Drip-applied Soil Fumigation for Freesia Production

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Summary. Field trials were conducted to test fumigants as alternatives to methyl bromide (MB) for production of hybrid freesia (*Freesia ×hybrida*). One trial compared rates of 1,3-dichloropropene (DP) combined with chloropicrin (CP); the second trial compared iodomethane (IM) together with CP, DP:CP, and furfural with and without metham sodium; and the third trial compared rates and formulations of IM:CP to the standard MB:CP treatments. Most treatments reduced populations of *Pythium* spp. and controlled weeds compared to the untreated controls. Formulations of IM:CP reduced the incidence of disease caused by *Fusarium oxysporum*. Treatments of IM:CP performed as well as MB:CP, and treatments of DP:CP performed as well as IM:CP. Presently only the DP, CP and metham sodium formulations are registered for use on ornamental crops. Registration of the IM formulations will improve the options available to cut flower growers for management of plant pathogens and weeds.

In 2003, California growers produced cut flowers and cut cultivated ornamental greens with a wholesale value of more than $330 million (U.S. Department of Agriculture, 2004). Crops were produced on 2817 acres of covered area and on 9689 acres of open ground. The three top-valued cut flower categories are lilies (*Lilum* spp.), roses (*Rosa* spp.), and tulips (*Tulipa* spp.), with hundreds of other cut flower crops also produced in California.

Hybrid freesia is grown for cut flower production in field soil under shade on the coast of California. A variety of weed species can quickly overgrow the sparse canopy of the crop, reducing yield and quality. The crop is susceptible to *Fusarium oxysporum,* which causes fusarium yellows (Farr et al., 1989). Preplant soil fumigation with methyl bromide/chloropicrin (MB:CP) is commonly employed as a means of weed and pathogen control. The soils are usually fumigated with a 98 MB:2 CP formulation using the hot gas method (the chemical is condensed in a heat exchanger and injected directly under a polyethylene tarp), or the fumigants may be shank-injected using either a 67 MB:33 CP or 50 MB:50 CP formulation.

The broad-spectrum biological activity of MB:CP makes the product a key tool for the control of pathogens and weeds for freesia production as well as many other cut flower crops. The growers require a tool such as MB:CP to ensure a successful crop and to avoid great financial losses that would result from crop failure (Deepak et al., 1996). Chemical companies have been reluctant to register products for ornamental crops because of the relatively few acres involved and the high risk due to the value of these crops. Many of the cut flower crops have a relatively short growing period, and often a grower will follow one crop with a different species to supply a niche market. This practice limits the availability of products that might be used due to residual chemical effects and the extreme sensitivity of certain cut flower crops. In 1988, the U.S. signed the Montreal Protocol, which prohibits the production and importation of MB after 1 Jan. 2005 (U.S. Environmental Protection Agency, 1993). Some use will continue in the short term for quarantine and pre-shipment uses as well as for approved critical uses. Cut flower growers may currently use methyl bromide under the critical use exemption, but this could change on a yearly basis. Alternatives must be found for the very near future.

Since the widespread introduction and use of MB:CP, methods have been improved to deliver alternative fumigants through drip irrigation systems (Ajwa et al., 2002; Apt and Caswell, 1988; Roberts et al., 1988). This technology allows for better distribution of these chemicals, which have lower vapor pressure compared to MB, and the fumigants are applied through a totally enclosed system, increasing worker safety as well as environmental impact.

