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Perennial Crop Nurseries Treated with Methyl Bromide and Alternative Fumigants: Effects on Weed Seed Viability, Weed Densities, and Time Required for Hand Weeding

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Data on the efficacy of alternative fumigants to methyl bromide for weed control in perennial crop nurseries in California are needed because few herbicides are registered for this purpose. Field studies were conducted from 2003 to 2006 in four commercial perennial crop nurseries in California. Treatments included a nonfumigated control; methyl bromide (98%) (MeBr) with high-density polyethylene (HDPE) film; iodomethane (50%) + chloropicrin (50%) with HDPE film; 1,3-dichloropropene (1,3-D) with HDPE film; 1,3-D (61%) + chloropicrin (35%) with HDPE film; 1,3-D (62%) + chloropicrin (35%) subsurface drip; and 1,3-D (61%) + chloropicrin (35%) with virtually impermeable film (VIF). All the fumigants reduced the seed viability of common purslane, johnsongrass, and tall morningglory but were not as effective on little mallow and field bindweed. Although total weed densities and the level of control provided by each fumigant differed between locations, weed density was generally reduced by all the fumigation treatments, compared to the nonfumigated control. At three locations, alternative fumigation treatments usually resulted in hand-weeding time similar to MeBr. Reductions in weed seed viability, weed emergence, and weed densities suggest that these alternative fumigants will provide weed control similar to MeBr in perennial nurseries.

Nomenclature: 1,3-dichloropropene; chloropicrin (trichloronitromethane); iodomethane; methyl bromide; common purslane, *Portulaca oleracea* L. POROL; field bindweed, *Convolvulus arvensis* L. CONAR; little mallow, *Malva parviflora* L. MALPA; johnsongrass, *Sorghum halepense* (L.) Pers. SORHA; tall morningglory, *Ipomoea purpurea* (L.) Roth PHBPU.
Key words: Herbicide, Montreal protocol, mulch films, stratospheric ozone, seed viability.

Methyl bromide has been used for several decades as a broad-spectrum preplant soil fumigant to control pests in more than 100 agricultural crops (Unruh et al. 2002). The annual use of MeBr in U.S. agriculture, before phaseout, was about 21,000 metric tons (U.S. Environmental Protection Agency [USEPA] 2006), of which about 50% was used in California (U.S. Department of Agriculture [USDA] 2000). This fumigant is a highly volatile molecule contributing to ozone depletion in the stratosphere (Chakrabarti and Bell 1993; Yates et al. 2003). Field studies have shown that up to 87% of soil-applied MeBr can eventually escape into the atmosphere (Majewski et al. 1995; Wang and Yates 1998; Yagi et al. 1995). Worldwide concerns about stratospheric ozone depletion led to the 1987 "Montreal Protocol on Substances that Deplete the Ozone Layer," which was amended several times thereafter (United Nations Environment Programme [UNEP] 2000). This amended protocol mandated the phaseout of MeBr in developed and developing countries by 2005 and 2015, respectively (UNEP 2000; USDA 2000).

Because MeBr has been a very effective fumigant for broad-spectrum pest control in high-value crops, its phaseout has serious consequences to these cropping systems. Therefore, research programs worldwide have focused on transitioning to alternative fumigants and pest-control methods in cropping systems that depend on MeBr (Hanson and Shrestha 2006). One such area of research in recent years has been alternatives to MeBr for pest control in preplant and postharvest situations (Schneider et al. 2003). Open-field nursery production of tree, vine, and ornamental stocks in California must adhere to strict certification procedures for production of pest- and pathogen-free stock (California Department of Food and Agriculture [CDFA] 2001). In these nurseries, MeBr not only provides control of soil-borne pathogens and nematodes, but also provides long-term, broad-spectrum control of weeds, including troublesome species such as yellow nutsedge (*Cyperus esculentus* L.) and purple nutsedge (*Cyperus rotundus* L.) (Rosskopf et al. 2000). Although some nonchemical methods, e.g., solarization and biofumigation (Chellemi et al. 1997; Guererro et al. 2005; Stapleton et al. 2000) have been identified as potential alternatives to MeBr, a majority of the studies have focused on alternative fumigants (e.g. Gilreath et al. 2004; Haar et al. 2003; Klose et al. 2007; Rosskopf et al. 2000; Santos et al. 2006). This could be partly because many high-value fruit, vegetable, and ornamental crops require immediate short-term alternative fumigants as other safe, efficacious, and economic pest control methods or registered pesticides are lacking (Hanson and Shrestha 2006; Klose et al. 2007). In California, very few herbicides are registered for use in perennial crop nurseries, and the loss of MeBr could result in reliance on expensive methods of weed control such as hand weeding (R. Wooley, personal communications). Therefore, this study was designed to address the short-term needs of California perennial crop

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Table 1. Duration of trial, soil characteristics, and irrigation systems at the experimental locations.

