Alternatives to methyl bromide for Queensland strawberry production

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Department of Employment, Economic Development & Innovation

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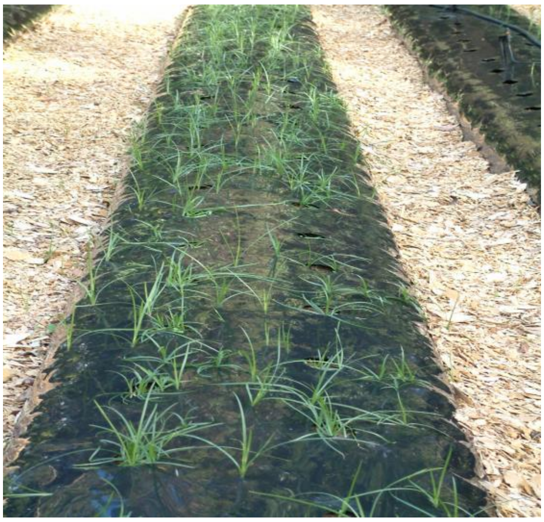
Alternatives to methyl bromide for strawberry production in Queensland



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Horticulture Australia Limited Project BS07017 – Alternatives to methyl bromide for Queensland strawberry production (21January 2010)

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Purpose of Project
The phasing out of methyl bromide as a soil fumigant in 2005 presented a serious challenge to the Australian strawberry industry to find suitable alternative management tools in runner and fruit production areas. Soil fumigants are used to control weeds and soil-borne diseases. This project aimed to assess the efficacy of new fumigants, methyl iodide: chloropicrin 30:70, dichloropropene: chloropicrin 40:60 (Telone C60), and dichloropropene: chloropicrin 65:35 (Telone C35 EC), in runner beds at Stanthorpe and on fruit farms at Nambour in Queensland. These experiments conducted over two years (2007/08 and 2008/09) complement similar studies undertaken in southern Australia. These results will contribute to the national registration of these products and their adoption by runner and fruit growers.

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Front cover: Severe soil-borne disease infections and weed infestations will result when methyl bromide is replaced by inferior fumigants or a fumigant free management program.

Nut grass (top left) and sedge control (bottom right) will become more difficult.

Severe losses to plant death associated with the fungus *Macrophomina phaseolina* (bottom left) can be minimised with the efficient use of effective alternatives to methyl bromide on runner and fruit farms.

Cultivars with resistance to *Fusarium* wilt and crown rot, (top right) will become more important. The total demise of the highly susceptible cultivar (left hand row) contrasts with the still vigorous growth shown by the more resistant cultivar (right hand row), two months after commercial harvest ceased.

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Media summary

Australia produces 40,000 tonnes of strawberries worth $240 million each year. Winter production in south-east Queensland is worth $140 million. Each year, Queensland fruit growers plant 30 - 35 million transplants supplied by runner growers in Queensland and Victoria. Before methyl bromide was phased out in 2005 because it depleted the ozone layer, runner growers depended on it to control soil borne diseases and weeds. Effective fumigant replacements for strawberry runner and fruit production were needed.

Earlier work showed that front ranking alternatives were less effective than methyl bromide. We compared new fumigants, methyl iodide plus chloropicrin (30:70 in Year 1, and 50:50 in Year 2), 1,3-dichloropropene: chloropicrin 65:35 EC (Telone C35® emulsifiable concentrate), and dichloropropene: chloropicrin 40:60 (Telone C60®) with the old standard methyl bromide plus chloropicrin 50:50, dichloropropene: chloropicrin 65:35(Telone C35®), and chloropicrin alone. The evaluations were conducted on two Stanthorpe runner farms in 2007/08 and 2008/09, and a Nambour fruit production site in 2008.

Methyl iodide plus chloropicrin 50:50 at 350 kg/ha and 500 kg/ha, dichloropropene: chloropicrin 40:60 (Telone C60®) and 1,3-dichloropropene: chloropicrin 65:35, were shown to be useful for strawberry runner production. Choice of fumigant by growers will depend on prior history of disease and weed incidence at a given site. Chloropicrin was less effective against weeds but it could be used where the weed load is low.

All the fumigants controlled but did not eradicate Fusarium wilt on a fruit farm. The alternative fumigants gave acceptable control but not eradication of nut grass, with chloropicrin being the least effective. All treatments improved fruit yield. Methyl iodide plus chloropicrin 50:50 at 500kg/ha and 1,3-dichloropropene: chloropicrin 65:35 EC gave the highest yield.

The strawberry industry should monitor for increasing levels of the following diseases in runner and fruit production areas: i) crown rot caused by the fungus, *Macrophomina phaseolina* - alternative fumigants are less effective than methyl bromide; ii) crown rots associated with Fusarium and Verticillium wilts.

If the sedge, *Cyperus eragrostis*, or nut grass, *Cyperus rotundus*, is a problem in a production area, growers should consider other ways to control these weeds as they are not well controlled by these alternative fumigants.

1,3-dichloropropene: chloropicrin 40:60 and 1,3-dichloropropene: chloropicrin 65:35 EC were registered before the project was completed as Rural Telone C-60 Soil Fumigant® and Rural Inline Soil Fumigant® respectively. Methyl iodide plus chloropicrin (50:50) was still in the registration process both here in Australia and in the USA.

DEEDI staff are currently developing a plant resistance breeding strategy as a long term alternative to the use of fumigants for control of soil borne diseases.

Technical summary

Winter production of strawberries in South-East Queensland is worth $140 million. The Queensland industry purchases transplants annually from nurseries at Stanthorpe in Queensland, and Toolangi in Victoria. Runner Scheme Rules in Australia require the use of highly effective fumigants to prevent infection of commercial runners and the build-up of soil-borne pathogens in runner farm soils. Diseases caused by *Fusarium oxysporum* f.sp. *fragariae*, *Verticillium dahliae*, root lesion (*Pratrylenchus vulnus*) and root knot (*Meloidogyne hapla*) nematodes, are proscribed. Low levels of *Phytophthora cactorum* and *Colletotrichum* spp. diseases are tolerated. Disease incidence will increase on runner and fruit farms if ineffective fumigants are used for runner production.

Since the phase-out of the ozone depleting fumigant methyl bromide in 2005, runner growers in Queensland have had to increasingly rely on 1, 3 dichloropropene : chloropicrin 65:35 to give good control of soil borne diseases and weeds.

