1.5	6.2	44
Telone C35	8	1.1	5.8	49
LSD ($P = 0.05$)	47	n.s.	n.s.	14

Table 11. The effect of soil fumigation on the number of weeds growing in 'Gaviota' strawberry plots at Nambour in 2003/04 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The fumigants had no significant effect on the emergence of nutgrass specimens on 26 June or 2 August. The runners for this experiment were produced at Toolangi using the same fumigants in the runner beds.

Treatment	Broad leaf weeds			Nutgrass		
	5 May	26 June	2 August	5 May	26 June	2 August
Control	11	2	1	8	2	2
Chloropicrin	8	3	2	2	2	1
Methyl bromide+ chloropicrin	8	1	3	2	1	2
Telone C35	5	8	6	1	3	3
LSD (P =0. 05)	n.s.	3	3	5	n.s.	n.s.

Table 12. The effects of soil fumigation on cumulative yield and average fruit weight of 'Gaviota' strawberries grown at Nambour in 2003/04 (runner and fruit farm fumigation). Data are the means of five replicates per treatment. The runners for this experiment were produced at Toolangi using the same fumigants in the runner beds.

Treatment	2 August	30 August	27 September
	Yield (g per plant)		
Control	80	145	281
Chloropicrin	113	226	394
Methyl bromide + chloropicrin	97	186	345
Telone C35	112	236	446
LSD (P = 0.05)	14	37	65
	Average fruit weight (g)		
Control	13.4	15.1	15.4
Chloropicrin	15.4	18.9	17.5
Methyl bromide + chloropicrin	14.4	17.5	17.2
Telone C35	15.7	19.4	18.5
LSD (P = 0.05)	0.8	1.8	1.4

An evaluation of methyl iodide for fumigating strawberry fields

Don Hutton and Apollo Gomez

Commercial summary

Methyl bromide is the standard fumigant used to control soil-borne diseases, weeds and nematodes in strawberry fields in Australia, but has to be replaced by new chemicals and technologies that are less harmful to the earth's ozone layer. We examined the effects of the related chemical, methyl iodide, on runner and fruit production in strawberries grown in southern Queensland. The performance of methyl iodide plus chloropicrin was assessed along with Telone C35, and methyl bromide plus chloropicrin. In experiments on the Sunshine Coast, methyl iodide was as effective as methyl bromide in terms of weed control and fruit yield. Methyl iodide was also as good as Telone C35 for controlling losses of strawberry plants due to Fusarium wilt. On the runner farms at Stanthorpe, methyl iodide matched the performance of methyl bromide in terms of weed control and nursery runner production. The results of the research reported here and those of earlier experiments indicate that Telone C35 and methyl iodide provide the best options for replacing methyl bromide used in strawberry production.

Introduction

Methyl bromide is the standard fumigant used to control soil-borne diseases, weeds and nematodes in strawberry fields in Australia (Hutton *et al*., 2001). However, this chemical will soon be unavailable because it depletes the concentration of ozone (O_3) in the earth's atmosphere, which protects life on the earth's surface from harmful ultraviolet (UV) radiation. Research conducted in Victoria and in southern Queensland indicates that Telone C35 can match the performance of methyl bromide under most circumstances (Porter *et al*., 1998, 1999; Hutton *et al*., 2001). Here, we report on the effectiveness of methyl iodide, a chemical related to methyl bromide, and its possible role in commercial strawberry production.

Research was conducted to compare the effectiveness of methyl iodide with that of Telone C35 and methyl bromide plus chloropicrin. The first experiments were conducted on the Sunshine Coast, with information collected on weed infestations in the strawberry fields along with data on plant health and yield. In the second series of experiments, the same chemicals were compared for their impact on runner production at Stanthorpe (see below).

Materials and methods

A comparison of different fumigants on fruit farms

Two experiments were conducted at Nambour on the Sunshine Coast to examine the effectiveness of methyl iodide as a potential fumigant for the strawberry industry in Australia. The trial site was infested with nutgrass (*Cyperus rotundus*) and *Fusarium oxysporum* f. sp. *fragariae*s.

In year 1, treatments were: nonfumigated control; methyl bromide plus chloropicrin (98:2) at 500 kg per ha shank injected, or at 1000 kg per ha injected as hot gas; methyl iodide as hot gas at 1000 kg per ha; and methyl iodide plus chloropicrin (30:70) at 500 kg per ha shank injected. The fumigants were applied on the 14 April, and 'Rubygem' strawberry runners planted on 19 May 2004, four weeks after the holes for the plants were cut in the plastic mulch.

In year 2, treatments were: nonfumigated control; Telone C35 at 500 kg per ha; methyl bromide plus chloropicrin (50:50) at 500 kg per ha; and methyl iodide plus chloropicrin (30:70) at 350 or 500 kg per ha. The fumigants were shank injected on 19 April 2005, and the holes for the plants cut a week later. Runners of the cultivar Jewel were planted on 24 May.

The experiments were laid out in randomised blocks, with four replicates per treatment and 20 plants per plot. Data were collected on the number of nutgrass plants and broad-leafed weeds growing in each plot, fruit yield, and the number of plants dying or wilting in each plot. The data were analysed by one-way analysis of

variance (5 treatments x 4 blocks), with each year analysed separately. The number of plants wilting or dying was subjected to angular transformation before analysis.

Successful germination of lettuce seed in soil from the experimental plots indicated no phytotoxicity due to the fumigants prior to planting of the strawberry runners (data not presented).

A comparison of different fumigants on runner farms

Two experiments were conducted at Stanthorpe in southern Queensland to compare the performance of methyl iodide and other fumigants on weed infestations, and on the growth of strawberry plants in the runner beds, with the experiments conducted on new ground each year. Plots were 2.3 m wide and 30 or 100 m long.

The treatments were: Telone C35 at 500 kg per ha; methyl bromide plus chloropicrin (70:30 in year 1 and 50:50 in year 2) at 500 kg per ha; and methyl iodide plus chloropicrin (30:70) at 350 or 500 kg per ha. The fumigants were applied on 21 September 2004 and on 14 October 2005.

In year 1, the relative toxicity of the chemicals to plant growth was assessed by recording the germination of lettuce seeds in samples from the fumigated plots collected at soil depth of 20 cm on 29 September and at 15 cm on 6 and 27 October (8, 15 and 36 days after fumigation). The germination of the lettuce seeds was assessed a week later using the technique described by Shanks (2003). A similar test was conducted in year 2, with soil samples collected from 5 to 10 cm and from 15 to 20 cm on 9 November, 26 days after fumigation. The number of weeds growing in each fumigated plot and in plots outside the fumigated area along the irrigation mains were recorded, along with the number of stolons per mother plant (n = 20 plants per plot).

The experiments were laid out in randomised blocks, with four replicates per treatment. Data were analysed by one-way analysis of variance (4 treatments x 4 blocks), with each year analysed separately.

Results and discussion

Fruit farms

Experiment 1. All the fumigants controlled nutgrass to a similar degree compared with the population in the control plots (Table 1). There were no differences between the hot gas and shank treatments even though the rates for hot gas were double those for the shank application. The control of broadleaf weeds followed a similar response, with the fumigated plots all better than the non-fumigated plots (Table 1). The fumigant plots were similar in terms of fruit production, and all were better than the control plots (Table 2). Fumigated plots also had fewer strawberry plants wilting or dying (1 to 4 plants per plot) than the non-fumigated plots (17 plants per plot) (LSD P = 0.05, 10).

Experiment 2. Fumigated plots had fewer nutgrass specimens than nonfumigated plots (Table 3). Overall, methyl bromide plus chloropicrin or methyl iodide plus chloropicrin at 500 kg per ha gave the best control. Fumigation also controlled the broad-leafed weeds compared with the populations found in the control plots, with no difference amongst the different chemicals (Table 4).

The plots treated with Telone C35 had higher yields than the control plots at the first harvest, and this treatment, along with methyl bromide plus chloropicrin at 500 kg per ha, and methyl iodide plus chloropicrin at 500 kg per ha had higher yields than the controls at the later harvests (Table 5). All the chemical treatments resulted in improved plant health compared with that in the control plots; methyl bromide plus chloropicrin generally performed better than the other fumigants (Table 6).

These experiments on the fruit farms showed that methyl iodide was as effective as methyl bromide in terms of weed control and fruit yield. Methyl iodide was also as good as Telone C35 for reducing losses of strawberry plants due to Fusarium wilt.