Potential methyl bromide alternatives include formulations containing 1,3-dichloropropene (DP) and CP (Ajwa and Trout, 2004; Chellami et al., 1997; Csinos et al., 2000, 2002; Fennimore et al., 2003; Gilreath et al., 2004a, 2004b, 2004c; Hutchinson et al., 2004; Larson and Shaw, 2000; Nelson et al., 2001; Rieger et al., 2001; Webster et al., 2001). An emulsified concentrate containing 60.8% DP and 33.3% CP (InLine; Dow AgroSciences, Indianapolis) may be applied through drip irrigation systems (Ajwa et al., 2002). The commercial product is currently labeled at rates from 13 to 56 gal/acre, the maximum rate for pineapple (*Ananas sellowiawa*). Presently, the maximum rate that can be used on ornamentals is 20.5 gal/acre. Previous studies with strawberry (*Fragaria ×ananassa*) have

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
3.7854	gal	L	0.2642
9.3540	gal/acre	$L·ha^{-1}$	0.1069
2.5400	inch(es)	cm	0.3937
1.1209	lb/acre	$kg·ha^{-1}$	0.8922
0.0254	mil	mm	39.3701
28.3495	oz	g	0.0353
6.8948	psi	kPa	0.1450

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shown that higher rates (42 gal/acre) control disease and weeds as well as MB:CP fumigation, and that yield was as good as the standard MB:CP treatment (Ajwa and Trout, 2004). Another material proposed as an alternative to MB:CP soil fumigation is furfural [2-furaldehyde (Multiguard Protect; Agriguard, Cranford, N.J.) (Bauske et al., 1994, 1997; Rodriguez-Kabana et al., 1993)], both alone and in combination with a methyl isothiocyanate generator such as metham sodium [MS (Vapam HL; AMVAC Chemical, Los Angeles)]. Several different formulations and rates of IM and CP (Midas; Arvesta, San Francisco) have been tested as alternatives in strawberry as well as other crops (Ajwa and Trout, 2004; Becker et al., 1998; Dowler, 1999; Duniway, 2002; Eayre et al., 2000; Fennimore et al., 2003; Hutchinson et al., 1999a, 1999b, 2000, 2004; McMillan et al., 1996; Ohr et al., 1996; Webster et al., 2001). Neither furfural nor IM are presently labeled for use in the U.S. on any crop.

During 2003 and 2004, three experiments were established to evaluate alternative fumigants applied through the drip irrigation systems for freesia production in California. This research is crucial not only to provide economical alternatives for cut flower production, but also is required to secure critical use exemptions to continue using MB in areas where drip fumigation cannot be used.

Materials and methods

Trial 1: Nipomo

A freesia flower trial, to compare rates of DP:CP, was established in Nipomo, Calif. (San Luis Obispo County) on Oceano sand (9% to 30% slope; sand: 92%, silt: 5%, clay: 3%; organic matter: 1.4%). The trial was conducted under shadecloth (netted, generic shade, 50% light exclusion). A 6 × 6 Latin square design was used because the grower plants different cultivars of the crop in each bed. The plots were 180 inches long and 42 inches wide. The treatments were delivered in five irrigation tapes evenly spaced over the width of the bed. The drip tape was a T-Tape model 506-04-1.0 (T-Systems International, San Diego) with emitter spacing of 4 inches and flow rate of 1 gal/min per 100 ft at 8 psi. The plots were covered with polyethylene mulch (3 mil thick) before treatments were applied. The treatments were applied 1 Oct. 2003 in 66 gal of water per plot. The trial consisted of five DP:CP rates (20, 30, 40, 50, and 56 gal/acre) compared to the water control. The polyethylene mulch was removed 2 weeks following the applications and five soil cores (1-inch diameter) were collected from the surface 6 inches of each plot. The soil samples were pooled and returned to the laboratory where they were allowed to dry at room temperature for at least 2 weeks. Populations of *Pythium* spp. were determined from the samples by dilution plating (1 g soil in 10 mL sterile water; 0.5 mL on each of five replicated plates) on Martin's medium (Martin, 1992); populations of *Fusarium oxysporum* were determined by dilution plating (1 g soil in 10 mL sterile water; 0.3 mL on each of five replicated plates) on Komada's medium (Komada, 1975). The trial was planted with corms on 24 Nov. 2003. Weeds were counted in the center of each plot (1-m^2 area) on 2 Dec. 2003 and again on 7 Jan. 2004. Final data for this trial were collected on 6 Apr. 2004. Measurements on this date included plant height (average of five plants in center 1 m^2), a vigor rating, and disease incidence. All data were analyzed by PROC GLM of SAS (SAS Institute, Cary, N.C.) and means were separated by Fisher's protected least significant difference.