Location	Duration of trial	Soil type and series	Soil organic matter content	Method of irrigation
			%	
Oakdale, CA	August 2003–December 2004	Hanford sandy loam (coarse–loamy, mixed, superactive, nonacid, thermic Typic Xerorthent)	0.8	Sprinkler
Yuba City, CA	September 2003–December 2005	Marcum–Gridley clay loam (fine, smectitic, thermic Typic Argixerolls)	1.5	Flood
Le Grand, CA	May 2004–December 2005	Madera loam (fine, smectitic, thermic Abruptic Durixeralfs)	0.8	Flood
Hickman, CA	August 2004–August 2006	Greenfield sandy loam (coarse–loamy, mixed, active, thermic Typic Haploxeralfs)	0.8	Surface drip

nurseries for effective and readily available alternatives to MeBr for broad-spectrum weed control. Specific objectives of this study were to assess the effects of alternative fumigants on weed seed viability, seasonal weed densities, and time required for hand removal of weeds.

Materials and Methods

Field experiments were conducted in perennial crop nurseries at four locations in California: Yuba City, Oakdale, Le Grand, and Hickman, CA. At Yuba City and Hickman the nursery crops were grown for 2 yr, whereas at Oakdale and Le Grand the crops were grown for 1 yr according to commercial grower practices. The nursery crop at Yuba City was walnut (*Juglans* sp.) whereas at the other three locations it was almond (*Prunus dulcis* [Mill.] D. A. Webb). The dates of initiation and termination, soil characteristics, and method of irrigation at each location are provided in Table 1. Crop planting and management were similar in all the treatment plots. Details of data on crop planting and growth parameters are not included in this article.

Although fumigant treatments and application rates, methods, and dates were similar at each nursery, some extra treatments were included at some locations (Table 2). All fumigants were shank applied, either with a Noble plow[1] or a modified Telone rig[2] by a commercial applicator,[3] except 1,3-D (62%) + chloropicrin (35%) (1,3-D:PIC [I]), which was applied with water through buried drip irrigation tubing (thin-walled drip tubing [tape][4] with an emitter flow rate of 0.9 L/h at 1 bar). The distance between emitters was 30 cm. The drip tapes were placed 60 cm apart at a soil depth of 15 cm in the center of the bed and in the furrow to obtain a broadcast treatment over the entire plot. The 1,3-D:PIC (I) was injected for 18 h into the drip irrigation system from a nitrogen-pressurized cylinder containing the fumigant. All the fumigated plots were covered with either HDPE[5] or VIF.[6] The films were removed 1 to 2 wk after fumigation. Raised beds were formed after the films were removed. The beds were 45 cm wide at Oakdale and Yuba City, and 30 cm wide at Le Grand and Hickman. In each location, the experimental design was a randomized complete block with four replications. Individual plot sizes were 27.4 by 7.6 m, 27.4 by 10 m, 26.2 by 10 m, and 26.2 by 10 m at Oakdale, Yuba City, Le Grand, and Hickman, respectively. Spacing between tree rows at each site was 132 cm. Thus, in each plot, there were five rows of trees in Oakdale and seven rows at the other locations.

Herbicide treatments varied between the locations. At Oakdale, an application of 1.12 kg/ha isoxaben plus 0.46 kg/ha pendimethalin was made on April 15, 2004. At Yuba City, a pre-emergent application of 4.48 kg/ha oryzalin was made on October 29, 2003 immediately after planting of the nursery crop, followed by an application of 0.9 kg ai/ha glyphosate on February 15, 2004 prior to crop emergence. At Le Grand, 0.8 kg/ha paraquat was applied on January 6, 2006 prior to emergence of the nursery crop whereas in Hickman, 0.9 kg ai/ha glyphosate was applied on November 16, 2004 prior to nursery crop emergence. No other herbicides were applied during the study. The interrow space was mechanically cultivated several times during the growing season/s at all sites.

Seeds of weeds[7] common to perennial nurseries in central California were selected for the study. At Oakdale and Le Grand, seeds of little mallow, common purslane, field bindweed, and tall morningglory were used. At Yuba City, johnsongrass also was included, in addition to these four species. At Hickman, seeds of little mallow, common purslane, tall morningglory, and johnsongrass were used. Germination tests on the seeds indicated that all species had > 90% viability. Fifty seeds of each species were placed in 13 cm by 9 cm cheesecloth bags. Two seed bags were attached to a 60-cm nylon string and a steel washer and a piece of flagging tape were attached to aid in relocation. One day before fumigation, two 30-cm-deep holes were dug with a soil auger at GPS-marked locations near the center of each plot but out of the planned shank path. Two seed bags were buried at 2.5 and 15 cm deep, respectively, and the soil was compacted to approximately the bulk density of the undisturbed areas. Two to four weeks after fumigation, the bags were retrieved, transported to the laboratory, and stored at 15 C. The bag burial and retrieval dates, respectively, were: Oakdale—August 28 and October 2, 2003; Yuba City—September 8 and October 3, 2003; Le Grand—May 17 and June 17, 2003; and Hickman—August 4 and September 2, 2004.