Runner farms

Experiment 1. In the first sample from 20 cm depth eight days after fumigation, soil taken from the plots treated with Telone C35 or treated with the higher rate of methyl iodide plus chloropicrin was more toxic to lettuce seeds than soil taken from the plots treated with methyl bromide plus chloropicrin and the lower rate of methyl iodide plus chloropicrin (Table 7). When the samples were collected 15 days after fumigation, the soil treated with Telone C35 was the least toxic, while there were no differences between the treatments 36 days after fumigation (Table 7).

There were fewer than 3 weeds per m^2 in the plots when they were assessed in October, with no significant ($P > 0.05$) difference between the various chemicals.

Strawberry plants in plots fumigated with Telone C35 had more stolons on 7 January (6 stolons per plant) than the plots fumigated with methyl bromide plus chloropicrin (4 stolons per plant), methyl iodide plus chloropicrin at 350 kg per ha (4 stolons per plant), and methyl iodide + chloropicrin at 500 kg per ha (4 stolons per plant) (LSD P=0.05, 1). In contrast, the later assessments conducted on 18 January (8 to 9 stolons per plant) and 2 February (20 or 21 stolons per plant) indicated similar rates of stolon development on plants in all fumigated plots.

Experiment 2. Lettuce seed germination tests 26 days after fumigation indicated no evidence of phytotoxicity in the treated plots (Table 8).

There were no significant ($P > 0.05$) effects of the fumigants on weed control in the plots (50 m^2) when they were assessed on 9 November (6 to 20 weeds per plot), 28 November (0 or 1 weed per plot) or on 17 January (7 to 32 weeds per plot). In contrast, the plots treated with methyl bromide plus chloropicrin had fewer weeds (7 weeds per plot) on 19 December than the plots treated with the low dose of methyl bromide plus chloropicrin (20 weeds per plot) (LSD $P = 0.05$, 7). There were 115 to 221 weeds per plot detected in the non-fumigated soil adjacent to the fumigated blocks across the four assessments, indicating effective weed control with the chemicals. The majority of the weeds in the plots were broad-leafed species.

The number of stolons per mother plant on 17 January ranged from 38 to 45, with no significant ($P > 0.05$) difference amongst the fumigants (data not presented).

The results of the experiments conducted on the runner farms at Stanthorpe show that methyl iodide can match the performance of methyl bromide in terms of weed control and runner production. The findings of the research reported here, and those of earlier experiments (Hutton *et al*., 2001) indicate that Telone C35 and methyl iodide are the best potential replacements for methyl bromide in strawberry production.

Both chemicals have advantages and disadvantages for strawberry producers. Telone C35 can be toxic to strawberry plants if it is applied too soon before planting the mother plants for runner production, especially in cool, wet weather, while methyl iodide is expensive. The use of virtually impermeable plastic films (VIF) can reduce the dose required to kill weeds and plant diseases by 50% or more, and is one way of making methyl iodide applications more attractive to strawberry producers. However, extra care must be taken in the removal of these plastics after fumigation. The VIFs are more expensive than current low density polyethylene plastics, and add to the cost of the new technology.

Conclusions

The results of the research reported here and those of earlier experiments (Hutton *et al*., 2001), indicate that Telone C35 and methyl iodide are the best potential replacements for methyl bromide in strawberry production.

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Table 1. The effect of fumigants on the number of weeds in 'Rubygem' strawberry plots (cumulative for nut grass) on a fruit farm at Nambour, Sunshine Coast in 2004 (Fruit Experiment No. 1). Data are the means of four replicates per treatment.

Treatment	Nutgrass			Broad-leaved weeds
	25 May	21 June	2 August	2 August
Control	148	170	388	100
Methyl bromide + chloropicrin (98:2) shank injected (500 kg per ha)	4	12	34	6
Methyl bromide + chloropicrin (98:2) hot gas (1000 kg per ha)	10	18	48	5
Methyl iodide as hot gas (1000 kg per ha)	19	33	60	4
Methyl iodide + chloropicrin (30:70) shank injected (500 kg per ha)	48	71	122	17
LSD ($P = 0.05$)	65	66	122	36

Table 2. The effect of fumigants on cumulative yield of 'Rubygem' strawberries (g per plot) on a fruit farm at Nambour, Sunshine Coast in 2004 (Fruit Experiment No. 1). Data are the means of four replicates per treatment, with 20 plants per plot.

Treatment	30 August	20 September	11 October
Control	3834	5549	9194
Methyl bromide + chloropicrin (98:2) shank injected (500 kg per ha)	5390	7711	13539
Methyl bromide + chloropicrin (98:2) hot gas (1000 kg per ha)	4612	6986	11520
Methyl iodide as hot gas (1000 kg per ha)	4613	6906	11584
Methyl iodide + chloropicrin (30:70) shank injected (500 kg per ha)	4978	7148	11702
LSD ($P = 0.05$)	1149	1182	2016

Table 3. The effect of fumigants shank injected, on the cumulative number of nutgrass specimens in 'Jewel' strawberry plots on a fruit farm at Nambour, Sunshine Coast in 2005 (Fruit Experiment No. 2). Data are the means of four replicates per treatment.

Treatment	16 May	6 June	27 June	17 August
Control	522	594	623	649
Telone C35 (500 kg per ha)	129	197	223	255
Methyl bromide + chloropicrin (50:50) (500 kg per ha)	19	41	72	86
Methyl iodide + chloropicrin (30:70) (350 kg per ha)	186	239	264	281
Methyl iodide + chloropicrin (30:70) (500 kg per ha)	47	96	125	157
LSD ($P = 0.05$)	122	147	150	155

Table 4. The effect of fumigants shank injected, on the number of broadleaf weeds in 'Jewel' strawberry plots on a fruit farm at Nambour, Sunshine Coast in 2005 (Fruit Experiment No. 2). Data are the means of four replicates per treatment.

Treatment	17 August	16 September	Total to 16 September
Control	86	58	144
Telone C35 (500 kg per ha)	6	3	9
Methyl bromide + chloropicrin (50:50) (500 kg per ha)	8	7	15
Methyl iodide + chloropicrin (30:70) (350 kg per ha)	25	12	37
Methyl iodide + chloropicrin (30:70) (500 kg per ha)	4	1	5
LSD ($P = 0.05$)	25	24	47

Table 5. The effect of fumigants shank injected, on cumulative yield of 'Jewel' strawberry (g per plot) on a fruit farm at Nambour, Sunshine Coast in 2005 (Fruit Experiment No. 2). Data are the means of four replicates per treatment, with 20 plants per plot.

Treatment	15 Aug.	5 Sept.	26 Sept.	17 Oct.
Control	819	1457	2043	2314
Telone C35 (500 kg per ha)	1672	3065	4070	4426
Methyl bromide + chloropicrin (50:50) (500 kg per ha)	1288	2835	4086	4618
Methyl iodide + chloropicrin (30:70) (350 kg per ha)	1102	2070	2952	3433
Methyl iodide + chloropicrin (30:70) (500 kg per ha)	1323	2544	3620	4131
LSD ($P = 0.05$)	536	927	1286	1317

Table 6. The effect of fumigants shank injected, on the number of 'Jewel' strawberry plants wilting or dying in plots on a fruit farm at Nambour, Sunshine Coast in 2005 (Fruit Experiment No. 2). Data are the means (angular transformations) of four replicates per treatment.

Treatment	27 Sept.	31 Oct.	18 Nov.
Control	40	60	66
Telone C35 (500 kg per ha)	20	34	41
Methyl bromide + chloropicrin (50:50) (500 kg per ha)	6	11	16
Methyl iodide + chloropicrin (30:70) (350 kg per ha)	23	37	43
Methyl iodide + chloropicrin (30:70) (500 kg per ha)	12	23	29
LSD ($P = 0.05$)	12	13	14

Table 7. The toxicity of different fumigants used for strawberry production as assessed by the germination of lettuce seeds. The tests were conducted 8, 15 and 36 days after fumigation of the strawberry plots on the runner farm at Stanthorpe (Runner Experiment No. 1). Data are the means of four replicates per treatment, and are presented as the percentage of seeds germinating.

Treatment	At 20 cm on 29 September	At 15 cm on 6 October	At 15 cm on 20 October
Telone C35 (500 kg per ha)	16	39	15
Methyl bromide + chloropicrin (500 kg per ha)	45	33	14
Methyl iodide + chloropicrin (350 kg per ha)	33	28	14
Methyl iodide + chloropicrin (500 kg per ha)	18	33	21
LSD ($P = 0.05$)	7	6	n.s.
Non-fumigated		44	30

Table 8. The toxicity of different fumigants used for strawberry production as assessed by the germination of lettuce seeds. The tests were conducted 26 days after fumigation of the strawberry plots on the runner farm at Stanthorpe (Runner Experiment No. 2). Data are the means of four replicates per treatment and are presented as the percentage of seeds germinating.