Trial 2: Encinitas

The second freesia trial was established in Encinitas, Calif. (San Diego County) on Marina loamy coarse sand (2% to 9% slope; sand: 80%, silt 10%, clay 10%; o.m. 4.8%) to test both furfural alone and in combination with MS, the DP:CP formulation used in the first trial and an IM:CP formulation. The trial was conducted in a greenhouse and the experimental design was a 5 × 5 Latin square. The plots were 240 inches long and 46 inches wide. The treatments were delivered in four irrigation tapes evenly spaced over the width of the bed. The tape was Toro model EA5080867-750 (The Toro Co. El Cajon, Calif.) with emitter spacing of 8 inches and flow rate of 0.67 gal/min per 100 ft at 10 psi. Each bed was covered with high density polyethylene sheeting before chemigation. The treatments, made on 15 Oct. 2004 in 72 gal of water per plot, included 1) IM:CP (50:50) at 400 lb/acre; 2) DP:CP at 56 gal/acre; 3) furfural at 960 lb/acre; 4) furfural at 480 lb/acre + metham sodium at 210 lb/acre; and 5) a non-treated control. All chemicals were emulsified by the formulators except for metham sodium, which is water soluble. The trial was planted with corms on 5 Nov. 2003. Soil samples were collected and processed as in the previous trial. On 5 Nov. 2003, weed counts were made on the entire plots. Final data were collected on 24 Feb. 2004 and the same parameters were measured as in the previous trial.

Trial 3: Nipomo

The final freesia trial was established on the same ranch as Trial 1 in Nipomo to compare rates and formulations of IM:CP to an untreated control and to a standard MB:CP treatment. The soil characteristics, growing methods, and irrigation equipment, and experimental design were the same as in trial one. Treatments were made on 26 May 2004 and included 1) IM:CP (50:50) at 300 lb/acre; 2) IM:CP (50:50) at 400 lb/acre; 3) IM:CP (33:67) at 300 lb/acre; 4) IM:CP (33:67) at 400 lb/acre; 5) MB:CP (50:50) at 400 lb/acre; and 6) water (control). The treatments were made through the drip irrigation tape in 66 gal of water per plot. The trial was planted with corms on 6 July 2004. Soil samples were collected and processed as before. Weeds were counted in the center of each plot (1-m^2 area) on 12 July and 11 Aug. 2004. Final data were collected on 17 Nov. 2004 and the same parameters were measured as before; the numbers of flower spikes were also counted in each plot.

Results and discussion

In the first Nipomo trial, *Pythium* spp. populations were greatly reduced in all treatments compared to the control plots (Table 1). *Fusarium oxysporum* populations averaged 1210 cfu/g soil in the control plots and could not be determined for any of the chemical treatments due to interference by a *Trichoderma* species, which probably occurred due to the biological vacuum created by the chemical treatment that was exploited by the *Trichoderma* (Ohr et al., 1973). Early season weed control was reasonably good with all treatments compared to the control plots (Table 1). The most prevalent weed, mustard (*Brassica* sp.), still had lower populations during the second count

Table 1. Populations of *Pythium* spp. in soil samples, weed counts, stem length, vigor rating, and counts of plants symptomatic of fusarium yellows in a freesia trial treated with several rates of 1, 3-dichloropropene (60.8%) + chloropicrin (33.3%) in Nipomo, Calif., in Oct. 2003 (values are the average of six plots). Plant height, vigor, disease, and weed cover data collected on 16 Apr. 2004.