The reported research aimed to find effective replacements for methyl bromide in strawberry runner and fruit production. We compared the following new fumigants: methyl iodide plus chloropicrin 30:70 in Year 1, and 50:50 in year 2, 1, 3 dichloropropene; chloropicrin 65:35 EC and 1,3 dichloropropene; chloropicrin 40:60 with the old standard methyl bromide: chloropicrin 50:50, chloropicrin alone, and dichloropropene; chloropicrin 65:35. Evaluations were conducted on Stanthorpe runner farms in 2007/08 and 2008/09, and a Nambour fruit production site in 2008. Project data would support a national registration application.

In the first year runner trial, only methyl bromide plus chloropicrin 50:50 eradicated the sedge, *Cyperus eragrostis*. There were no differences between the other much less effective treatments. This result suggests that methyl iodide plus chloropicrin 50:50 at 350 kg/ha would be ineffective against the sedge. In both years chloropicrin was less effective than the other treatments against some weeds. It should only be used in runner production areas where weed levels are low. All fumigants eradicated buried fungal inoculum of *Sclerotium rolfsii* and *Macrophomina phaseolina* in Years 1 and 2, but only methyl bromide plus chloropicrin killed *M. phaseolina* in all buried infected crowns in Year 1. Strawberry crown rot and plant death associated with *M. phaseolina* are on the increase in Queensland, Victoria, Western Australia, USA, Spain and Israel.

All the fumigants gave adequate control of Fusarium wilt in fruit production. No fumigant eradicated nut grass, but each gave acceptable control, with chloropicrin being the least effective. Severe nutgrass infestations *Cyperus rotundus* should be controlled before fumigating the soil for fruit production. All fumigants improved fruit yield. Methyl iodide plus chloropicrin 50:50 at 500kg/ha, and 1, 3 dichloropropene; chloropicrin 65:35 EC gave the highest yield.

Methyl iodide plus chloropicrin 50:50 at 350 kg/ha and 500 kg/ha, 1, 3 dichloropropene; chloropicrin 65:35, and 1,3 dichloropropene; chloropicrin 40:60 can be used for strawberry runner and fruit production, subject to appropriate registrations. Dichloropropene; chloropicrin 65:35 EC and chloropicrin can also be used for fruit production.

Two results from this work showed that alternative fumigants are not as effective as methyl bromide. Only methyl bromide plus chloropicrin 50:50 eradicated the sedge, *Cyperus eragrostis*, and the fungus, *M. phaseolina*, in buried, infected crowns.

The following recommendations are made to the industry, research providers and funding bodies as a consequence of this work:

- The strawberry industry should continuously monitor for the presence of diseases associated with *Fusarium oxysporum, Verticillium dahliae,* and other crown rots.
- It should also monitor for the presence of crown rot caused by the fungus, *M. phaseolina*. There is concern in the USA, Spain and Israel for the potential of this disease to increase in importance with the withdrawal of methyl bromide.
- Germplasm resistance to diseases such as Fusarium wilt and Macrophomina crown rot should be urgently considered. These can be serious diseases where strawberries are grown in warmer areas. DEEDI staff are currently developing a plant resistance breeding strategy as a long term alternative to the use of fumigants for control of soil borne diseases.
- Plant stress factors that can contribute to rapid onset of Macrophomina crown rot need to be researched in strawberries.
- Growers should use other management tools to control the sedge, *Cyperus eragrostis*, or nut grass, *Cyperus rotundus*. This should be done before the area is prepared for fumigation prior to strawberry runner or fruit production.

Introduction

Background

The use of the ozone depleting soil fumigant, methyl bromide, to control weeds, nematodes and soil-borne diseases in strawberry runner beds and fruit production areas was phased out in 2005 under the Montreal Protocol. Small quantities of the chemical were available until 2008 under "Critical Use Exemptions" for strawberry runner production.

At the commencement of this project in July 2007, runner growers did not have access to adequate amounts of methyl bromide. Chloropicrin was not acceptable because it provided inadequate weed control. 1,3-dichloropropene: chloropicrin 65:35 was available but came with genuine concern about the possibilities of phytotoxicity, especially in cold wet situations, which is a common circumstance at Toolangi and Stanthorpe. Runner growers were also concerned that 1,3 dichloropropene: chloropicrin 65:35 was not as good as methyl bromide for weed control.

Larson and Shaw (2000) stated that meta-analysis indicated that fumigation with methyl bromide plus chloropicrin was more effective than was chloropicrin alone at any rate of application. They also stated that for mixtures of 1, 3-dichloropropene plus chloropicrin, nursery productivity was maximised by using at least 280 kg/ha of chloropicrin in the mix. This amount is sixty percent more than the 175 kg/ha applied when 1, 3-dichloropropene plus chloropicrin 65:35 is used at the recommended rate of 500 kg/ha. This work substantiates runner grower concerns that 1, 3-dichloropropene plus chloropicrin 65:35 is not as good as methyl bromide.

Larson and Shaw (2000) observed in California that soil fumigation reduced the risk of disseminating soil-borne pathogens and pests to other nurseries and fruiting fields. As effective nursery soil fumigants are banned or restricted because of environmental concerns and regulatory action, the dissemination of soil-borne pathogens and pests will probably become an increasingly important issue. They concluded that there is no alternative treatment that gives results equal to methyl bromide, and growers could expect a minimum ten per cent reduction in fruit yield when methyl bromide was withdrawn. They also noted that further cumulative reductions could be expected if runner growers ceased using methyl bromide, resulting in lower quality planting material.

At the start of this project the Australian strawberry fruit industry depended on 1,3-dichloropropene plus chloropicrin, 65:35, and chloropicrin alone, each of which had its strengths; but they were not as consistent in effect as methyl bromide (Mattner, 2005). Hutton *et al.* (2001) and Hutton and Gomez (2006), in small plot experiments found that 1, 3-dichloropropene plus chloropicrin 65:35 and chloropicrin performed as well as the methyl bromide plus chloropicrin mixtures in fruit production, but metham sodium and metham potassium would be unsuitable replacements for methyl bromide.

Previous work in Queensland by Hutton and Gomez (2006), and in Victoria by Mattner (2005), showed that methyl iodide: chloropicrin 30:70 was as effective as methyl bromide in small-plot experiments. After this research was completed, Arysta

LifeSciences changed to a 50:50 formulation for registration. Before methyl iodide: chloropicrin 50:50 could be registered, the APVMA required that “scale-up” trials be conducted in the major runner production areas across Australia. Runner growers needed to know if methyl iodide: chloropicrin 50:50 was similar to or better than the existing fumigants in terms of weed and disease control in their enterprises. We planned to conduct replicated field experiments at the two runner production farms at Stanthorpe in Queensland over two seasons, in 2007/08 and 2008/09. Efficacy comparison work with methyl iodide: chloropicrin 50:50, 1, 3-dichloropropene plus chloropicrin 65:35, 1, 3-dichloropropene plus chloropicrin 65:35 EC, 1, 3-dichloropropene plus chloropicrin 40:60, and chloropicrin at a fruit production site, was also planned for 2008.