Treatment	5-10 cm	15-20 cm
Telone C35 (500 kg per ha)	57	54
Methyl bromide + chloropicrin (500 kg per ha)	54	43
Methyl iodide + chloropicrin (350 kg per ha)	43	49
Methyl iodide + chloropicrin (500 kg per ha)	49	46
LSD ($P = 0.05$)	8	8
Non-fumigated	29	28

Suitable plant back times for soil fumigants

Don Hutton and Apollo Gomez

Commercial summary

Chemicals such as methyl bromide, chloropicrin and Telone C35 can be toxic to strawberry plants if applied too close to planting. This can be a problem in strawberry fields in Victoria and in runner fields in southern Queensland if it is cool and wet following the application of the fumigants. In contrast, the risk of toxicity is less on the Sunshine Coast where cool, wet weather is unlikely following fumigation. We investigated the toxicity of Telone C35 and other fumigants to strawberry plants growing on the Sunshine Coast. The fumigants were applied to the fields in April, and runners planted 14 to 42 days later. The fumigants were applied later than normal commercial practice, which is usually application of the chemicals in January or February in southern Queensland. The research demonstrated that Telone C35, the potential replacement for methyl bromide, can be safely applied to fields on the Sunshine Coast in April, two weeks before planting. Under normal management practices, this chemical should be quite safe for fruit production in coastal southern Queensland, particularly when the directions for use on the label are followed (planting six weeks after fumigation).

Introduction

In Victoria, cool, wet weather is often experienced during the strawberry planting period in May each year. Such conditions reduce the rate of breakdown of the fumigant Telone C35 in the soil. This can lead to high concentrations of the chemical in the beds, which can be harmful to the newly sown strawberry plants, and resulted in Mattner (2002) suggesting that Telone C35 should be applied at least six weeks before planting in such geographic areas. In contrast, the risk of toxicity to the plants is lower if fumigation is carried out during warm, dry weather. Overall, the risk to the strawberry plants is greater in southern Victoria and in the runner-growing area near Stanthorpe in southern Queensland than in fruiting fields on the Sunshine Coast.

We report on the toxicity of Telone C35 and other fumigants to strawberry plants growing on the Sunshine Coast. The fumigants were applied to the fields in April, and runners planted 14 to 42 days later. The fumigants were applied later than is normal commercial practice for southern Queensland, which is usually in January or February.

Materials and methods

Two experiments were conducted at Nambour on the Sunshine Coast to evaluate the susceptibility of strawberry plants to different soil fumigants. In the first experiment, Telone C35 was applied in April, runners planted at various times after fumigation, and the number of plants dead or dying determined after a few months. In the second

experiment, different fumigants were applied in April or May, runners planted after a few weeks, and the plots assessed for live and dead plants.

In year 1, the treatments were: non-fumigated control plots, planted on 28 April 2004; plots fumigated with Telone C35 at 500 kg per ha on 14 April, with the runners planted 14, 21, 28 or 42 days later (seven days after the holes for the plants were cut in the plastic). This was equivalent to planting dates of 28 April, and 5, 12 and 26 May.

In year 2, the treatments were: non-fumigated controls, or plots fumigated with Telone C35 at 500 kg per ha on 19 April, with the runners planted on 24 May 2005 in both treatments; non-fumigated control, or fumigated with Telone C35 at 500 kg per ha (on 19 April), methyl bromide plus chloropicrin (50:50) at 500 kg per ha (on 19 April), or metham potassium at 600 L per ha (on 26 April), with runners planted on 7 June. Thus in this experiment, the first Telone C35 plots were planted 35 days after fumigation, and the second Telone C35 plots were planted 49 days after fumigation. The methyl bromide plus chloropicrin plots were planted 38 days after fumigation, and the metham potassium plots were planted 31 days after fumigation.

The cultivars Earlibrite (2004) and Jewel (2005) were planted 40 cm apart in the row in these experiments.

In year 1, the relative toxicity of the chemicals to plant growth was assessed by recording the germination of lettuce seeds placed in fumigated soil samples collected at 10 and 20 cm soil depths on 30 April and 6 May (16 and 22 days after fumigation). The average length of lettuce seed hypocotyls was assessed one week later using the technique of Shanks (2003) (see below). The number of plants that had wilted or died in each plot was also recorded on the 24 of November.

In year 2, the number of weeds growing in each plot was recorded on 17 August, and the number of plants that had wilted or died in each plot was recorded on 28 September. The experiments were laid out in randomised blocks, with four replicates per treatment. Data were analysed by one-way analysis of variance (5 or 6 treatments x 4 blocks), with each year analysed separately.

Results and discussion

Experiment in year 1. There was no evidence of phytotoxicity when the lettuce seeds were germinated in the fumigated soil samples, with the length of the lettuce hypocotyls ranging from 20 to 50 mm across the different treatments. The percentage of plants dying ranged from 1 to 7% in the fumigated plots compared with 2% in the non-fumigated plots (LSD $P = 0.05$, 4). There was no clear relationship between plant deaths and the time between planting and fumigation. This was probably due to variability across the experimental area in the distribution of *Fusarium oxysporum* in the soil. There was no evidence of toxicity to strawberry plants arising from runners planted two weeks after fumigation with Telone C35, and a week after the holes were cut in the plastic.

Experiment in year 2. All the fumigated plots had fewer weeds on 17 August than the comparative control plots, with 47 weeds per control plot and 6 weeds per Telone C35 plot planted on 24 May. For the second series of treatments planted on 7 June, there were 25 weeds per control plot, 6 weeds per Telone C35 plot, 3 weeds per methyl bromide plus chloropicrin plot, and 14 weeds per metham sodium plot (LSD $P = 0.05$, 15). The effectiveness of the chemicals in controlling weed infestation was clearly demonstrated.

All the fumigants (except metham sodium) reduced plant losses compared with the level observed in the relevant control plot when the blocks were assessed on 28 September. Twenty-seven percent of the plants wilted or died in the control plots compared with twelve percent in the Telone C35 plots planted on 24 May. For the second planting, control plots suffered 25% losses, Telone C35 plots 11% losses, methyl bromide plus chloropicrin plots 4% losses, and metham sodium plots 12% losses (LSD $P = 0.05$, 14). These results suggest that none of the fumigants was toxic to the strawberry plants when applied six weeks before the runners were sown.

Conclusions

As expected, these results are at variance with experience in Victoria and Stanthorpe, where fruit and runner production can be inhibited by Telone C35 under cool, wet conditions. Telone C35 should be quite safe when used on fruit fields in coastal southern Queensland if directions for use on the label are followed (planting six weeks after application). Strawberry producers are encouraged to complete fumigation operations as early as possible after the removal of the previous crop, allowing sufficient time for chemical residues to dissipate before planting. However, the research demonstrated that Telone C35, the potential replacement for methyl bromide, can be safely applied to strawberry fields on the Sunshine Coast in April, up to two weeks before planting, if circumstances dictate that timetable.

Reference

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The use of solarisation to control soil-borne diseases and weeds

Don Hutton and Apollo Gomez

Commercial summary

Soil solarisation has the potential to improve strawberry production in the absence of methyl bromide fumigation, which normally controls nematodes, weeds and soil-borne diseases. We compared the effects of different coloured plastics on the performance of strawberries growing at Nambour on the Sunshine Coast over four years. In the first three experiments, the growth and yield of plants grown on soil that had been covered by hessian or black, silver or clear plastic over summer were compared with that of plants from plots treated with the soil fumigant, Telone C35. In the fourth year we compared black and silver plastic with and without metham potassium fumigation, along with Telone C35. Soil solarisation with silver plastic generally reduced weed growth and the incidence of plant diseases, and increased plant growth and yield compared with untreated plots, with the best response recorded after three consecutive years of solarisation. In contrast, soil solarisation with clear or black plastic was less effective. Solarisation using plastic films must be repeated over several years if it is to match the performance of commercial fumigants.

Introduction

Soil solarisation has the potential to improve the health and yield of strawberry plants in the absence of methyl bromide fumigation, which normally controls nematodes, weeds and soil-borne diseases (Hartz *et al.*, 1993; Katan, 1984, 1981; Ristaino *et al.*, 1991, 1996; Stapleton, 1994). Maximum soil temperatures in summer in southern Queensland can be as high as 61^{o}C at 5 cm depth under clear plastic, and 56^{o}C at 20 cm, with maximum air temperatures (shaded) about 32^{o}C (Hutton *et al*., 2001). Equivalent maximum temperatures under silver plastic are 43^{o}C and 38^{o}C. These high temperatures can be lethal to many weed seeds, and the spores and resting bodies of soil-borne diseases.