Chemical rate (gal/acre)[z]	*Pythium* spp. (cfu/g soil)[y]	Total weeds on 2 Dec. 2003 (no.)[x]	Total weeds on 7 Jan. 2004 (no.)[x]	Freesia plant ht (cm)[w]	Freesia vigor rating (1–5 scale)[v]	Plants showing yellows symptoms (no.)
0	133	119	124	51.5	3.0	1.3
20	1	11	17	57.7	3.9	0.1
30	0	36	38	55.0	4.1	1.0
40	2	10	17	55.9	4.3	0.8
50	0	9	29	58.2	4.3	0.3
56	0	6	18	55.9	4.0	0.5
P[u]	<0.0001	0.0019	0.0042	0.0005	<0.0001	0.6626
LSD[t]	33	54	55	2.6	0.4	

[z]1 gal/acre = 9.3540 L·ha^{-1}.
[y]1 cfu/g = 0.0353 cfu/oz.
[x]All weed counts were taken from the center 1 m^2 (10.8 ft^2) of each plot.
[w]1 cm = 0.3937 inch.
[v]Vigor was rated subjectively from a low value of 1 to a high of 5 based on the appearance of the entire plot
[u]Probability from the analysis of variance.
[t]Least significant difference.

Table 2. Populations of *Pythium* spp. and *Fusarium oxysporum* in soil samples, weed counts plant height, and counts of fusarium yellows in a freesia trial treated by drip irrigation with various chemical combinations in Encinitas, Calif., in Oct. 2003 (values are the average of five plots). Plant height, and disease data collected on 24 Feb. 2004.

Treatment[z]	*Pythium* spp. (cfu/g soil)[y]	*F. oxysporum* (cfu/g soil)	Bitter-cress (no.)[x]	Chickweed (no.)[x]	Freesia plant ht (cm)[w]	Plants showing yellows symptoms (no.)
IM:CP	1	262	0	0	91.4	25
DP:CP	6	1040	1	0	89.9	12
Furfural	97	643	8	3	87.0	26
FMS	27	1096	0	1	90.4	18
Control	171	1507	30	8	87.1	30
P[v]	0.0001	0.1221	0.0003	0.0005	0.0120	0.3610
LSD[u]	58		11	3	2.7	

[z]Treatments included (IM:CP) iodomethane + chloropicrin (50:50) at 400 lb/acre, (DP:CP) 1,3-dichloropropene + chloropicrin at 56 gal/acre, furfural at 960 lb/acre, (FMS) furfural at 480 lb/acre + metham sodium 210 lb/acre, (control) water (1.0 lb/acre = 1.1209 kg·ha^{-1}; 1 gal/acre = 9.3540 L·ha^{-1}).
[y]1 cfu/g = 0.0353 cfu/oz.
[x]All weed counts were taken from entire plot.
[w]1 cm = 0.3937 inch.
[v]Probability obtained from the analysis of variance (ANOVA).
[u]Least significant difference. Differences among means according to the LSD value are invalid unless protected by the P obtained from the ANOVA ($P \leq 0.05$).

for all other treatments compared to the control, but the differences were nonsignificant (data not shown); total numbers of weeds were also lower at this date for all treatments (Table 1). At the end of the trial, all treatments had taller stems, better vigor, and less weed cover compared to the control (Table 1). The incidence of fusarium yellows was not significantly different for any treatments, but the incidence was very low throughout the trial (Table 1).

For the Encinitas trial, average populations of *Pythium* spp. were lower for all treatments compared to the control, and the IM:CP, DP:CP, and furfural plus metham sodium treatments had lower *Pythium* spp. counts compared to the treatment with furfural alone (Table 2). Populations of *F. oxysporum* were not significantly different among treatments (Table 2). On 5 Nov. the two most prevalent weeds were chickweed (*Cerastium arvense*) and bitter-cress (*Barbarea vulgaris*). Average weed counts were lower in all treatments compared to the control (Table 2). At the end of the trial, average plant height was greater for all treatments except for furfural alone compared to the control (Table 2). There was no significant difference in the incidence of fusarium yellows among any of the treatments (Table 2). Vigor ratings were not significantly different between treatments (data not shown).