Runner growers regard chloropicrin and 1, 3-dichloropropene plus chloropicrin 65:35 as being less effective than methyl bromide for weed control. Chloropicrin is highly effective against soil-borne pathogens, while 1, 3-dichloropropene plus chloropicrin 65:35 is less effective against some diseases (Mattner, 2005) and can cause phytotoxicity to the strawberry plants, especially in cold soils (Mattner, 2005). Methyl iodide: chloropicrin 30:70 has been shown to be as effective as methyl bromide (50:50) and 1, 3-dichloropropene plus chloropicrin 65:35 in small plot experiments (Hutton and Gomez, 2006; Mattner, 2005). Commercial evaluation initially of methyl iodide: chloropicrin 30:70, and later, methyl iodide: chloropicrin 50:50 and 1, 3-dichloropropene plus chloropicrin 40:60, in the strawberry runner beds in Queensland was required for registration of these chemicals.

Fruit growers were using 1, 3-dichloropropene plus chloropicrin 65:35, chloropicrin, and metham sodium at the commencement of this project. Earlier work (Hutton *et al.*, 2001) showed that 1, 3-dichloropropene plus chloropicrin 65:35 and chloropicrin alone performed as well as methyl bromide: chloropicrin 70:30. Metham sodium enhanced weed control but not yield. It was important that the commercial evaluation of methyl iodide: chloropicrin 50:50, 1, 3-dichloropropene plus chloropicrin 40:60, and 1, 3-dichloropropene plus chloropicrin 65:35 EC be done on the Sunshine Coast.

Many soil-borne diseases have the potential to cause major losses in strawberry fields. Fumigation of the runner beds, which can substantially minimise the spread of soil-borne diseases from runner to fruit farms, is an important strategy used to break this disease cycle. Runner Schemes either proscribe diseases or have tight tolerances on the level allowed. Fusarium wilt and crown rot, *Fusarium oxysporum* f.sp. *fragariae,* and verticillium wilt, *Verticillium dahliae,* commonly have a zero tolerance. Some diseases such as the crown rots caused by *Phytophthora cactorum* and *Colletotrichum gloeosporioides* may be tolerated in transplants at a low level because of the difficulty associated with attaining total freedom from them.

It is the authors’ opinion that the diseases most likely to increase in importance in the post methyl bromide era are Fusarium wilt, and crown rot, *F.oxysporum* f.sp. *fragariae,* and crown and root rot caused by *Macrophomina phaseolina.*

The worldwide phase-out of methyl bromide, the possible unavailability of an equivalent replacement fumigant, and the high cost of possible replacements as well as decreasing margins for profitability have already caused strawberry growers to consider alternative management practices. Failure to fumigate or replanting into used plastic mulch for two or three successive years has contributed to the higher incidence of these diseases in Queensland in recent seasons (Hutton and Gomez, 2006). Uniform high levels of crown rot and wilt, caused by *F.oxysporum* f.sp. *fragariae,* developed in a strawberry field at Nambour under continuous monoculture of strawberries without any sorghum cover-cropping between seasons. The same organism caused a high incidence of root and crown rot was caused by in strawberry cultivars Camarosa and Gaviotta in the coastal sub-tropical strawberry growing area north of Perth in WA (Golzar *et al*., 2007). The disease built up in non-fumigated or poorly fumigated soils on old strawberry land destined for development.

Plant death associated with *M. phaseolina* and *Sclerotium rolfsii* has been observed in runner beds on the Granite Belt, albeit at very low levels. *M. phaseolina* affects a wide range of agricultural crops. Losses on strawberry fruit farms have generally occurred in dry years following plant stress. Hutton *et al*. (2001) reported serious losses to crown rots associated with *M. phaseolina* on several Queensland fruit farms. Losses estimated to be as high as 60-80% were experienced in August 2009 in a crop that had been partially defoliated early, in preparation for ratooning the following year. This procedure was followed by a week of temperatures in excess of 40^0C, which severely stressed the crop. In all of these instances either metham or no fumigants had been used. Hutton *et al.* (2001) reported on the ineffectiveness of metham compared with methyl bromide plus chloropicrin mixes. Another example of severe losses occurred in Victoria following a crop of sorghum (Mattner *pers. comm*., 2002). Golzar and Phillips (2007) reported the recovery of *M. phaseolina*, often in association with *F.oxysporum* f.sp.*fragariae*, *Phytophthora cactorum* and *Pythium* spp. in Western Australia.

M. phaseolina crown rot has been recorded in Israel (Zveibil *et al.*, 2005), Florida (Mertely *et al*., 2005), Spain (Avilles *et al.*, 2007) and California (Koike, 2008). The authors of these records speculate that *M. phaseolina* may be an emerging threat as strawberry industries worldwide move to alternative fumigants.

Mattner (2005) reported less control of *S. rolfsii* with 1, 3-dichloropropene plus chloropicrin 65:35 compared to methyl bromide. The effect of alternative fumigants on *C. gloeosporioides*, which potentially carries over in the cool dry soils at Stanthorpe, was not known.

The efficacy of methyl iodide: chloropicrin, 1, 3-dichloropropene plus chloropicrin 65:35 EC, and 1, 3-dichloropropene plus chloropicrin 40:60 in runner and fruit production, weed control and soil-borne disease control would be evaluated.

Fumigant evaluation in commercial runner production

Commercial summary

- Methyl iodide: chloropicrin 50:50, 1,3-dichloropropene plus chloropicrin 40:60 and 1,3-dichloropropene plus chloropicrin 65:35 can be used for strawberry runner production. Chloropicrin was less effective than the other treatments against weeds, though there may still be a place for it in runner production in areas where weeds are of less importance.
- Growers wanting to use new land that is infested with *Cyperus eragrostis* will not get adequate control of that weed using any of the test fumigants immediately prior to planting mother plants. Relying on hand weeding, cultivation and herbicide use in a sensitive crop is cost prohibitive and impractical. It should be controlled separately before planting mother stock.
- Runner growers should be constantly vigilant for the causes of plant death in runner crops. There are at least two soil borne pathogens, which will not be eradicated by the current alternatives to methyl bromide.