Solarisation has improved the health and yield of several crops, including strawberry, tomato, capsicum, eggplant and lettuce compared with non-solarised plots (Gamliel and Stapleton, 1993; Hartz *et al.*, 1993; Ristaino *et al.*, 1991). The benefits of a single period of solarisation often extend over several seasons (Afek *et al.*, 1991). The effectiveness of solarisation is related to the number of hours of intense sunlight during the treatment, since it is sunlight that warms the soil under the plastic.

The type of plastic used and how well it is laid can influence the response to soil solarisation. Chase and Sinclair (1997) showed that over summer, clear, UV-bubble and thermal infrared-absorbing (IR) polyethylene films gave higher soil temperatures than when black plastic was used. Temperatures regularly rose above 50°C, and occasionally above 60°C under the first three films, but never above 50°C under black

film. The higher temperatures killed all annual weeds, along with the shoots of *Cyperus* spp., nut sedges. In contrast, solarisation in winter was ineffective.

Montealegre *et al.* (1997) reported complete control of *Fusarium oxysporum* f. sp. *fragariae* at soil depths of 10, 20 and 30 cm 40 days after fumigation with methyl bromide plus chloropicrin compared with untreated plots. Control after 40 days of solarisation was 79, 68 and 63% at the same depths. The maximum temperatures of the solarised soils were 46^{o}C, 38^{o}C and 35^{o}C, respectively. Sugimora *et al*. (2001) showed that when *Fusarium* infested soil was heated to 40^{o}C for seven days or to 45^{o}C for two days, the population of the fungus decreased by 100 fold, with few plants succumbing to the disease. Kodama and Fukui (1982) reported maximum temperatures under plastic mulch were 45^{o}C to 47^{o}C and 38^{o}C to 40^{o}C at depths of 5 cm and 20 cm, respectively. *Fusarium* was not detected at 5 cm, while populations at 10 to 15 cm were only 40% of control values. There was less disease in solarised plots than in control plots, especially in mulched fields, in lightly infested soils and after warm summers.

Most of the research conducted on solarisation in horticultural crops has been in the USA, with little work carried out in Australia. There is no published research on the response of strawberry fields to solarisation in Australia. In this report, we compared the effects of different plastics on the performance of strawberries growing at Nambour on the Sunshine Coast over four years. In the first three experiments, the growth and yield of plants grown on soil that had been covered with hessian or black, silver or clear plastic over summer were compared with that of plants from plots treated with the soil fumigant, Telone C35. In the fourth year, we compared black and silver plastic with and without metham potassium fumigation, along with the Telone C35 standard.

Materials and methods

The experiments were conducted at Nambour on the Sunshine Coast on a sandy loam soil, with the plants grown in two row beds, 40 cm apart within the rows, and were treated as commercial crops using standard strawberry agronomy (Vock, 1997).

Treatments in years 1, 2 and 3

Treatments in 2002, 2003 and 2004 were: untreated (non-fumigated) control; and black, silver or clear plastic laid in summer (without fumigation). In 2002 and 2003, an additional treatment was added and included plots (no solarisation) fumigated on 26 March and 1 April, respectively with Telone C35 at 500 kg per ha. The control and Telone C35 plots were covered with hessian during summer, and were re-covered with black plastic in autumn when the fumigant was applied (see below).

In the first experiment, the summer plastic was laid on 14 February 2002 and the winter plastic laid on 26 March and runners of 'MRS-022' planted on 16 April. Plants from the first trial were left *in situ* at the end of the strawberry season in October 2002 and the plastic removed the day before the summer plastic was laid on 8 January 2003. The site was prepared for the second solarisation by rotary hoeing the old beds, re-forming them and laying new plastic in one operation. This ensured that

the treated plots were on the same site each year, providing an estimate of their cumulative effects over three years. These operations were repeated between the second and third experiments, with the summer plastic laid on 3 December 2003. The cultivar Jewel was used in 2003 (winter plastic applied on 1 April and runners planted on 14 April) and 2004 (winter plastic applied on 12 March and runners planted on 20 April). The experiment was set out in a randomised block design, with four replications per treatment and 30 plants per plot.

Treatments in year 4

The site was cleared of plants in November 2004, and rotary hoed several times in different directions to facilitate the uniform spread of *Fusarium oxysporum* inoculum which was the main soil-borne disease organism isolated from the site. Treatments were: black or silver plastic laid on 17 December 2004, with and without metham potassium; metham potassium alone; and Telone C35 alone.

Eight beds of each type of plastic were laid on 17 December 2004, and hessian used to cover the subplots to be fumigated. Metham potassium was applied via the trickle tape at 500 L per ha, five days after the beds were formed on 22 December. Three lines of trickle tape were laid in each bed to ensure adequate distribution of the chemical in the rootzone, with regular pulse irrigation ensuring that the beds were moist prior to fumigation.

Telone C35 was applied on 19 April 2005 at 500 kg per ha, and black plastic laid over the top of the bed. All the existing plastic from other treatments was removed and

replaced with black plastic. A week later, holes were cut for all the treatments except the metham potassium alone. The metham potassium alone treatment was applied at this stage on 26 April by pulsing the chemical through the trickle irrigation, and holes for the plants cut a week later. The experiment was set out in a randomised block design, with four replications per treatment and 30 'Jewel' plants per plot planted on 25 May.

Data collection and analyses

Temperature loggers were installed 5 cm and 15 cm into the soil soon after the plastic was laid each year in the first three experiments (see below). The control and Telone C35 plots were covered with hessian during summer, and were re-covered with black plastic in autumn when the fumigant was applied. Data were collected on the number of weed plants in each plot (2003 and 2004), along with the diameter of each strawberry plant in the middle of the season, cumulative fruit yield (only in 2002 for the Telone C35 treatments in the first series) and the number of plants that had died in each plot by the end of the season. Plant diameter was recorded by measuring the plants at right angles to the row direction.

The data were analysed by one-way analysis of variance (5 or 6 treatments x 4 blocks), with each year analysed separately. The percentage of plants dying in each plot was subjected to angular transformation before analysis.

Results

Experiments in years 1, 2 and 3

Soil temperature. Average soil temperatures during the solarisation period were higher under the plastic covered plots than under the control plots, with the relative

order of magnitude within the films being clear plastic > black plastic > silver plastic (Table 1). Maximum soil temperatures at 5 cm were 8^{o}C to 14^{o}C higher under the clear plastic compared with the comparable (exposed, non-shaded) air temperature, whereas minimum soil temperatures at 5 cm were only a few degrees higher. Differences in soil temperature (maxima and minima) between the treatments at 15 cm were less clear.

Yield. Yield data for the standard fumigant were only available for the first experiment, and showed that Telone C35 outperformed all the other treatments, including the control (Table 2). The black plastic treatment resulted in higher yields than the control in 2002; all the plastics higher yields than the control in 2003; and silver and clear plastics higher yields than the control in 2004 (Table 2). In 2004, the yield in the plots with silver plastic was triple the yield of the control plots and double the yield of plants on soil solarised with clear or black plastic.

Plant growth. The plants in the plots fumigated with Telone C35 were larger than those in the control plots in 2002 (Table 3). Plants on soil covered with solarising plastic were similar in size to those in the control plots in 2002 and larger than the controls in 2003. In 2004, there was a mixed response; plants on soil under silver and clear plastic in summer were larger than the controls, and plants under black plastic similar to the controls.

Weeds. Information was collected on weed growth in the plots in 2003 and 2004. In 2003, the fumigated plots, and those under clear plastic over summer were virtually weed free (Table 4). Solarisation with black and silver plastic was also effective, with about a 50% reduction in the counts of weeds compared with the controls. In 2004, only the silver plastic reduced the weed population compared with the control plots.

Mortality. In 2002 and 2003, the standard strawberry fumigant was included as a comparative treatment to indicate how effective soil solarisation controlled soil-borne diseases (yield data also collected in 2002). In these two years, fewer plants died in the plots treated with Telone C35 or covered with silver plastic over summer than in the untreated controls, whereas the black and clear plastic treatments were ineffective (Table 5). The silver plastic was also effective in 2004 (no fumigation in that year).

Experiment in year 4

Plots fumigated with Telone C35 or metham potassium alone had higher yields than the plots under plastic in summer, or under plastic in summer and treated with metham potassium (Table 6). Within the plastic treatments, there was no benefit from fumigation. The higher yields of the Telone C35 and metham potassium alone plots compared with the other treatments were associated with greater plant growth (Table 7). The plots fumigated with metham potassium but not solarised over summer also had fewer plants dying than the other treatments. Information was also collected on the number of plants wilting, and was combined with the data on mortality. The plots treated with just metham potassium were the best in terms of this response (Table 7).