Weed seeds were removed from the bags and sorted by species. The seeds were then subjected to a tetrazolium assay (Grabe 1970). Seeds were placed in petri dishes (100-mm diameter, 15-mm depth) on a Whatman® No. 1 filter paper,[8] moistened with 1 ml of deionized water for imbibition. Each petri dish was sealed with parafilm®[9] and placed in a cabinet

Table 2. Experimental treatments, application rates, application methods, and dates of fumigation at the experimental locations.[a]

Location	Treatment	Application rate	Application method	Film type	Date of fumigation
		kg/ha			
Oakdale	Nonfumigated control	–	–	No film	September 2, 2003
	Methyl bromide (98%)	448	Noble plow	HDPE	
	Iodomethane (50%) + chloropicrin (50%)	448	Noble plow	HDPE	
	1,3-dichloropropene[b]	380	Modified Telone rig	HDPE	
	1,3-dichloropropene (61%) + chloropicrin (35%)[c]	600	Modified Telone rig	HDPE	
	1,3-dichloropropene (61%) + chloropicrin (35%)	600	Modified Telone rig	VIF	
Yuba City	Non-fumigated control	–	–	No film	September 9, 2003
	Methyl bromide (98%)	448	Noble plow	HDPE	
	Iodomethane (50%) + chloropicrin (50%)	448	Noble plow	HDPE	
	1,3-dichloropropene (61%) + chloropicrin (35%)	600	Modified Telone rig	HDPE	
	1,3-dichloropropene (61%) + chloropicrin (35%)	600	Modified Telone rig	VIF	
Le Grand and Hickman	Nonfumigated control	–	–	No film	May 13, 2004 and August 6, 2004
	Methyl bromide (98%)	448	Noble plow	HDPE	
	Iodomethane (50%) + chloropicrin (50%)	448	Noble plow	HDPE	
	1,3-dichloropropene	380	Modified Telone rig	HDPE	
	1,3-dichloropropene (61%) + chloropicrin (35%)	600	Modified Telone rig	HDPE	
	1,3-dichloropropene (62%) + chloropicrin (35%)[d]	600	Subsurface drip	HDPE	
	1,3-dichloropropene (61%) + chloropicrin (35%)	600	Modified Telone rig	VIF	

[a] Abbreviations: HDPE, high-density polyethylene; VIF, virtually impermeable film.

[b] Telone® II, Dow AgroSciences LLC, Indianapolis, IN 46268.

[c] Telone® C-35, Dow AgroSciences LLC, Indianapolis, IN 46268.

[d] InLine®, Dow AgroSciences LLC, Indianapolis, IN 46268.

in the lab at room temperature (21 C) in darkness for 24 h. Imbibed seeds were cut with a scalpel and placed in another petri dish containing a Whatman® No. 1 filter paper. The cut surface of the seed was laid on the filter paper. The filter paper was moistened with 1 ml of a 0.1% (w/v) 2,3,5-tetrazolium chloride[10] solution, resealed with parafilm®, placed in the cabinet for 24 h, and examined under a microscope for staining of the embryo. The seeds with a stained embryo were deemed viable.

In each plot, a crop row (bed) was selected at random and maintained as the data row for the duration of the experiment. All the weeds in a strip 45 cm wide by the length of the plot were counted and then hand weeded with a hoe. Hand-weeding time in each data row was recorded in successive evaluations conducted every 2 to 3 mo to estimate fall, winter, spring, and summer weed emergence. Evaluations at Oakdale were done 5, 6, 9, 11, and 13 mo after fumigation. At Yuba City, the evaluations were done 4, 6, 8, 10, 12, 17, 20, and 26 mo after fumigation. At Le Grand, evaluations were done 8, 10, 13, 15, and 18 mo after fumigation, whereas at Hickman the evaluations were done 3, 7, 9, 14, 20, and 23 mo after fumigation. Care was taken to remove every emerged weed in the hand-hoeing process to avoid escapes that could otherwise result in counting of the same weeds in successive evaluations. The remaining rows in each plot were hand weeded by the nursery field crew after evaluations on the data row were completed.