Introduction

Soil fumigants are used to control weeds, nematodes and soil-borne diseases in strawberry runner beds and fruit production areas. The issue of ongoing concern with the phasing out of methyl bromide is the potential for soil-borne disease to increase if the replacement fumigants are less efficacious. *M. phaseolina* and *Sclerotium rolfsii* are seen occasionally at low levels at Stanthorpe. *M. phaseolina* has been reported as a new disease in California, Florida, Spain and Israel. Runner Schemes proscribe Fusarium wilt and crown rots (*F. oxysporum* f.sp. *fragariae)* and Verticillium wilt (*Verticillium dahliae*), and put limits on the tolerated level of diseases caused by *Phytophthora cactorum* and *Colletotrichum* spp. Although these diseases are not a problem, the need for an effective fumigant to minimise the risk of inoculum build-up in the soil is essential. The Queensland Runner Scheme required methyl bromide to be used, but this has been phased out because of its impact on the ozone layer. It is essential that replacement fumigants are as effective as methyl bromide.

Research has demonstrated that chloropicrin and 1,3-dichloropropene plus chloropicrin 65:35 are less effective than methyl bromide: chloropicrin mixtures (Mattner, 2005; Larsen and Shaw, 2000). Methyl iodide: chloropicrin 30:70 was as good as the standard fumigants, 1,3-dichloropropene plus chloropicrin 65:35 and methyl bromide: chloropicrin, in small plot runner bed trials at Stanthorpe in 2004 (Hutton and Gomez, 2006).

Further experiments over two years (2007/08 and 2008/09) were planned to complement similar runner bed studies in southern Australia. Alternative fumigants methyl iodide: chloropicrin 30:70 (Year 1), methyl iodide: chloropicrin 50:50 (Year 2) and 1,3-dichloropropene plus chloropicrin 40:60, were compared with the standards, 1,3-dichloropropene plus chloropicrin 65:35 and chloropicrin. This work would contribute to the national registration of methyl iodide: chloropicrin 50:50, 1, 3-dichloropropene plus chloropicrin 40:60.

Materials and methods

At Stanthorpe, Trials 1-3 were conducted at Site 1, and Trial 4 at Site 2. The treatments were applied by 'R&R Fumigation' in the first year, 2007/2008. 'R&R Fumigation' also carried out gas flow audits on local fumigation rigs prior to soil treatment in Year 2 of the project. Trials were conducted at both locations again in 2008/2009 (see Table 1).

Treatments

In Year 1 of the project (2007-2008) the trials compared the standard methyl bromide: chloropicrin 50:50 at 500 kg/ha, with 1,3-dichloropropene: chloropicrin 65:35 at 500 kg/ha, chloropicrin at 500 kg/ha with methyl iodide: chloropicrin 30:70 at 500 kg/ha (Table 1). We buried various forms of fungal inoculum immediately after fumigation in the non-replicated Experiment 3 in an unused part of the Site 1 farm.

In 2008-09, the second year of the project, we compared methyl bromide: chloropicrin 50:50 at 500 kg/ha (Sites 1 and 2), methyl iodide: chloropicrin 50:50 at 350 and 500 kg/ha (Site 1 only), 1, 3-dichloropropene: chloropicrin 65:35 at 500 kg/ha, (Sites 1 and 2), 1, 3-dichloropropene: chloropicrin 40:60 at 500 kg/ha (Sites 1 and 2) and chloropicrin alone at 500 kg/ha (Site 1 only) (Table 1). As in the previous year, we buried various forms of fungal inoculum immediately after fumigation in a non-replicated experiment located in a non-production area on one farm.

Table 1. Runner trials for soil fumigation treatments 2007/08

		2007-2008				2008-2009		
	Rate Kg/ha	Site 1			Site 2	Site 1	Site 1	Site 2
Fumigant		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7
Methyl bromide: chloropicrin 50:50	500	✔	✔	✔	✔	✔	✔	✔
Methyl iodide: chloropicrin 30:70	500	✔	✔	✔	✔			
Methyl iodide: chloropicrin 50:50	500					✔	✔	
Methyl iodide: chloropicrin 50:50	350					✔	✔	
chloropicrin	500	✔	✔	✔	✔	✔	✔	
1, 3-dichloropropene: chloropicrin 65:35	500	✔		✔	✔	✔	✔	✔
1, 3-dichloropropene: chloropicrin 40:60	500					✔	✔	✔
Untreated				✔			✔	

Nematode studies

2007-2008 *Nematode assessments*

Soil samples for nematode assessment were taken from each plot before and after fumigation in Year 1 of the project. Tests were conducted by Dr Jenny Cobon and Wayne O'Neill at QDPI&F Research Centre at Indooroopilly. Plant parasitic nematodes were counted after being extracted from 200mL soil samples placed in Whitehead trays for 3 days. Statistical analyses were not applied to these data.

Inoculum survival studies
Immediately after fumigation, 15 (Year 1) and 30 (Year 2) crowns infected with *C. gloeosporioides* and *M. phaseolina*, as well as 200 sclerotes of *S. rolfsii* and 200 micro-sclerotes of *M. phaseolina*, were separately buried at a depth of 15 cm and 50 cm from the sealed edge of the plastic. The plastic was lifted one week later and buried inoculum was taken to the laboratory where we plated-out four tissue samples from each infected crown. If *C. gloeosporioides* or *M. phaseolina* grew out from one to four pieces of tissue, that crown was recorded as having viable fungus present. Results express the percentage of crowns from which we isolated *M. phaseolina* or *C. gloeosporioides*. We placed 100 *S. rolfsii* sclerotes and 100 *M. phaseolina* micro-sclerotes onto potato dextrose agar plus 50 ppm streptomycin sulphate. Results show the percentage of sclerotes and micro-sclerotes that remained viable after fumigation. Comparative samples of infected crowns and sclerotes or micro-sclerotes were also held in a fridge at 5^{O}C at MRS to demonstrate that identical inoculum stored under ideal conditions remained viable.

Weed control
Data were collected on weed infestations during the early life of the crop. For each fumigated plot, counts of weed seedlings in six random $1m^2$ quadrats were made. Data are expressed as the mean number of weeds per square metre. Data were analysed using Genstat 9.0.

Harvest assessment
Just prior to commercial dig, we dug plants from six $0.25m^2$ quadrats from each plot. After unsaleable runners were discarded this provided us with the yield of saleable runners (number) from that area. These data are presented as the number of saleable plants/square metre. Leaf length, root length, root weight (dry), top weight (dry) and crown health were also measured.

Results
Nematodes
2007-2008. All fumigants eliminated dagger *(Xiphinema* sp.), reniform (*Rotylenchulus* sp.), ring (C*riconemella* sp.) and spiral (*Helicotylenchus* sp.) nematodes. We were not able to detect root knot (*Meloidogyne* sp.) or root lesion (*Pratylenchus* sp.) nematodes in either pre-fumigation or post-fumigation assessments.