Discussion

Overall, fumigation with Telone C35 or metham potassium gave greater fruit yields than solarisation under plastic, with this response due to fewer plant deaths and more extensive plant canopies. The differences in yields between the plastic treatments were small in the first two years of the first series of experiments, with the silver plastic treatment substantially better than the black or clear plastic treatments after three successive years of solarisation. Once again, higher productivity was associated with more extensive leaf canopies and fewer plant losses.

In the first series of experiments, plots under silver plastic in summer yielded more than the untreated plots in all three years and was as good as Telone C35 in the first year when the standard fumigant was included for comparison of yield data. In contrast, a different response was noted in year four, when the soil in the trial site was mixed across the plots, and presumably weed seeds and spores were introduced into areas that were previously relatively clean. In this experiment, solarisation with silver plastic was not as affective in terms of yield, shoot growth or plant health, as fumigation with Telone C35 or metham potassium. These results suggest that solarisation under silver plastic needs to be carried out over at least three years.

We are not able to explain the better performance of silver plastic over the clear or black films in terms of differences in soil temperature, as the maximum soil temperatures recorded under this plastic were lower than that achieved with the other plastics. Fukaya and Kato (1997) found soil temperatures above 40°C for 152 to 172 days at 15 cm depth reduced the incidence of Verticillium yellows and increased yields in Chinese cabbage. In our trials, the temperature of the soil 5 cm under the silver plastic exceeded these temperatures in summer and was close to 40^{o}C at 15 cm, indicating that temperatures that were possibly lethal to soil-borne diseases were achieved.

Weed control under plastic was inconsistent in the experiments. Most weeds did not germinate on the bed surface. Problems with clear plastic (where we could see the weeds) were more likely to be along the edges of the beds. Many commercial growers use black plastic with slots cut for the insertion of plants rather than holes, which allows minimal entry of light under the plastic, and minimal weed growth. Herbicides such as metalochlor and napropamide may be needed to control weeds if solarisation is adopted by the strawberry industry. Such chemicals have shown promise in controlling weed species in strawberry fields in southern Australia (Mattner *et al*., 2000).

Gullino *et al.* (1998) found solarisation plus half the standard rates of methyl bromide and dazomet improved the control of *Rhizoctonia solani* and *Sclerotinia sclerotiorum*, compared with untreated plots in open field experiments in northern Italy. This response is different to that noted in our experiment, where there was no benefit in yield or the incidence of disease from the application of metham potassium in combination with the black or silver plastic.

Conclusions

Soil solarisation with silver plastic generally reduced weed growth and the incidence of plant diseases, and increased the growth and yield of strawberry crops compared with untreated plots on the Sunshine Coast, with the best response recorded after three consecutive years of solarisation. In contrast, soil solarisation with clear or black plastic was less effective. These results demonstrate that solarisation with plastic films must be carried out on the same site over several years if it is to match the performance of commercial fumigants.

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Table 1. The effects of various plastics used in soil solarisation on mean daily maximum and minimum soil temperatures (^{o}C) in strawberry plots at Nambour on the Sunshine Coast from 2002 to 2004. Figures in parenthesis are minimum soil temperatures. Average (exposed unshaded) air temperatures also shown. Data are the averages recorded during the soil solarisation period. The summer plastic was laid on 14 February 2002, 8 January 2003 and 3 December 2003, and the winter plastic applied on 26 March 2002, 1 April 2003 and 12 March 2004, respectively.

Treatment	2002		2003		2004	
	5 cm	15 cm	5 cm	15 cm	5 cm	15 cm
Control	40.6	43.7	38.1	40.2	43.2	37.7
	(18.4)	(19.1)	(18.1)	(17.0)	(19.8)	(21.3)
Black plastic	45.5	42.4	48.4	40.6	na	42.4
	(18.4)	(18.4)	(17.0)	(15.6)	(na)	(20.6)
Clear plastic	49.9	43.7	54.1	46.9	54.1	44.1
	(18.4)	(19.1)	(17.7)	(18.1)	(19.1)	(18.8)
Silver plastic	44.1	41.1	na	38.9	48.4	40.2
	(20.6)	(18.4)	(na)	(16.3)	(20.9)	(19.8)
Air temperature	38.9		39.4		46.0	
	(15.6)		(14.5)		(14.5)	

Table 2. The effect of soil solarisation and fumigation on cumulative yield of strawberries to mid-August at Nambour on the Sunshine Coast from 2002 to 2004. Data are the means of four replicates per treatment.

Treatment	Yield in 2002 (g per plant)	Yield in 2003 (g per plant)	Yield in 2004 (g per plot)
Control	144	210	4380
Black plastic	184	377	4461
Silver plastic	173	411	14648
Clear plastic	163	434	6268
Telone C 35	216	na	na
LSD (P = 0.05)	35	96	1548

Table 3. The effect of soil solarisation and fumigation on canopy diameter (mm) of strawberry plants at Nambour on the Sunshine Coast from 2002 to 2004. Data are the means of four replicates per treatment.

Treatment	30 July 2002	20 June 2003	9 August 2004
Control	280	225	251
Black plastic	292	254	244
Silver plastic	276	258	346
Clear plastic	289	276	277
Telone C 35	323	na	na
LSD ($P = 0.05$)	17	22	13

Table 4. The effect of soil solarisation and fumigation on the number of weeds growing in strawberry plots at Nambour on the Sunshine Coast in 2003 and 2004. Data are the means of four replicates per treatment.

Treatment	16 June 2003	2 August 2004
Control	81	26
Black plastic	42	33
Silver plastic	32	3
Clear plastic	2	18
Telone C 35	1	na
LSD ($P = 0.05$)	33	19

Table 5. The effect of soil solarisation and fumigation on the percentage of plants dying in strawberry plots at Nambour on the Sunshine Coast from 2002 to 2004. Data are the means of four replicates per treatment. Data for 2004 subjected to angular transformations before analysis.

Treatment	1 November 2002	13 August 2003	28 July 2004
Control	31	38	44
Black plastic	23	30	47
Silver plastic	13	23	6
Clear plastic	26	32	44
Telone C 35	9	19	na
LSD ($P = 0.05$)	15	13	7

Table 6. The effect of soil solarisation and fumigation on the cumulative yield of strawberries (g per plot) at Nambour on the Sunshine Coast in 2005. Data are the means of four replicates per treatment, with 30 plants per plot.

Treatment	15 August	5 September	26 September
Black plastic	1493	2963	4262
Silver plastic	1479	2929	4121
Black plastic with metham potassium	1248	2798	4398
Silver plastic with metham potassium	1345	2634	3815
Metham potassium	2023	4298	6730
Telone C35	2230	4158	6038
LSD ($P = 0.05$)	571	1166	1898

Table 7. The effects of soil solarisation and fumigation on canopy diameter, percentage of plants dying and percentage of plants wilting or dying in strawberry plots at Nambour on the Sunshine Coast in 2005. Data are the means of four replicates per treatment.

Treatment	Canopy diameter (mm)	Percentage of plants dying	Percentage of plants wilting or dying
Black plastic	208	31	40
Silver plastic	213	37	42
Black plastic with metham potassium	199	22	31
Silver plastic with metham potassium	202	24	33
Metham potassium	241	16	28
Telone C35	231	24	32
LSD ($P = 0.05$)	9	8	7

The incidence of Fusarium wilt in Queensland cultivars

Don Hutton and Apollo Gomez

Commercial summary

Strawberry plants grown in southern Queensland are susceptible to Fusarium wilt, which is caused by *Fusarium oxysporum*, with severe losses occurring in some seasons in fields that have not been fumigated. We investigated the relative resistance of a range of cultivars to *F. oxysporum* over three years at Nambour on the Sunshine Coast. In the main experiments, 'Jewel' the comparative cultivar, was extremely susceptible to wilt, 'Kabarla' was moderately susceptible, 'Selva' slightly susceptible, and 'Camarosa', 'Festival', 'Gaviotta' and 'Sugarbaby' less susceptible. In other experiments, cultivars with low susceptibility included 'Rubygem', 'Cal Giant 3', 'Adina', 'Earliblush', 'Majestic', 'Redlands Crimson' and 'Parker'. In contrast, 'Earlisweet' was moderately susceptible. These results suggest that losses due to wilt could be severe in some cultivars in non-fumigated soils. Cultivars with high levels of resistance to Fusarium need to be developed for the strawberry industry.