All data were analyzed with the use of SAS (1998). Data were tested for homogeneity of variance with the Shapiro–Wilk test with the use of PROC UNIVARIATE. Several conventional transformations failed to improve homogeneity of variance, so analysis was performed on nontransformed data with the use of PROC MIXED and least-square means were separated with the use of the PDIFF option at $P < 0.05$ level of significance. Data on seed viability was expressed as a percentage of nonfumigated control, i.e., viability for the nonfumigated control was considered 100%, and the data for each fumigant treatment was normalized as a percent of nonfumigated control. There were no interactions ($P > 0.05$) between fumigant treatments and depth of seed burial or between fumigant treatments and nursery locations; therefore, viability data were pooled across soil depths and nursery locations. Because of significant interactions ($P < 0.05$) between treatment and location for weed density (number/m^2) and hand-weeding time (h/ha), these data were analyzed by nursery location. Hand-weeding times over the growing season were summed and data analysis was conducted on cumulative time.

Results and Discussion

Weed Seed Viability. All the fumigants reduced the percentage of viable weed seeds compared to the nonfumigated control treatment (Table 3). However, the percentage of viable seeds of tall morningglory, common purslane, and johnsongrass after fumigant treatments were much lower than field bindweed or little mallow. Differences in the percentage of viable seeds also were observed between the fumigation treatments. For example, 1,3-dichloropropene (1,3-D) and 1,3-dichloropropene + chloropicrin (1,3-D:PIC) (applied with HDPE or VIF film) were as effective as MeBr in reducing tall morningglory seed viability. The 1,3-D:PIC (I) treatment also was as effective as the 1,3-D and 1,3-D:PIC treatments, whereas iodomethane (IM:PIC) provided the least control of tall morningglory (Table 3).

All the alternative fumigants, except IM:PIC, provided similar or better reduction in the number of viable seeds of common purslane compared to MeBr. The 1,3-D and 1,3-

Table 3. Effect of fumigants on the viability of weed seeds.[a,b]

Treatment[c]	Weed species				
	Tall morningglory	Common purslane	Johnsongrass	Field bindweed	Little mallow
	% viability				
Nonfumigated control	100.0 a	100.0 a	100.0 a	100.0[d] a	100.0 a
Methyl bromide	9.9 d	27.1 c	26.6 d	76.8 b	85.7 c
Iodomethane (50%) + chloropicrin (50%)	27.2 b	42.1 b	52.9 b	77.3 b	90.6 b
1,3-dichloropropene	13.1 cd	15.5 d	18.4 cd	80.6 b	91.9 b
1,3-dichloropropene (61%) + chloropicrin (35%) (HDPE)	15.7 cd	18.6 cd	26.2 cd	74.6 b	90.7 b
1,3-dichloropropene (62%) + chloropicrin (35%)	17.1 c	26.8 c	31.6 c	–[e]	91.4 b
1,3-dichloropropene (61%) + chloropicrin (35%) (VIF)	14.1 cd	25.3 c	45.4 cd	96.1 a	90.8 b

[a] Abbreviations: HDPE, high-density polyethylene; VIF, virtually impermeable film.

[b] Viability of weed seeds for the nonfumigated control considered 100% and the data for each treatment were normalized as a percent of nonfumigated control.

[c] Treatment means are averaged over soil depths and nursery locations because there were no interactions ($P > 0.05$) between these two variables and treatment.

[d] Means within a column followed by the same letter do not differ at a 0.05 level of significance.

[e] Not tested on field bindweed.

D:PIC treatments resulted in the greatest reduction in the number of viable seeds of common purslane seeds, whereas IM:PIC resulted in the least reduction.

Differences between the fumigants also were observed for reduction of johnsongrass seed viability. For example, 1,3-D and 1,3-D:PIC (applied with a HDPE film or VIF) were as effective as MeBr in reducing johnsongrass seed viability. The 1,3-D:PIC (I) treatment was less effective than MeBr but was similar to the 1,3-D and 1,3-D:PIC treatments. Among the fumigants, IM:PIC was the least effective on johnsongrass and resulted in only about a 53% reduction in the number of viable seeds (Table 3). From these results, it can be concluded that the alternative fumigants 1,3-D, 1,3-D:PIC, and 1,3-D:PIC (I) can reduce the percentage of viable seeds of common nursery weeds such as tall morningglory, common purslane, and johnsongrass. However, IM:PIC was generally less effective on these weed seeds compared to MeBr and the other fumigants. Fennimore and Haar (2003) reported that 1,3-D:PIC (InLine®), 1,3-D:PIC, chloropicrin, and metam sodium also effectively reduced the percentage of viable seeds of prostrate knotweed (*Polygonum aviculare* L.), another common weed in perennial nurseries in California.