Inoculum survival
2007-2008. Methyl bromide: chloropicrin 50:50 killed the fungi in all the buried material. *C. gloeosporioides* in buried crowns, and sclerotes of *S. rolfsii* and *M. phaseolina* did not survive fumigation with methyl iodide: chloropicrin 30:70. Chloropicrin allowed a 13% recovery of viable *M. phaseolina* from crowns. 1, 3-dichloropropene: chloropicrin 65:35 killed *S. rolfsii* and *M. phaseolina* sclerotes, but allowed a 7% recovery of both *C gloeosporioides* and *M. phaseolina* in crowns (see Table 2).

2008-2009. Each fumigant killed all the sclerotes of *S. rolfsii* and *M. phaseolina*. *C. gloeosporioides* survived in 26.7% of dried, buried, infected crowns in

1,3-dichloropropene: chloropicrin 65:35 treated soil, and in 3.3% of crowns for 1,3-dichloropropene: chloropicrin 40:60 and chloropicrin (see Table 3).
Refrigerated laboratory controls demonstrated that the buried inoculum was highly viable in both years (Table 3).
These results should only be used as a guide because the trials were not replicated.

Table 2. Effect of fumigation on survival (%) of buried fungal inoculum 2007-2008.

Treatment	Crowns with *C. gloeosporioides*	Crowns with *M. phaseolina*	Sclerotes of *S. rolfsii*	Sclerotes of *M. phaseolina*
Methyl bromide: chloropicrin 50:50	0	0	0	0
Methyl iodide: chloropicrin 30:70	0	3	0	0
chloropicrin	0	13	0	0
1,3-dichloropropene: chloropicrin 65:35	7	7	0	0
Untreated	40	77	90	74
Refrigerator storage	44	57	100	78

Table 3. Effect of fumigation on survival (%) of buried fungal inoculum 2008-2009.

Treatment	Crowns infected with *C. gloeosporioides* %	Sclerotes of *S. rolfsii* %	Microsclerotes of *M. phaseolina*
Methyl bromide: chloropicrin 50:50	0	0	0
1,3-dichloropropene: chloropicrin 65:35	26.7	0	0
chloropicrin	3.3	0	0
1,3-dichloropropene: chloropicrin 40:60	3.3	0	0
Methyl iodide: chloropicrin 50:50 (350 kg per ha)	0	0	0
Methyl iodide: chloropicrin 50:50 (500 kg per ha)	0	0	0
Refrigerator storage	80	90	84

Weed control

2007-2008: Only methyl bromide: chloropicrin prevented any sedge *Cyperacae eragrostis* growth. 1, 3-dichloropropene: chloropicrin 65:35, methyl bromide: chloropicrin, and methyl iodide: chloropicrin 30:70 gave better grass and broad-leaf control than chloropicrin alone (see Table 4).

2008-2009. There were no differences between the fumigant treatments against broad-leaf weeds at Site 1 and grass weeds at Site 2. Chloropicrin was less effective than other fumigants against grass weeds at Site 1. Methyl bromide: chloropicrin (1.3/m^2) and 1, 3-dichloropropene: chloropicrin 40:60 (2.0/ m^2) gave better broad-leaf weed control than 1, 3-dichloropropene: chloropicrin 65:35 (3.8 /m^2) at Site 2 (Table 5). The result for broad-leaf weeds is consistent with runner grower experience.

Table 4. The effect of soil fumigation on weed control in strawberry runner trials at Stanthorpe 2007-2008. Data are the number of plants per square metre.

Treatment	sedge[1]	grass[1]	broadleaf[1]
Methyl bromide : chloropicrin 50:50	0.0 b	0.00 b	0.667 b
1,3-dichloropropene: chloropicrin 65:35	678.7 ab	2.667 b	2.333 b
Methyl iodide: chloropicrin 30:70	826.7 a	2.00 b	1.667 b
chloropicrin	989.3 a	13.667 a	10.667 a

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Table 5. The effect of soil fumigation on broad-leaf and grass weed control in strawberry runner trials at Stanthorpe 2008-2009. Data are the number of plants per square metre.

	Site 1[1]		Site 2[1]	
Treatment	Broadleaf	Grass	Broadleaf	Grass
Methyl bromide : chloropicrin 50:50	3	0.7 b	1.3 b	0.1
1,3-dichloropropene: chloropicrin 65:35	3	0 b	3.8 a	0.1
chloropicrin	1.5	4.4 a		
1,3-dichloropropene: chloropicrin 40:60	9.6	0 b	2.0 b	0
Methyl iodide: chloropicrin 50:50 350 kg per ha	0.7	0.7 b		
Methyl iodide: chloropicrin 50:50 500 kg per ha	3	0 b		

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Runner harvest data

2007-2008. There were no significant differences between treatments in the number of runners produced. Dry weight of runners produced in 1, 3-dichloropropene: chloropicrin 65:35 and methyl iodide: chloropicrin 30:70 treated soils was greater than for chloropicrin at Site 1 (Table 6). The differences between treatments for petiole length, root length and crown diameter are of little practical significance (Table 7).

Table 6. Effect of fumigation on number and weight of saleable runners/m^2 2007-2008

	Site 1		Site2	
Treatments	Number[1]	Dry weight [1]	Number[1]	Dry weight [1]
Methyl bromide: chloropicrin 50:50	124	353.1 ab	103	513
Methyl iodide: chloropicrin 30:70	118.2	386.3 a	114	504
1,3-dichloropropene: chloropicrin 65:35	129.1	412.2 a	104	503
chloropicrin	116.4	300.0 b	92	426

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Table 7. Effect of fumigation on petiole and root length and crown diameter (cm) 2007-2008

	Site 1[1]			Site 2[1]		
Treatments	Petiole	Root	Crown	Petiole	Root	Crown
Methyl bromide: chloropicrin 50:50	11.47b	12.02a	10.63a	15.2	16.6	13.2
Methyl iodide: chloropicrin 30:70	11.61b	11.92a	10.64a	15.1	16.3	12,9
1,3-dichloropropene: chloropicrin 65:35	13.91a	12.80a	10.84a	15.7	15.6	12.9
chloropicrin	13.50a	10.91b	10.20b	14,4	15.5	12.6

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Runner Harvest data

2008-2009. Although there were some significant differences between treatments, these would have little practical impact (Tables 8, 9). All treatments resulted in sturdy plants that could be expected to perform well.