Introduction

Fusarium wilt caused by *Fusarium oxysporum* F. sp. *fragariae* was first recognised in Queensland in 1962, when it killed numerous strawberry plants in an era well before the use of methyl bromide fumigation (Winks and Williams, 1965) (see below). After the introduction of fumigation in the 1970s, this disease became relatively rare. In recent years, however, the phase-out of methyl bromide worldwide and the accompanying increase in the price of the product and that of possible replacements, has caused strawberry growers to consider alternative management practices. The common practice of replanting into used plastic mulch for two or three successive years has also contributed to the higher incidence of this disease in recent seasons, with several fruit growers on the Sunshine Coast experiencing serious losses.

One way of reducing the losses to wilt is to develop new cultivars that are resistant to or tolerant of the disease. Here we report on the relative performance of a range of commercial strawberry cultivars grown in Australia, planted into a soil infested with the wilt organism. The effect of the disease on each cultivar was assessed in experimental plots at Nambour over three years.

Materials and methods

Experiments were conducted over three years at Nambour on the Sunshine Coast on a sandy loam soil with high concentrations of organic matter and high concentrations of *Fusarium oxysporum.* The runners were planted in beds under black plastic mulch, and were managed as a commercial crop (Vock, 1997).

The main experiment included plantings of seven cultivars each year: 'Camarosa', 'Festival', 'Gaviotta', 'Kabarla', 'Selva', 'Sugarbaby' and 'Jewel' (the comparative

cultivar). Previous research showed that ‘Jewel’ was very susceptible to wilt. Some other cultivars were included for one or two years (see ‘Results’).

Each plant was assessed at the end of the strawberry season and scored for susceptibility to the disease: 0 = plant healthy with erect growth and full vigour; 1 = plant healthy, with a smaller canopy and moderate vigour; 3 = plant with a slight wilt, with the lower leaves affected; 5 = plant with a moderate wilt, with the mature leaves collapsing but young leaves still healthy; 7 = plant with a severe wilt, with most of the plant collapsed and mature leaves desiccated; 9 = plant with a very severe wilt, with the entire plant collapsed and most of plant desiccated; and 10 = plant dead (see below).

The experiments were laid out in randomised blocks, with ten replicates per treatment (test cultivars) and ten plants in each plot. Each test plot also contained ten plants of 'Jewel'. Data for the main six cultivars were analysed by two-way analysis of variance (6 cultivars x 3 years x 10 blocks). Data for the other cultivars are presented as treatment means (across years), with standard errors.

Results

In the main experiment with the six cultivars over three years, 'Jewel', the comparative cultivar, was extremely susceptible to wilt, with scores of 8 to 10 (Table 1). 'Kabarla' was moderately susceptible (scores of 5 to 7), 'Selva' slightly susceptible (scores of 2 to 4), and the other cultivars less susceptible (scores of 0.1 to 2.5).

The mean value for the other cultivars was 1.3 ± 0.2 in 2003, 1.8 ± 0.4 in 2004, and 2.1 ± 0.5 in 2004. Cultivars with low susceptibility included 'Cal Giant 3', 'Adina',

'Earliblush', 'Majestic', 'Redlands Crimson' and 'Parker', with scores below 1. In contrast, 'Earlisweet' had a score of 4.8 and 'Tioga' a score of 5.0. 'Rubygem', a popular cultivar, had a score of 2.4 in 2003 and 1.7 in 2005.

Discussion

Our research showed that most of the commercial cultivars grown in the last few years possessed reasonable resistance or tolerance to *Fusarium oxysporum*. However, "resistant" cultivars such as 'Festival' and 'Gaviotta', which had scores below 2.5 in the present experiments, can suffer up to 5% losses under second year plastic in soils that have been fumigated with methyl bromide and Telone C35. Much higher losses have been observed in 'Kabarla'.

The original record of this disease in Queensland referred to the standard variety of the day, 'Majestic', being affected (Winks and Williams, 1962). In our experiments, this cultivar was not very susceptible, with a score of 0.5. 'Phenomenal', another cultivar of that time was more susceptible, with a rating of 2.7.

There are many examples of crops succumbing to Fusarium wilt or to new races of the disease as shown by data presented for onion, aster, cauliflower, cabbage, banana, cucumber, watermelon, rockmelon, gladiolus, passionfruit, pea, cowpea and ginger (Simmonds, 1966). Management practices such as moving to new ground, enabled flower producers to continue to grow highly valuable crops in southern Queensland in the 1980s. The need to do this was removed with the adoption of methyl bromide fumigation by these industries. Strawberry growers are generally committed to growing strawberries on 100% of their cropping area each year, with few opportunities for crop rotation or fallowing.

Resistance to Fusarium wilt diseases in other plant species that produce seed is readily achieved, especially when a highly resistant parent or wild parent is available. The experience in Queensland with tomatoes shows that it is possible to select for resistance to new races of Fusarium (McGrath and Maltby, 1989). This should be a very achievable goal with strawberries, with our work showing a wide range in resistance to *Fusarium oxysporum*. It is essential in this post-methyl bromide era that strawberry breeders produce cultivars that are resistant to wilt.

Conclusions

There was a range in resistance to Fusarium wilt in strawberry cultivars grown at Nambour over three years. In the main experiment, 'Jewel', the comparative cultivar was extremely susceptible to wilt, 'Kabarla' was moderately susceptible, 'Selva' slightly susceptible, and 'Camarosa', 'Festival', 'Gaviotta' and 'Sugarbaby' less susceptible. In other experiments, cultivars with low susceptibility included 'Rubygem', 'Cal Giant 3', 'Adina', 'Earliblush', 'Majestic', 'Redlands Crimson' and 'Parker'. In contrast, 'Earlisweet' was moderately susceptible. These results suggest that losses due to Fusarium could be severe in some cultivars in non-fumigated soils. Cultivars with high levels of resistance to wilt need to be developed for the strawberry industry.

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Table 1. The susceptibility of strawberry cultivars to Fusarium wilt at Nambour on the Sunshine Coast over three years. Data are the means of ten replicates per cultivar (for the six main cultivars). Each plant was assessed at the end of the strawberry season and scored for susceptibility to the wilt: 0 = plant healthy with erect growth and full vigour; 1 = plant healthy, with a smaller canopy and moderate vigour; 3 = plant with a slight wilt, with the lower leaves affected; 5 = plant with a moderate wilt, with the mature leaves collapsing but young leaves still healthy; 7 = plant with a severe wilt, with most of the plant collapsed and mature leaves desiccated; 9 = plant with a very severe wilt, with the entire plant collapsed and most of plant desiccated; and 10 = plant dead. The LSD is for comparing the six main cultivars. Results for 'Jewel', a highly susceptible cultivar are given for comparative purposes.

Year	Camarosa	Festival	Gaviotta	Kabarla	Selva	Sugarbaby	Jewel
2003	2.3	0.6	0.8	5.1	3.2	0.3	8.2
2004	1.7	2.4	1.8	6.5	2.6	0.1	9.4
2005	1.6	1.1	1.2	6.1	3.9	1.0	8.6
LSD ($P = 0.05$)			0.7				

Technology transfer

Information development by Noel Vock

The timely access to quality information is a key ingredient of profitable strawberry production. From the findings of a farm survey conducted in Queensland in 2004, three important products were identified – a problem-solving field guide; an annual update of R&D; and a handbook for new farmers entering the industry. The first two of these products were developed in 2005, while the new farmer handbook is being further researched to identify the most appropriate format.

Strawberry problem solver and bug identifier field guide

This book is designed to be used in the field, packing shed or farm office to identify the pests, diseases, disorders, and beneficial insects likely to be found in Australian strawberry fields. The book is arranged in four colour-coded sections to help quickly find a particular problem or bug, and contains 198 full colour photographs covering 62 pest, disease, nutritional and other symptoms, 28 pests, and 17 beneficial insects (see below).

Although the main content of the book was derived from the Problem Solver section of the superseded Agrilink strawberry kit designed for Queensland conditions, the contents have been broadened to make the publication relevant to the whole Australian strawberry industry. For this, input was provided from other states by specialists such as Chloe Thomson (Victorian Strawberries), Dr Scott Mattner (Victorian Department of Primary Industries), Lawrence Ullio (NSW Department of Primary Industries) and Dennis Phillips (WA Department of Agriculture).

The book costs $27.00 plus $2.70 GST and is available from DPI&F Nambour (Phone 07 5441 2211; Fax 07 5441 2235). Copies are also available from Chloe Thomson,

IDO of the Victorian Strawberry Growers' Association (Phone 03 9207 5562; Fax 03 9207 5576).

Strawberry R&D Update

The update is designed to keep farmers and other industry members in touch with the latest results from the DPI&F's strawberry team. The update will be produced on an annual basis, with the first edition released in July 2005, and a second edition planned for December 2006.