Although field bindweed and little mallow seeds were less affected than the other weed species by fumigation, all of the treatments except 1,3-D:PIC (VIF) reduced the viability of field bindweed seeds by 19 to 25% (Table 3). For little mallow, MeBr resulted in about a 15% reduction in number of viable seeds, whereas the other fumigation treatments resulted in about a 10% reduction (Table 3). This shows that field bindweed and little mallow are more difficult to control with the fumigants compared to the other weed species. Haar et al. (2003) also reported no effect of chloropicrin on little mallow seeds, and the type of film (HDPE or VIF) had very little effect on percent seed viability of this species. Similarly, Fennimore and Haar (2003) reported very little reduction in percentage of viable seeds of little mallow with 1,3-D:PIC, 1,3-D:PIC (InLine®), chloropicrin, and metam sodium.

The seed coat of field bindweed is relatively impermeable and has physical exogenous dormancy that helps the seeds to persist in the soil for a long time (Makowski and Morrison 1989; Rolston 1978). Similar limitation of fumigant entry into the seed or embryo of little mallow may also be attributed to its hard seed coat (Egley 1986). However, seed impermeability can vary with time and place of collection due to differences in relative humidity, temperature, light, soil fertility, and genetic factors (Rolston 1978). The field bindweed seeds used in this experiment were locally collected and thus probably were adapted to the warm and arid conditions that exist in the central valley of California. Very little reduction in the percentage of viable seeds of burclover (*Medicago polymorpha* L.), another common weed in perennial nurseries in California, by fumigants has also been reported (Agamalian et al. 1994). This again can be attributed to the hard seed coat of burclover (Porqueddu et al. 1996). Therefore, seed characteristics can play an important role in the susceptibility of weed seeds to fumigants, including MeBr, and the success of the fumigants in providing weed control will be influenced by the weed seed species prevalent in the soil seed bank. Supplemental weed control measures may be necessary, therefore, to manage hard-seeded weed species in perennial nurseries with any of the fumigants used in this study.

Weed Emergence Patterns and Density. Native weed seedling densities were generally reduced by all the fumigation treatments compared to the nonfumigated control at all locations (Figures 1A–D). Total weed densities differed among nursery locations. For example, weed densities in general were very low in Oakdale (Figure 1A) compared to the other locations (Figures 1B–D). At Oakdale, weed densities were lowest in the IM:PIC treatment during February, whereas the other fumigant treatments had similar weed densities. In March, weed densities were similar among all fumigated treatments, which had densities lower than the nonfumigated control. The herbicide application in April resulted in good weed control, and very few weeds emerged in any of the plots through most of the summer. No differences occurred between any of the treatments in June. More weeds emerged in the nonfumigated plots in September, compared to the fumigated plots. By the end of the season, prior to crop harvest, there was considerable variability in weed emergence in all the plots. Therefore, no differences in weed densities were observed between any of the treatment plots (Figure 1A).