Table 8. Effect of fumigation on number and weight of saleable runners/m^2 2007-2008

	Site 1		Site 2	
Treatments (kg/ha)	Saleable [1]	Dry weight [1]	Saleable [1]	Dry weight [1]
Methyl bromide: chloropicrin 50:50	131 a	331	76 b	395
1,3-dichloropropene: chloropicrin 65:35	107 bc	310	84 ab	415
Chloropicrin	111.9 bc	267	92 a	423
1,3-dichloropropene: chloropicrin 40:60	103 c	318		
Methyl iodide: chloropicrin 50:50 (350)	124 ab	324		
Methyl iodide: chloropicrin 50:50 (500)	114 abc	295		

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Table 9. Effect of fumigation on petiole and root length (cm)

	Site 1[1]		Site 2[1]	
Treatments (kg/ha)	Petiole	Root	Petiole	Root
Methyl bromide: chloropicrin 50:50	231 a	105 d	190 c	122 c
1,3-dichloropropene: chloropicrin 65:35	197 c	124 ab	224 a	129 b
chloropicrin	188 d	115 c		
1,3-dichloropropene: chloropicrin 40:60	211 b	128 a	210 b	138 a
Methyl iodide: chloropicrin 50:50 (350 kg per ha)	203 c	120 b		
Methyl iodide: chloropicrin 50:50 (500 kg per ha)	205 c	125 a		

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Discussion

The fumigants all gave good control of exposed nematode and fungal material (sclerotes). The survival of *M. phaseolina* in buried crowns is notable. It was recovered after fumigation with chloropicrin and 1, 3-dichloropropene: chloropicrin 65:35. This organism is a common soil-borne pathogen with a very wide host range, and occurs in many warm areas of the world. High temperatures and low soil moisture predispose susceptible plants to infection (Mass, 1998). The organism is prevalent in fruit production areas. While losses to date in runner fields have been minimal, there have been several events resulting in significant losses on fruit farms. Mertely *et al.* (2005) report a crown rot associated with *M. phaseolina* being concentrated along field margins where inadequate fumigation with methyl bromide had occurred. They also postulate that this fungus may be an emerging threat as strawberry industries change to other fumigants. Similar concerns are expressed by Zveibil *et al.* (2005) in Israel, Avelies *et al.* (2008) in Spain, and Koike *et al.* (2008) in California. In Queensland, we have experienced two serious crown rot events associated with *M. phaseolina* in non-fumigated fields.

The recovery of *C. gloeosporioides* from buried crowns is also of interest. The disease is moved around in infected runners, but the role of buried inoculum in the development of *C gloeosporioides* crown rot is limited (Mass, 1998). Current project work shows that viable inoculum is unlikely to carry over from one season to the next on runner or fruit farms.

Remarkable sedge, *Cyperus eragrostis*, control was achieved by methyl bromide in a virgin block of land (Table 4). Trial variability resulted in 1, 3-dichloropropene: chloropicrin 65:35 being not statistically different from the methyl bromide: chloropicrin 50:50. The sedge load in the 1, 3-dichloropropene: chloropicrin 65:35 plots was unacceptable to the runner grower. The result with broad-leaf and grass weeds was variable; differences in germination occurred under low weed pressure (Tables 3 and 4).

Significant statistical differences between treatments for most of the yield and harvest parameters measured were not of any commercial interest.

Fumigant evaluation in commercial fruit production

Commercial summary

- All the fumigants gave adequate control, but not eradication of Fusarium wilt in a field trial.
- None of the fumigants will eradicate nut grass, but acceptable control is offered, with chloropicrin being the least effective. Serious nut grass loads should be controlled by alternative management practices prior to fumigation and laying of plastic for a new season's fruit production.
- All the treatments resulted in improved fruit yield. Methyl iodide: chloropicrin 50:50 at 500kg/ha and 1, 3-dichloropropene: chloropicrin 65:35 EC gave the highest yield.

Introduction

Soil fumigants are used to control weeds and soil-borne diseases in fruit production areas. The issue of ongoing concern associated with the phasing out of methyl bromide is the potential for soil-borne diseases to increase if the replacement fumigants are less efficacious. The diseases most likely to become more significant in the Sunshine Coast production area of Queensland are Fusarium wilt, and crown rot (*F.oxysporum* f.sp. *fragariae*) and Macrophomina crown rot (*M. phaseolina*). The aim of this work was to compare the new fumigants, methyl iodide: chloropicrin 50:50, 1,3-dichloropropene: chloropicrin 40:60, and 1, 3-dichloropropene: chloropicrin 65:35EC with the current industry standards, 1, 3-dichloropropene: chloropicrin 65:35 and chloropicrin. Methyl bromide was not available.

Materials and methods

A block with a history of nutgrass and Fusarium wilt (*F. oxysporum* f.sp. *fragariae*) infestation was chosen for this work. The site consisted of 34 rows, each of about 30 metres in length. Such a relatively short length of row was always going to be a challenge for accurate application of the fumigants.
Fumigant cylinders were weighed before and after application to the treated areas. Table 10 shows the required treatment rates as well as the actual amount of fumigant applied per hectare over four plots. The percentage variation from the required rate is shown. Standard fumigants, 1, 3-dichloropropene: chloropicrin 65:35 and chloropicrin applied at 500 kg/ha, were compared with test fumigants, methyl iodide: chloropicrin 50:50 applied at 500kg/ha and 350kg/ha, 1,3-dichloropropene: chloropicrin, 40:60 at 500kg/ha, and 1,3-dichloropropene: chloropicrin 65:35 EC at 500kg/ha. Two untreated plots were included in each block. Methyl bromide: chloropicrin was not available for this work.

The fumigation rig was set up by the local fumigation operator, Mr Rod Spakman, under the supervision of 'R&R Fumigation'. The gas fumigants were applied on 26 February 2008. The EC formulation was applied by 'SA Rural' on 29 February 2008 through the trickle tape.

Planting holes were cut in the plastic on 7 March, one week after application of the 1, 3-dichloropropene: chloropicrin 65:35 EC. Prior to planting we tested for fumigant residues at 150mm depth at the lower end of each plot. Copper probes were inserted into the soil and air was drawn from the soil with a syringe through a Gastec tube containing crystals that change colour when the presence of gas (benzene - methyl iodide, tricloroethylene – 1,3-dichloropropene, and carbon tetrachloride - chloropicrin) is detected. 200mL of air were extracted for each sample. If no colour change occurred after 200mL had been extracted, this was regarded as a negative response for the presence of residual gas.

Eighty runners of the cv. Kabarla were planted in each plot on 7 April, 2008. These plants constituted the area from which plant production data was taken.
The trial was set up at Maroochy Research Station at Nambour as a randomised complete block design with four replicates of eight treatments. Senior Biometrician, Janet Giles, provided advice and analysis of the data.