Strawberry field day in July 2006

A field day was held at Wamuran on 12 July, 2006 with members of DPI&F's strawberry team, and representatives of the Florida industry (Mr Chip Hinton, Florida Strawberry Growers' Association) and researchers from the University of Florida, Drs Craig Chandler and Natalia Peres. The field day was organized and supported by the Queensland Strawberry Growers' Association. Topics discussed included the state of the subtropical industry in Florida, the use of containerized plants, and pest and disease management, including the control of crown rots in runner beds. About 80 growers from the Sunshine Coast attended the field day (see below).

Strawberry field day in July 2005

A field day was held at Maroochy Research Station on 20 July, 2005. Members of the Better Berries Program supported by the local industry, Horticulture Australia and Queensland Department of Primary Industries and Fisheries presented updates on their R&D programs. The Victorian IDO, Chloe Thomson, also presented a review of her work. About 45 growers and industry representatives attended.

The talks contained information on:

- Pest management (update on trials of new chemicals which are compatible with spider mite predators) by Geoff Waite
- Disease management (update on *Colletotrichum* crown rot research; trials of a new fungicide for powdery mildew; the latest in methyl bromide research; and getting a better understanding of lethal yellows disease) by Don Hutton, Geoff Waite and Apollo Gomez
- Containerised plants (update on research evaluation of containerised plants or plugs as an alternative to traditional runners) by Chris Menzel
- Information – (update on the development of better information products for growers) by Noel Vock

The new book, the '*Strawberry problem solver and bug identifier*', was also released at the farm walk. The book is the first of a new suite of information products produced under a partnership between DPI&F, Horticulture Australia Ltd (HAL), Strawberries Australia, Growcom and the Queensland Strawberry Growers' Association.

Berry industry expo in June 2005

Industry representatives and approximately 120 berry growers from four states gathered at The International, Lilydale, near Melbourne for the First Berry Industry Expo and Information Day. Organised by the Victorian Strawberry Industry Development Officer, Chloe Thomson, and the Australian Rubus and Blueberry Industry Development Officer, Alison Brinson, the day was created out of the demand by growers for more information, and the requests of service providers and researchers to transfer information and communicate more effectively with growers. The Expo was free to growers and was run as a relaxed conference, with strawberry-related presentations conducted before lunch, and rubus/blueberry-related ones in the afternoon. Twenty-eight displays of industry-related research, products and services were also featured.

Talks from team members included:

- Disease management (update on Colletotrichum crown rot research; trials of a new fungicide for powdery mildew; the latest in methyl bromide research; and getting a better understanding of lethal yellows disease) by Don Hutton
- Containerised plants (update on research evaluation of containerised plants as an alternative to traditional runners) by Chris Menzel

International Strawberry Symposium in September 2004

The major extension activity for 2004 was the Fifth ISHS International Strawberry Symposium, held at the Hyatt Regency Coolum, Queensland from 5 to 10 September. The symposium was underwritten by the Queensland Strawberry Growers' Association (QSGA) with support from Horticulture Australia Ltd (HAL). It was organised by a QSGA committee chaired by the former Better Berries Program coordinator, Neil Greer. The strawberry project team reported on current research activities. Speakers from Victoria, New South Wales and Western Australia also reported on the results of their projects funded by HAL. Over 80 speakers presented talks and demonstrations, and 120 technical posters were prepared. About 300 delegates attended the meeting. On Thursday 9 September we ran a special program in parallel with the scientific presentations, targeting the needs of commercial strawberry growers to ensure they received maximum benefit from this event. The Proceedings, edited by Geoff Waite, were published in 2006 as *Acta Horticulturae* Volume 708.

Strawberry field day in July 2003

The project team reported on progress to date and planned project activities at the Better Berries Program Strawberry Field Day at Redlands in July 2003. Over 160 growers attended. The event included formal taste testing of the four new subtropical cultivars released, plus two cultivars from Californian and one from Florida, imported by the DPI&F. The Queensland Minister for Primary Industries and Rural Communities Henry Palaszczuk, officially launched the subtropical cultivar, 'Rubygem'. Articles were also published in the QSGA newsletter and Strawberries Australia R&D newsletter.

Strawberry field day in May 2002

The project team reported on progress to date at a Strawberry Seminar held in Wamuran in May 2002. Approximately 160 growers attended. All participants received a copy of the Seminar Proceedings covering project outcomes, recommendations and planned activities. The seminar included a hands-on sap analysis training session for individual producers. Analysis kits were then made available through one of the strawberry industry consultants. A follow-up presentation on cultivar selection, disease management and lethal yellows was made to 60 growers at a QSGA meeting in Beerwah in July 2002.

Strawberry field days in November and December 2001

The project team reported on project activities to a Queensland Strawberry Growers' Association meeting held in Beerwah in November 2001. Approximately 60 growers attended. In December 2001, three members of the team made similar presentations to members of the South Australian Strawberry Growers' Association in Lenswood, where approximately 25 producers attended.

Publications

1. Azam, M.G.N., Walter, D.E., Waite, G.K. and Hargreaves, J.R. (2005). Rainforest habitat resistance to the migration of *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) in south-eastern Queensland. *Australian Journal of Entomology* 44: 52-6.

2. Greer, G.N. (2002). The Better Berries Program - coordinating research, development, extension and information for the Queensland strawberry industry. *Acta Horticulturae* 567: 535-7.

3. Greer, G., Hutton, D., Vock, N. and Waite, G. (2005). *Strawberry problem solver and bug identifier*. Department of Primary Industries and Fisheries, Brisbane, 113 pp.

4. Herrington, M.E. and Chandler, C.K. (2006). Strawberry breeding in a subtropical environment. *Acta Horticulturae* 708: 441-7.

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Key outcomes

Australia produces about 40,000 tonnes of strawberries worth $200 million each year, and the strawberry industry is a significant part of the local horticultural scene. The main production centres are located in Queensland, Victoria and Western Australia, with winter production worth $120 million in South-East Queensland. Key issues identified by the industry and that were addressed in our research conducted mostly in southern Queensland included:

- Do containerized plants have any economic advantage over bare-rooted plants?
- Are large runners more productive than small runners?
- Are runners from southern Australia more productive than those from southern Queensland?
- Can micro-sprinklers be used to establish bare-rooted runners and do they save water compared with traditional impact sprinklers?
- Do strawberry cultivars have different optimum petiole nitrate concentrations?
- Can bifenazate be included in a strategy to control spider mites and is it compatible with predatory mites?
- Can indoxacarb, emamectin and spinosad form part of a strategy to control *Helicoverpa* and *Spodoptera* caterpillars?
- How susceptible are strawberries to Queensland fruit fly, and would bait sprays be acceptable treatments for Queensland fruit shipped south in spring?
- How severe is lethal yellows in strawberry plantings on the Sunshine Coast, and what is the nature of the causal organism, insect vector and alternate host species?
- What is the level of crown rot, *Colletotrichum gloeosporioides* (*Cg*) infection in strawberry nurseries in Australia? Do low levels of infection in the nurseries translate into significant losses in fruiting fields in southern Queensland? Is the causal organism likely to become resistant to prochloraz, the fungicide currently used in strawberry nurseries to control the disease, and are there other fungicides that could be used in rotation with prochloraz to reduce the likelihood of resistance developing?
- What are the best fungicides to control the major fruit diseases, black spot (*Colletotrichum acutatum*), grey mould (*Botrytis cinerea*), and powdery mildew (*Sphaerotheca macularis*)?
- What are the best chemicals to replace methyl bromide used for the fumigation of strawberry fields in Australia? How soon can strawberry runners be planted after soil fumigation? Can soil solarisation be used to control weeds and soil-borne diseases? How susceptible is the present strawberry gene pool to soil-borne diseases such as Fusarium wilt?

Outcomes

The productivity of strawberries propagated as plugs in small 75 cm^3 containers, and runners was investigated over two years at Nambour on the Sunshine Coast. The plugs weighed only 20% of the weight of the runners at planting, and yielded 15 to 40% less, suggesting that plug plants grown in small containers offer no economic

advantage to commercial growers. Plug plants in large 125 cm^3 containers yielded 24% more than small runners and 17% more than large runners, while runners from Stanthorpe yielded 15% more than the runners from Toolangi. These results suggest that plug plants in large containers can have similar or greater yields than bare-rooted plants, while bare-rooted planting material from Toolangi may not always have an advantage in terms of overall cropping. Further research needs to be conducted to determine the relative performance of plugs and runners, especially a comparison of the two plant types at different planting times in southern Queensland. The relationship between yield and chilling during runner production also needs to be determined in this environment.