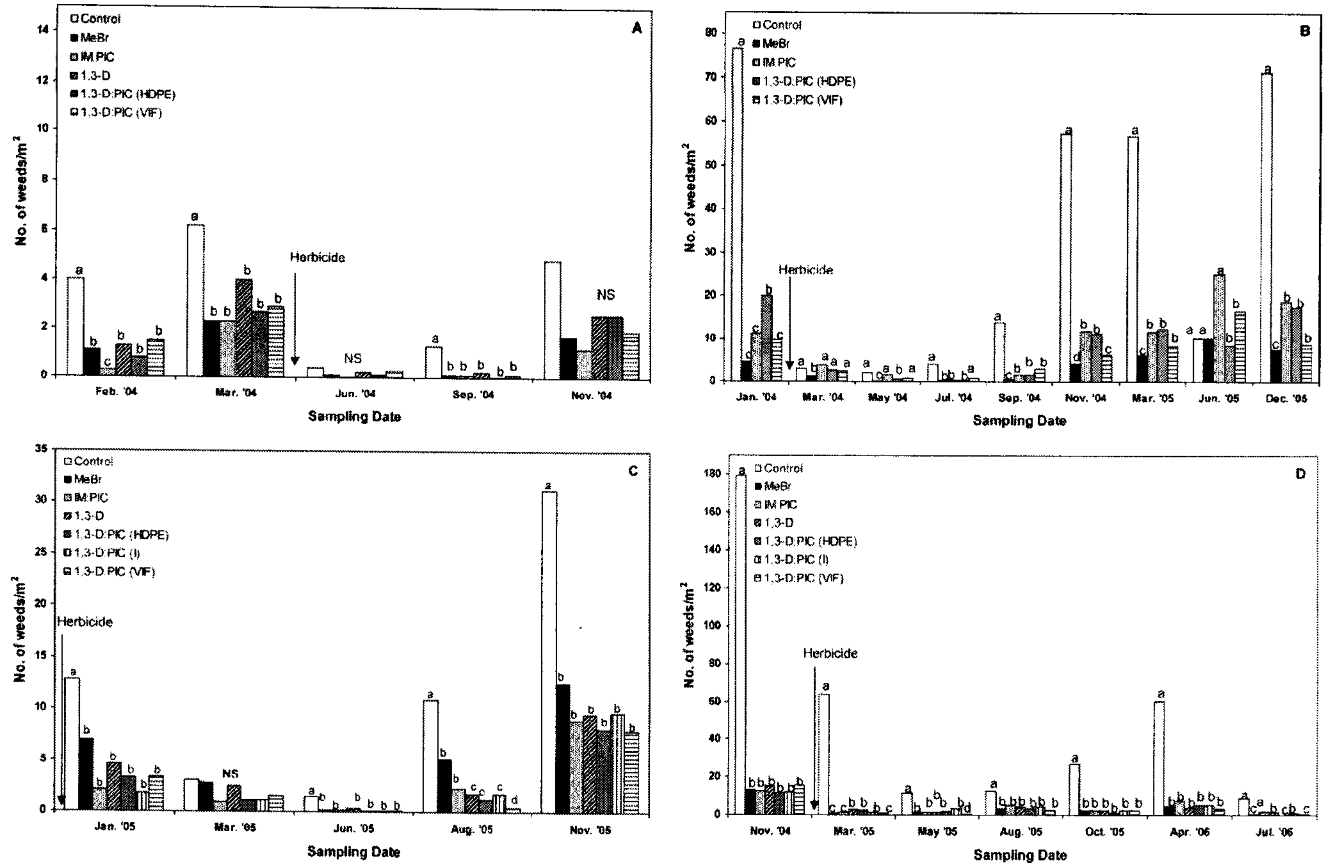

Figure 1. Total weed densities over time in the treatment plots at (A) Oakdale, (B) Yuba City, (C) Le Grand, and (D) Hickman. Bars with the same letters, within a sampling date, are not different from one another at the 5% level of significance.

The major weed species at the Oakdale site were Spanish clover [*Lotus purshianus* (Benth.) Clem. & Clem] and common purslane (data not shown). Spanish clover had once been used as a cover crop in this farm (T. Burchell, personal communication), and it is likely that the cover crop planting left a residual seed bank in the soil.

At the Yuba City site, the MeBr-treated plots had the least number of weeds at most of the sampling dates (Figure 1B). The 1,3-D:PIC (VIF) and IM:PIC were intermediate, whereas, 1,3-D:PIC (HDPE) provided the least weed control in January 2004. At the Yuba City location, the dominant weed was volunteer oats (*Avena sativa* L.) (data not shown). Oats was the previous crop in these plots. Weed populations remained relatively low until September, when common chickweed (*Stellaria media* L. Vill.) emerged as the major weed species (data not shown). More volunteer oats emerged in the spring of 2005, the second year of the trial. The other fumigant treatments generally had similar weed densities, but were lower than the nonfumigated plots.

At Le Grand, the most common weed species were common purslane, little mallow, shepherd's-purse (*Capsella bursa-pastoris* L.), and burclover (data not shown). All fumigants provided good control of most of these species (Figure 1C), except burclover and little mallow (data not shown). Hand weeding after the January evaluation removed most of the weeds, and very few weeds emerged until the end of July. In August, a new flush of weeds emerged, but all the fumigated plots had lower weed densities than the non-fumigated control plot; the lowest weed density being in the 1,3-D:PIC (VIF) plot (Figure 1C). Further weed emergence was observed at the November sampling date, but again all the fumigated plots had lower weed densities than the non-fumigated control plot.

At Hickman, all the fumigated plots had consistently lower weed densities than the nonfumigated control plot for the duration of the experiment (Figure 1D). There were some differences between the fumigants at various sampling times. For example, the MeBr, IM:PIC, and the 1,3-D:PIC (VIF) had lower weed densities than the other fumigation treatments in March 2005 whereas MeBr and 1,3-D:PIC (HDPE and VIF) had the lowest weed densities in July 2006 (Figure 1D). Glyphosate application in March controlled emerged weeds; however, there were new flushes of weeds in the nonfumigated control plots. Common chickweed continued to emerge in the spring, and its density was greatest in the nonfumigated control plots (data not shown). At all four locations, in general, there were no differences between the film type (HDPE or VIF) on weed emergence or densities.