Table 10 Rate of fumigants applied (kg/L per ha) in a fruit production trial at Nambour in 2008

Treatment	Rate required	Rate applied	% variation from required rate	Fumigation Date
Chloropicrin	500	553	+10.6%	1 March
1,3-dichloropropene: chloropicrin 65:35	500	471	-5.8%	1 March
1,3-dichloropropene: chloropicrin 40:60	500	494.3	-1.14%	1 March
1,3-dichloropropene: chloropicrin 65:35 EC	350	350	0	1 March
Methyl iodide + chloropicrin 50:50 (350 kg per ha)	500	553	+10.6%	1 March
Methyl iodide + chloropicrin 50:50 (500 kg per ha)	500	500	0	4 March
Control				

Weed control
Nut grass germination was assessed on several occasions. Plants were removed after each count. Data are expressed as the number of plants per $16m^2$ plot.

Harvest assessment
Fruit were harvested once weekly when full red in colour, and were counted and weighed. Average weight of fruit was also considered in statistical comparisons. These data are presented as cumulative data to each date.

Fusarium wilt and crown rot
Plants wilted and died as a result of infection with Fusarium wilt (*Fusarium oxysporum* f.sp. *fragariae*). The number of plants wilting, dying or dead was assessed on a number of occasions during the season.

Results

Weed control
Fumigated plots had substantially fewer nutgrass plants, *Cyperus rotundus*, than the control plots. There were significant differences in nut grass control between the fumigants, but the data were variable. Chloropicrin did not rank with the best treatments in either assessment (Table 11).

Fusarium wilt and crown rot control
Fumigants substantially reduced plant losses caused by *F.oxysporum* f.sp. *fragariae* compared with those recorded in the control plots (see Table 12). The results indicate that this disease has the potential to be a major problem in some strawberry fields on the Sunshine Coast in the absence of effective soil fumigation.

Table 11. The effect of soil fumigation on nutgrass control in a strawberry trial at Nambour in 2008. Data are the cumulative number of plants per plot (16 m^2).

Treatment	19 March	20 May
Control	48.6 a	145.1 a
Chloropicrin	8.0 b	32.9 b
1,3-dichloropropene: chloropicrin 65:35	3.6 bc	16.1 bc
1,3-dichloropropene: chloropicrin 40:60	3.9 bc	21.5 bc
1,3-dichloropropene: chloropicrin 65:35 EC	0.5 d	35.7 b
Methyl iodide + chloropicrin (350 kg per ha)	1.9 cd	10.6 c
Methyl iodide + chloropicrin (500 kg per ha)	2.4 bcd	9.2 c

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Table 12. The effect of soil fumigation on *Fusarium* wilt in a strawberry trial at Nambour in 2008. Data show the percentage of plants wilting or dying.

Treatment	30 June[1]	8 August[1]
Control	16.9 a	33.7 a
Chloropicrin	0.3 b	0.6 b
1,3-dichloropropene: chloropicrin 65:35	1.3 b	2.5 b
1,3-dichloropropene: chloropicrin 40:60	0.6 b	1.9 b
1,3-dichloropropene: chloropicrin 65:35 EC	0.9 b	3.8 b
Methyl iodide + chloropicrin 50:50 (350 kg per ha)	0 b	0.9 b
Methyl iodide + chloropicrin 50:50 (500 kg per ha)	0.3 b	0.3 b

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Harvest yields

All the fumigated plots produced higher yields than the control plots (see Table 13). 1,3-dichloropropene: chloropicrin 65:35, methyl iodide plus chloropicrin at 500 kg per hectare, 1,3-dichloropropene: chloropicrin 65:35 EC, and 1,3-dichloropropene: chloropicrin 60:40 gave the best early yield as measured on 10 June (Table 13). Methyl iodide plus chloropicrin at 500 kg per hectare and 1,3-dichloropropene: chloropicrin 65:35 EC ranked the best at the end of the commercial harvest on 1 September (Table 13).

Table 13. The effect of soil fumigation on cumulative yield in 'Kabarla' strawberries at Nambour in 2008.

Treatments	Yield (g/plant)[1] 10 Jun	Yield (g/plant)[1] 1 Sep
Control	22 e	200 d
Chloropicrin	30 c	330 b
1,3-dichloropropene: chloropicrin 65:35	44 a	346 b
1,3-dichloropropene: chloropicrin 40:60	41 ab	348 b
1,3-dichloropropene: chloropicrin 65:35 EC	49 a	390 ab
Methyl iodide + chloropicrin (350 kg per ha)	34 bc	359 b
Methyl iodide + chloropicrin (500 kg per ha)	43 a	401 a

[1] Means not followed by the same letter are significantly different at a probability of 5%.

Discussion

Nutgrass, *Cyperus rotundus*, control with non-methyl bromide fumigants in this trial was encouraging, but none of the fumigants eradicated that weed. The unavailability of the industry standard, methyl bromide, for this trial is regrettable, as it would have provided a good comparison with the other fumigants of the efficacy of methyl bromide: chloropicrin 50:50 against nut grass. Experience suggests that it would have acted as an eradicant. The comparison of the vastly superior methyl bromide fumigant's effect on *Cyperus eragrostis* (sedge) in the runner beds with essentially the same fumigants being used against another *Cyperus* sp. weed (nut grass) in a fruit farm trial, leads to the conclusion that strawberry growers with a nutgrass problem should control that problem by other means, well in advance of the laying of plastic and planting.

The effect of chloropicrin on fruit yield is not what would have been expected. Its poorer yield performance was a surprise in these trials. It gave good control of Fusarium wilt and crown rot. The results, when this product is used on its own, should be carefully monitored by growers.

Since this work was completed registrations have been obtained for 1,3-dichloropropene: chloropicrin 40:60 and 1,3-dichloropropene: chloropicrin 65:35 EC. These products, together with 1,3-dichloropropene: chloropicrin 65:35 and chloropicrin, will give good results. Registration of methyl iodide: chloropicrin 50:50 is still in the hands of regulators overseas, as well as in Australia. The extra cost associated with the use of this product will limit its use on fruit farms.

Hutton and Gomez (2006) showed that methyl bromide was as effective against Fusarium wilt as 1,3-dichloropropene: chloropicrin 65:35 and chloropicrin, but none acted as eradicants of the soil borne pathogen. It is probable that the ongoing serial use of replacement fumigants will lead to a higher incidence of this disease (Larsen and Shaw, 2000).