Traditionally, strawberry growers have relied on high output impact sprinklers for plant establishment, maintenance irrigation and frost protection. Research conducted on the Sunshine Coast showed that micro-sprinklers can potentially save up to 80% of the water used during establishment compared with knockers, when they are used with correct water pressure. Reducing plant establishment water use by 80% would save 30% of the total crop water use or 1.8 ML per ha. It is recommended that micro-sprinklers be installed in new plantings.

Assessment of petiole nitrate concentrations can be used to determine the nitrogen requirements of different strawberry cultivars. This technology can reduce the amount of nutrients applied to strawberry fields, with savings in fertilizer costs, and leaching and run-off of applied nutrients into water-ways and estuaries.

Two-spotted spider mite (*Tetranychus urticae*) is the major pest of strawberries in Queensland, but it is readily controlled by the Chilean predatory mite (*Phytoseiulus persimilis*). Bifenazate provided excellent control of spider mites and is compatible with the predatory mite, so that it can be used to correct an imbalance between pest and predator if necessary. Registration of this miticide is recommended to assist growers to manage miticide resistance in their crops.

Helicoverpa and other caterpillars infest strawberries in Queensland and other states. The caterpillars attack the leaves, flowers and the plant crown as well as the fruit. Indoxacarb, emamectin and spinosad controlled all species of caterpillar with no adverse effect on predatory mites. These chemicals are also less toxic to humans and the environment than the chemicals currently registered for this purpose. Spinosad has been registered for use in strawberries. The other two chemicals should also be registered.

Although laboratory studies indicated that strawberries are an excellent host for Queensland fruit fly (*Bactrocera tryoni*), the pest represents a minor issue in ground-grown strawberries on the Sunshine Coast. Bait sprays should be registered as acceptable treatments for Queensland fruit shipped to southern states after 20 September.

Depending on the season, 1 to 4% of runners supplied by Stanthorpe nurseries were infected with strawberry lethal yellows (SLY). The disease is associated with the phytoplasmas, *Candidatus* Phytoplasma australiense and tomato big bud, and a rickettsia-like-organism (RLO). *Ca*. P. australiense is also associated with strawberry green petal (SGP). Several other plant species in South-East Queensland tested

positive for the phytoplasma, although their role as sources of the disease organisms has not been elucidated. SLY is probably transmitted by a planthopper, most likely *Orosius argentatus*, which is distributed throughout south-east Australia. Continuing research into the etiology of this disease is required in order to develop an effective management strategy.

One of the major diseases affecting strawberries in Queensland is crown rot caused by *Colletotrichum gloeosporioides* (*Cg*). There was generally a very low level of infection in the strawberry nurseries, with an average of only 0.06% of symptomless petioles testing positive for the presence of *Cg* over five years. Visual symptoms of crown rot, including lesions on the petioles and stolons and wilting plants, were relatively rare in the nurseries, with plant losses ranging from 0 to 0.5%. Losses on fruit farms were highly variable (up to 20%), but generally low and less than 0.1%. There was no evidence of resistance to prochloraz. A fungicide based on cyprodininil plus fludioxinil offers promise for inclusion in a resistance management program with prochloraz.

Black spot (*Colletotrichum acutatum*), grey mould (*Botrytis cinerea*), and powdery mildew (*Sphaerotheca macularis*) are the most important fruit diseases affecting strawberries in southern Queensland. A strategy based on applications of tolylfluanid with trifloxystrobin gave the best control of powdery mildew and grey mould, and the best yields. This work contributed to a national registration for trifloxystrobin for the control of powdery mildew in strawberries.

There is a range in the level of resistance in strawberry cultivars to wilt diseases caused by *Fusarium oxysporum*, with severe losses suffered by some cultivars in non-fumigated soils. Cultivars with high levels of resistance to Fusarium wilt need to be developed for the strawberry industry.

Strawberry fields in southern Queensland are affected by a range of soil-borne diseases and weeds that have been traditionally controlled by fumigation with methyl bromide. Telone C35, chloropicrin and methyl iodide could replace methyl bromide. In contrast, metham potassium and metham sodium were less effective and would not be suitable replacements. Telone C35 should be quite safe for fruit production in coastal southern Queensland (no toxicity after planting two weeks after fumigation), particularly when the directions for use on the label are followed (planting six weeks after fumigation).

Soil solarisation has the potential to improve strawberry production in the absence of methyl bromide. Soil solarisation with silver plastic generally reduced weed growth and the incidence of plant diseases, and increased plant growth and yield compared with untreated plots, with the best response recorded after three consecutive years of solarisation. In contrast, soil solarisation with clear or black plastic was less effective. Because the effect is cumulative, solarisation using plastic films must be repeated over several successive years if it is to match the performance of commercial fumigants.

Two new information products were developed during the project. ‘The strawberry problem solver and bug identifier’ field guide is designed to be used in the field, packing shed or farm office to identify the pests, diseases, disorders, and beneficial insects likely to be found in Australian strawberry crops. ‘The strawberry R&D update’ is designed to keep farmers and other industry members in touch with the latest results and findings from our research. These products complemented regular grower field days and seminars held during the project.

Recommendations

1. Containerized plants in small 75 cm^3 cells offer no economic advantage to commercial strawberry growers in southern Queensland. In contrast, the yields of plugs in large 125 cm^3 cells were similar to or higher than those of bare-rooted plants. Research also showed that planting material from Toolangi may not always have an advantage over material from Stanthorpe in terms of overall cropping. Further research needs to be conducted to determine the relative performance of plugs and runners, especially a comparison of the two plant types at different planting times in southern Queensland. The relationship between yield and chilling during runner production also needs to be determined in this environment.

2. Micro-sprinklers offer potential savings of 80% in water use compared with knockers when they are used with the correct water pressure. Reducing plant establishment water use by 80% would save 30% of the total crop water use or 1.8 ML per ha. These micro-sprinklers are recommended for new plantings.

3. Assessment of petiole nitrate concentrations can be used to determine the fertilizer requirements of different strawberry cultivars. This technology can reduce the amount of nutrients applied to strawberry fields, with savings in fertilizer costs and run-off of applied nutrients into water-ways and estuaries, and it should become part of the agronomic management of the strawberry crop.

4. Bifenazate controls spider mites in strawberries and is compatible with predatory mites. Registration of this chemical should proceed as it would assist growers to manage miticide resistance in their fields.

5. Indoxacarb, emamectin and spinosad control caterpillars with little impact on predatory mites, and are less toxic to humans and the environment than currently registered chemicals. Spinosad has been registered for use in strawberries. The other two chemicals should also be registered.

6. Although laboratory studies indicate that strawberries are an excellent host for Queensland fruit fly, and experience is that hydroponically-produced strawberries are quite susceptible, the pest is a minor issue in ground-grown strawberries on the Sunshine Coast (more than 99.9% of the crop). Bait sprays should be registered as acceptable treatments for Queensland fruit shipped south from ground-grown plants after 20 September.

7. Between 1 to 4% of runners supplied by Stanthorpe nurseries were infected with strawberry lethal yellows. Continuing research into the etiology of this disease is required in order to develop an effective management strategy.

8. Infection of fruit farms with crown rot (*Colletotrichum gloeosporioides*) (*Cg*) was highly variable and was associated with low levels of infection or visible symptoms in the nurseries. Further research is required to determine how the

fungus is spread on the nursery and fruit farms. A fungicide product based on cyprodininil plus fludioxinil offers promise for inclusion in a resistance management program with prochloraz, and this should be pursued.

9. A strategy based on applications of tolylfluanid with trifloxystrobin gave the best control of grey mould (*Botrytis cinerea*) and powdery mildew (*Sphaerotheca macularis*). This work contributed to a national registration for trifloxystrobin for the control of powdery mildew in strawberries and its integration into current protection strategies is recommended.

10. There is a range in resistance of strawberry cultivars to wilt diseases such as *Fusarium oxysporum*, with severe losses in some cultivars in non-fumigated soils. Cultivars with high levels of resistance to wilt need to be developed for the strawberry industry.

11. Telone C35, chloropicrin and methyl iodide are the best potential replacements for methyl bromide used for soil fumigation in strawberry runner and fruit production. In contrast, metham potassium and metham sodium were less effective and would not be suitable replacements. Telone C35 should be quite safe for fruit fields in coastal southern Queensland (no toxicity after planting two weeks after fumigation) particularly when the directions for its use on the label are followed (planting six weeks after fumigation). Soil solarisation with silver plastic has the potential to improve strawberry production in the absence of methyl bromide, but probably needs to be repeated over several years if it is to match the performance of commercial fumigants. Growers should experiment with these alternatives on-farm to determine which application suits their particular enterprise.

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