Previous studies have shown that fumigant alternatives to MeBr that provide promising weed control include combi-

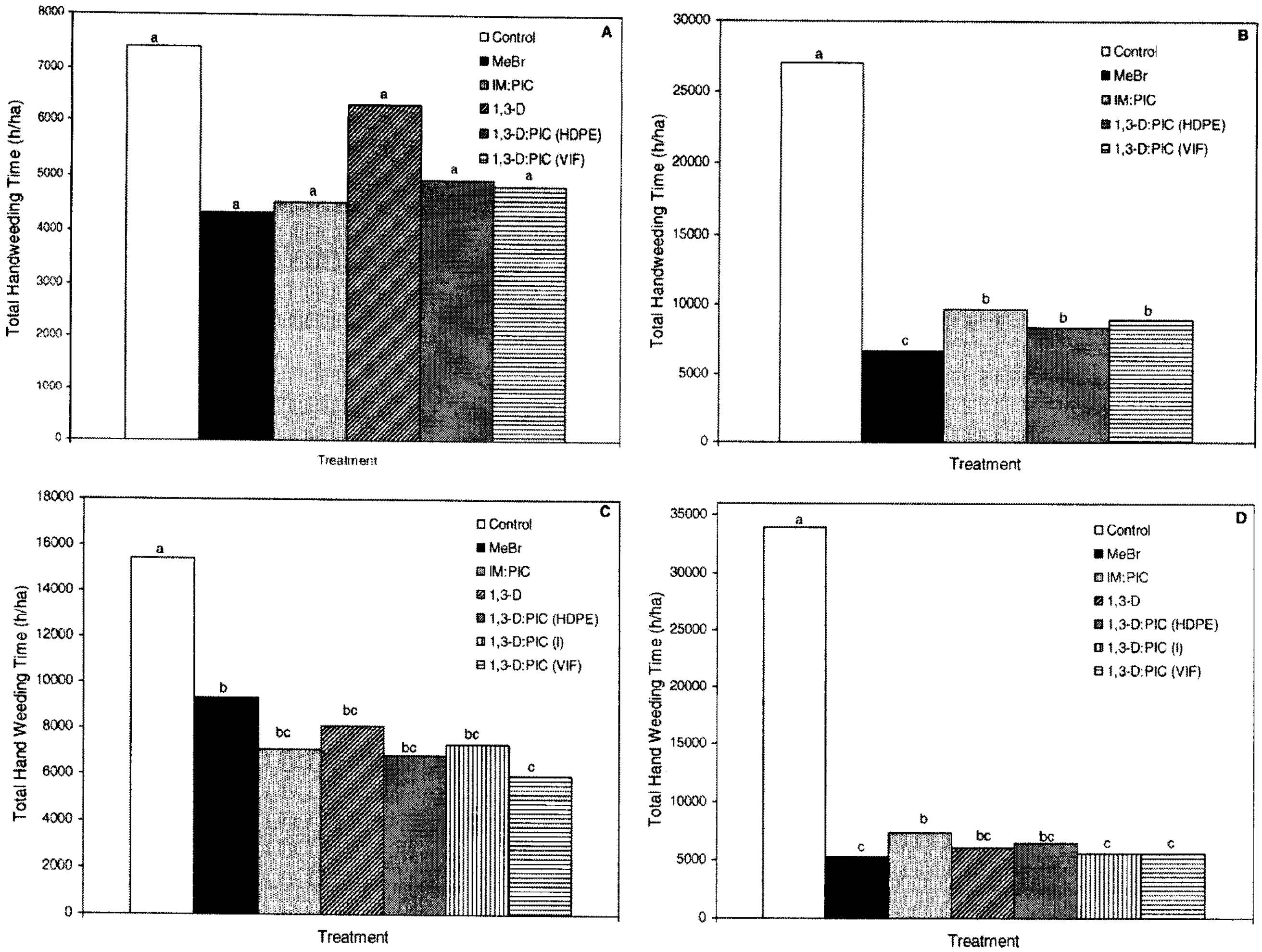

Figure 2. Total time required to hand weed the treatment plots over the entire growing season at (A) Oakdale, (B) Yuba City, (C) Le Grand, and (D) Hickman. Bars with the same letters are not different from one another at the 5% level of significance.

nations of metam-sodium plus chloropicrin, 1,3-D, 1,3-D:PIC, propargyl bromide, and iodomethane (Noling et al. 2000). Some studies suggest that, on average, chloropicrin or 1,3-D alone does not control weeds as well as MeBr (Goodhue et al. 2005). Alternative fumigants such as chloropicrin and 1,3-D:PIC have been reported to control the harder-to-suppress weeds such as nutsedges (Chase et al. 2006; Gilreath et al. 2005). Control of purple nutsedge was further improved when pebulate was applied in addition to 1,3-D:PIC and chloropicrin (Gilreath and Santos 2004). However, Locascio et al. (1997) reported poor control of nutsedges with low rates of chloropicrin. Iodomethane has also been reported to have good efficacy against yellow nutsedge (Hutchinson et al. 2003). In our study, the natural populations of yellow nutsedge were low, but when present, all the fumigants provided good control of the species (data not shown). Similar to our study, Csinos et al. (2000) also reported good control of common chickweed with chloropicrin. The alternative fumigants, in general, provided similar control of weeds as MeBr at all four locations in our study. The use of VIF did not result in increased weed control compared to HDPE film.