A strawberry field at Nambour developed high levels of *F. oxysporum* f.sp. *fragariae* under regular monoculture of strawberries. This field had not had any sorghum cover-cropping between seasons. Field trials with a large range of strawberry cultivars over three years from 2003 to 2005 in this ground demonstrated that plant resistance to Fusarium wilt is present. Varieties ranged from highly susceptible through moderately susceptible to highly resistant (Hutton and Gomez, 2006). The Australian strawberry industry in the post methyl bromide era requires ongoing access to Fusarium resistant varieties from local and overseas breeding programs. Resistance to this disease is being addressed in the current HAL breeding project being managed by Mark Herrington, DEEDI, Queensland.

Technology Transfer

The Queensland strawberry growing community was regularly kept informed about progress with trials and interest was frequently expressed when talks were given at meetings. The collaborating agribusinesses visited both the Sunshine Coast and Stanthorpe each year of the project.

The project data assisted in the registration of 1,3-dichloropropene: chloropicrin 40:60 and 1,3-dichloropropene: chloropicrin 65:35 EC prior to the finalisation of this report. Registration of methyl iodide is still in progress.

Runner growers are using 1,3-dichloropropene: chloropicrin 65:35, with the option of using 1,3-dichloropropene: chloropicrin 65:35. Chloropicrin is also an option where the weed load is low. Methyl iodide plus chloropicrin will also be an option when the registration process has been completed.

Fruit growers are using 1,3-dichloropropene: chloropicrin 65:35 or 1,3-dichloropropene: chloropicrin 40:60 and chloropicrin. There is still some concern about the possibility of phytotoxicity associated with these products in cold wet conditions. Queensland is fortunate in that fumigation occurs in the hot summer months. This results in quick dissipation of gases so long as heavy and continual rain does not occur soon after fumigation or plastic removal. The use of lettuce seed bioassays to test for the presence of fumigant to establish safe planting times is understood by growers.

Information about progress with the project was brought to strawberry growers through the opportunities and venues shown below.

Publications

Cameron, D., Gomez, A. and Hutton D.G. (2008). Are the alternative soil fumigants as good as methyl bromide used in strawberry runner production? *Simply Red* (*Qld Strawberry Industry Promotion Council)*, pp. 6-11, Issue 11.

Hutton, D.G., Gomez, A. O., Smith, J. P., Cameron, D. and Smith, L. (2008). Soil fumigants show mixed effects in the strawberry runner beds, pp. 27-29, *Queensland Strawberry Team R&D Update*.

Hutton, D.G., and Gomez, A.O. (2007). Evaluation of methyl iodide fumigation. *Queensland Strawberry Team R&D Update*.

Hutton, D. (2009). Alternatives to methyl bromide for Queensland strawberry production. *Project update for the Horticulture Australia, Strawberry Annual Industry Report for BS07017*.

Meetings with Queensland Strawberry Growers

Hutton, D.G. (2007). Disease incidence. Talk presented to QSGA quarterly meeting 16 October 2007, Beerwah RSL.

Hutton, D.G. (2008). Report on fumigation Trials. Talk presented to QSGA 5 February 2008, Annual Meeting Beerwah RSL.

Hutton D.G. (2008). Report on fumigation trials. Talk presented to QSGA Quarterly Meeting 6 May 2008, Beerwah RSL.

Meetings with runner growers

Hutton, D.G. (2008). Talk presented to meeting with strawberry runner growers, September 2 2008, Applethorpe.

Hutton, D.G. (2009). Talk presented to a meeting with strawberry runner growers, August 18 2009, Applethorpe.

Key Outcomes

Key issues were identified at the commencement of this project in 2007.

- Methyl bromide had been phased out since 2005. Small amounts had been permitted for use under the Montreal Convention Protocol for "Critical Use Exemptions" in runner production. Further quantities of methyl bromide would not be available to Queensland runner growers after 2008.
- The strawberry industry was dependent on 1,3-dichloropropene: chloropicrin 65:35 and chloropicrin, which were regarded as being less effective than methyl bromide.
- Methyl iodide: chloropicrin 30:70, followed later by methyl iodide: chloropicrin 50:50 was in advanced development in the USA. There were reports of that product being a straight swap for methyl bromide.
- There was interest in 1,3-dichloropropene: chloropicrin 40:60 and 1,3-dichloropropene: chloropicrin 65:35 EC, an emulsifiable concentrate, being registered
- The registration process for any of these new products required data to be generated in more than one location in Australia.

Outcomes

1) This project produced data that contributed to the registration of 1,3-dichloropropene: chloropicrin 65:35 EC, and 1,3-dichloropropene: chloropicrin 40:60. The methyl iodide: chloropicrin 50:50 registration process is continuing in Australia and internationally.
2) Work in this project showed that there is a place for methyl iodide: chloropicrin 50:50 at 500 kg/ha, methyl iodide: chloropicrin 50:50 at 350 kg/ha, 1,3-dichloropropene: chloropicrin 65:35, 1,3-dichloropropene: chloropicrin 40:60, 1,3-dichloropropene: chloropicrin 65:35 EC, and chloropicrin in runner and fruit production. Each product has strengths and weaknesses which will need to be considered when soil fumigation decisions are being made.
3) Each fumigant will control but not eradicate Fusarium wilt.
4) None of the methyl bromide alternatives killed all the fungus, *M. phaseolina*, in old buried crowns. This fungus and the diseases it causes should be monitored.
5) None of the alternative fumigants to methyl bromide killed all sedge or nut grass. This suggests that a management strategy that does not depend on fumigation alone should be considered.

Recommendations

1) All the fumigants tested can be considered for soil fumigation for strawberry runner or fruit production. When deciding which fumigant to use growers will need to consider the potential types of disease and species of weed, along with the likely pressure.
2) Management of severe nutgrass/ sedge infestations should be planned and executed well before planting for strawberry runner or fruit production. Current methyl bromide alternatives are substantially less effective than the previous standard, methyl bromide.
3) All fumigants tested give acceptable control of Fusarium wilt in strawberry fruit production, but disease levels should be closely monitored, as ongoing serial use may see an increase in disease levels.
4) The Australian strawberry industry in the post methyl bromide era should access Fusarium resistant varieties from local and overseas breeding programs. The current HAL supported breeding project in Queensland is addressing this issue. Local varietal resistance knowledge is available from previous projects, but this should be an ongoing focus.
5) Growers should set up a “Paddock Disease Register” for their farms. Cause of plant deaths should be accurately identified in a laboratory so that any disease increase in the post methyl bromide era is closely monitored.
6) Growers should also monitor for the diseases caused by *Fusarium oxysporum* f.sp. *fragariae* and *Macrophomina phaseolina*, as these are likely to occur more frequently as viable fungal material in carryover strawberry debris is not exterminated by current fumigants.

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