For the second Nipomo trial, populations of *Pythium* spp. were reduced for all chemical treatments compared to the control (Table 3). Populations of *F. oxysporum* averaged 1963 cfu for the control plots and again could not be determined for any of the chemical treatments, due to the same reason as in the first Nipomo trial. All chemical treatments had lower weed counts compared to the control on both dates (Table 3). At the end of the trial, all chemical treatments had higher vigor ratings and less fusarium yellows disease incidence compared to the control. There was no significant

Table 3. Populations of *Pythium* spp. in soil samples, weed counts, vigor rating, counts of plants symptomatic of fusarium yellows, and number of flower spikes in a freesia trial treated with several formulations of fumigants in Nipomo, Calif., in May 2004 (values are the average of six plots). Vigor, disease, and flower spike data collected on 17 Nov. 2004.

Treatment[z]	*P. ultimum* (cfu/g soil)[y]	Total weeds on 12 July 2004 (no.)[x]	Total weed count on 11 Aug. 2004	Freesia vigor rating (1–5 scale)[w]	Plants showing yellows symptoms (no.)	Flower spikes (no.)
IM:CP (50:50) 300 lb/acre	68	9	76	3.2	19	25
IM:CP (50:50) 400 lb/acre	55	12	77	3.5	21	35
IM:CP (33:67) 300 lb/acre	55	7	94	3.3	18	38
IM:CP (33:67) 400 lb/acre	2	7	62	3.3	20	24
MB:CP	55	6	68	2.8	21	35
Control	182	28	273	1.3	45	16
P[v]	0.0008	0.0020	0.0018	0.0004	<0.0001	0.0623
LSD[u]	67	10	99	0.9	7	

[z]Treatments included: 1) iodomethane (IM) + chloropicrin (CP) (50:50) at 300 lb/acre; 2) IM:CP (50:50) at 400 lb/acre; 3) IM:CP (33:67) at 300 lb/acre; 4) IM:CP (33:67) at 400 lb/acre; 5) methyl bromide + CP (MB:CP) (50:50) at 400 lb/acre, and 6) water (control) (1.0 lb/acre = 1.1209 $kg \cdot ha^{-1}$).

[y]1 cfu/g = 0.0353 cfu/oz.

[x]All weed counts were taken from the center 1 m^2 (10.8 ft^2) of each plot.

[w]Vigor was rated from a low value of 1 to a high of 5 based on the appearance of the entire plot.

[v]Probability obtained from the analysis of variance (ANOVA).

[u]Least significant difference. Differences among means according to the LSD value are invalid unless protected by the *P* obtained from the ANOVA procedure ($P \le 0.05$)

difference between treatments in the number of flower spikes produced (Table 3). There was no difference in plant height among treatments (data not shown).

Most of the treatments in these trials did a good job reducing the populations of *Pythium* spp. compared to the water-only controls. In the Encinitas trial, populations of *Pythium* spp. were reduced more effectively than populations of *F. oxysporum*, which has been previously reported (Hutchinson et al., 2000). Incidence of fusarium yellows was low in the first two trials, probably because they were conducted in the winter when disease incidence is rare. However, incidence of fusarium yellows was reduced by MI:CP in the trial with the greatest incidence of disease.

Weed control was good with all the treatments compared to untreated controls and were comparable to the MB:CP standard treatment in the final trial. Furfural alone did not perform as well as the other treatments and may not be adequate as a stand-alone treatment for this use.

In conclusion, the data indicate that a successful freesia crop can be produced using combinations of alternative chemicals applied through drip irrigation systems. Presently, only CP, DP:CP, and metham sodium formulations are registered for use on ornamental crops. Registration of the IM:CP formulations will improve the options of freesia growers to manage disease and weeds in their crops.

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