Hand-Weeding Time. At each nursery location, except at Oakdale, it took less time to hand weed the fumigated plots than the nonfumigated control plots (Figures 2A–D). These estimated hand-weeding times may be greater than that for a regular hand-weeding field crew used in these commercial nurseries because, in the experiment, care was taken to seek and remove every weed in the plots to prevent them from being recounted in the next sampling date. As mentioned earlier, weed densities were much lower at Oakdale than at the other sites, and all the fumigated plots took the same amount of time to hand weed as the nonfumigated control plots (Figure 2A). The 1,3-D treated plots at Oakdale tended to have greater weed densities than the other fumigated plots during the growing season (Figure 1A), and also tended to require more hand weeding (Figure 2A), but the difference was not statistically significant.

At Yuba City, the plots with the alternative fumigants required similar hand-weeding times, which was greater than that for MeBr but much lower than the for the nonfumigated control (Figure 2B). Weed densities were consistently low in the MeBr-treated plots at this site during the 2-yr growing period (Figure 1B), which partially accounts for the relatively low hand-weeding times. Differences in hand-weeding times could also have been influenced by the type of weed species present. For example, densities of johnsongrass and field bindweed were greater in some plots and it took longer to hand weed plots with these species because of their well-developed root system compared to other species.

At Le Grand, most of the alternative fumigants, except the 1,3-D:PIC (VIF) treatment, required similar hand-weeding time as the MeBr plots (Figure 2C). Although the 1,3-D:PIC (VIF) plots took the same amount of time to hand weed as the other plots with alternative fumigants, the time to hand weed was shorter than that for the MeBr plots.

At Hickman, the IM:PIC plots took longer to hand weed than the MeBr or the 1,3-D:PIC (I) and 1,3-D:PIC (VIF) plots (Figure 2D). However, all the 1,3-D plots with or without chloropicrin and regardless of the film type took similar amount of time to hand weed as the MeBr plots.

This study showed that the tested fumigant alternatives, with some exceptions, generally provided similar weed control as MeBr in perennial nurseries and could potentially replace MeBr. For the weed species tested in this experiment, the alternative fumigants were similar to MeBr in reducing the percentage of viable seeds. However, weed species differed in their level of susceptibility to the fumigants. The fumigants, including MeBr, reduced the viability of tall morningglory, common purslane, and johnsongrass seeds better than that of field bindweed and little mallow. Some differences were observed among the fumigants in their efficacy against certain weed seeds. IM:PIC had the least impact on tall morningglory and common purslane seed viability. 1,3-D caused the greatest reduction in the number of viable seeds of common purslane. Although total weed densities and the level of control provided by each fumigant differed among locations, weed seedling density was generally reduced by all the fumigation treatments compared to the nonfumigated control. The weed densities observed in this study suggest that alternative fumigants, in general, will provide similar control of weeds as MeBr. However, weed species with hard seed coats, such as field bindweed, burclover, and little mallow, may not be adequately controlled by any of the fumigants and will likely require additional weed control measures. All the alternative fumigants resulted in similar reduction in time required for hand weeding as MeBr in three of the four locations. Film type (HDPE or VIF) did not result in differences in weed control or time required for hand weeding. Therefore, the alternative fumigants tested in this experiment could be suitable as replacements to MeBr for weed control in perennial fruit nurseries. However, as Hanson and Shrestha (2006) reported, decisions on weed management can depend on environmental and soil factors, weed species present, crop grown, and the cropping system; thus development of a single alternative to MeBr for all regions or cropping systems is highly unlikely. Rather, crop and region-specific integrated pest management systems will be necessary.

Sources of Materials

[1] Noble plow, Tri-Cal, Inc., P.O. Box 1327, Hollister, CA 95024.

[2] Telone rig, Tri-Cal, Inc., P.O. Box 1327, Hollister, CA 95024.

[3] Commercial applicator, Tri-Cal, Inc., P.O. Box 1327, Hollister, CA 95024.

[4] Drip tubing, Netafim USA, 5470 East Home Avenue, Fresno, CA 93727.

[5] High-density polyethylene, Tyco Plastics, Princeton, NJ 08540.

[6] Virtually impermeable film, Bruno Riminni Ltd., London N12 8NP, UK.

[7] Seeds of weeds, Valley Seed Service, P.O. Box 9335, Fresno, CA 93791.

[8] No. 1 filter paper, Whatman Inc., Clifton, NJ 07014.

[9] Parafilm®Pechiney Plastic Packaging, Menasha, WI 54952.

[10] 2,3,5-tetrazolium chloride solution, Fisher Scientific, Pittsburgh, PA 15275.

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