ALTERNATIVE PRE-PLANT SOIL FUMIGATION TREATMENTS FOR DECIDUOUS TREE CROPS

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Introduction. Pre-plant use of methyl bromide (MB) for perennial deciduous tree crops in California is directed at management of complex biological "replant problems" and meeting sanitation standards for nursery stock certification. Mature orchards commonly support populations of plant parasitic nematodes, pathogenic fungi and bacteria, as well as unknown biological agents that can interfere with establishment and growth of replanted trees. The negative effects of these agents can be pronounced in the first few years after tree planting, but economic impacts of replant problems typically persist for the life of an orchard. Pre-plant fumigation has provided growers with an efficient and generally economical means to manage these complex replant problems, but the loss of MB and increasing regulatory restrictions on other fumigants is requiring continued reassessment of treatment options. California nursery crop certification programs rely to a large extent on pre-plant fumigation to produce clean stock, and certification protocols have emphasized complete control of plant parasitic nematodes. As MB is phased out, it will be challenging to meet the certification standards, particularly on fine-textured soils where fumigants generally are less effective. Deciduous nurserymen have relatively little experience with some of the MB alternatives or virtually impermeable films (VIF). VIF has proven effective in optimizing fumigant applications for strawberry (Fennimore et al, 2003) and could provide similar benefits for orchard and nursery industries.

Objectives. In fall 2003, we initiated research with the following objectives:

1. To determine effects of promising short-term MB alternatives on vegetative performance of almond and walnut nursery stock at commercial nurseries.
2. To determine effects of the alternatives on weed, nematode, and disease incidence at commercial nurseries.
3. To determine effects of promising short-term MB alternatives on health and productivity of replanted almond trees in commercial orchards.
4. To determine relative benefits of tree-site, row-strip, and broadcast treatments with the alternatives in commercial almond orchards
5. To complete cost-benefit analyses for the MB alternatives at commercial almond and walnut nurseries and almond orchards.
6. To demonstrate the performance of promising MB alternatives to nurserymen and growers and provide them with the key biological and economic information that they need for efficient transition to alternative fumigation strategies.

Progress. Nursery trial 1 (peach/plum) and 2 (walnut) were fumigated and planted in 2003/4 while nursery trials 3 (almond) and 4 (almond) were fumigated and planted in 2004/5. Nursery trial 1 is on a sandy loam soil in Stanislaus County and was fumigated and planted in 2003/4 to peach and plum on Myrobaln 29C rootstock. Nursery trial 2 is on a clay loam soil in Yuba County and was fumigated and planted in 2003/4 to walnut on Paradox rootstock. Nursery trial 3 is on a clay loam soil in Merced County and was fumigated and planted in 2004/5 to almond on Nemaguard rootstock. Nursery trial 4 is on a loam soil in Stanislaus County and is planted to almond on Nemaguard and Lovell rootstock. Nursery fumigation treatments are described in Table 1. In addition to the nursery trials, two orchard trials, one with almond replanted after almond and the other with almond planted after grape were also planted in 2003/4. Both of the orchard trials are located in Madera County on loam soils.

Data were collected in on nematode, weed, and pathogen survival in the nursery fumigation trials (Tables 1,2) and plant growth in the nursery and orchard trials (Table 3). Propagules of *Pythium ultimum*, citrus nematode, and several species of weeds were buried at different depths in soil of the nursery plots before fumigation and retrieved after fumigation to determine incidence of survival. Natural populations of nematodes and weeds are also being monitored in the plots. Midday stem water potential was measured approximately monthly on 1-4 trees per replication at each trial.

In nursery trials 1 and 2, all fumigation treatments killed most bagged inoculum of *Pythium ultimum* and all bagged inoculum of citrus nematode (Table 3). At nursery trial number 3, Telone II and Inline did not effectively kill *Pythium ultimum* at any depth, nor did Telone C35 at the 60 and 90cm depths. At nursery trial 4, IM-Pic and Inline did not effectively kill *Pythium ultimum*, particularly at the deeper levels. At nursery trials 3 and 4, results for Citrus nematode were similar to those for *Pythium ultimum* at the deeper depths but better control was achieved at the shallower depths (Table 3). Weed data from the nursery trials are presented in a separate report at this conference (Shrestha et al).

To date, nursery fumigation treatments have had only small or negligible effects on performance of the planted stock. Seedling emergence was significantly higher for one Telone C35 treatment at nursery trials 2-4 (Table 3). There were no significant differences in marketable trees, tree diameter or tree weight for any of the fumigation treatments in the final harvest from nursery 1 (Table 2). At nursery 1, trees were significantly less water stressed (less negative value of midday stem water potential) for the methyl bromide, IM:Pic, and Telone C35-VIF treatments although these differences did not translate to significant differences in tree harvest characteristics (Table 2).

In Orchard Trial 1, which involved replanting almond after pre-plant fumigation treatments in the cleared site of an old almond orchard, most of the broadcast and row-strip treatments with Telone II, Telone C35, IM:Pic, and Pic marginally increased tree trunk diameters, compared to the non-fumigated controls (Table 4, Experiment 1a). Trunk growth following MB broadcast and MB row strip treatments was intermediate between that of the controls and that of most other fumigation treatments, and MB row strip treatments under VIF did not improve tree growth. The tree site treatments, which were applied later than the broadcast and row-strip treatments caused phytotoxicity and did not improve plant growth (Table 4, Experiment 1b). The untreated control tended to be the most water stressed and also was near the lowest growing treatments (Table 4, Experiment 1).

In Orchard Trial 2, which involved replanting almond after pre-plant fumigation treatments on land formerly devoted to an old vineyard, there was no important effect of the pre-plant treatments on growth of the replanted almond trees. All of the replants grew vigorously (Table 4, Experiment 2). The untreated control was the least water stressed and tended to have the greatest growth in Orchard Trial 2 (Table 4, Experiment 2). In general trees at Orchard Trial 2 grew less water stressed and grew better than those at Orchard Trial 1 (Table 4).

Discussion. Nursery trials number 2-4 will be harvested in the fall of 2005. These data are needed before detailed conclusions and economic analyses are possible. Across all the nursery trials, methyl bromide was most effective for control of bioassay populations of *P. ultimum* and citrus nematode. Telone C35 was effective at all nursery trials at the 15-30 cm depths but tended to give more inconsistent control at deeper depths. Overall, at least one alternative fumigant gave effective control at each trial. Monitoring of plant growth, plant health, natural nematode, weed, and disease incidence will continue through the nursery tree harvests (winter 2005 for nursery trials 2-4).

The two established orchard trials represent two common replant scenarios for the San Joaquin Valley of California, namely planting new almond trees to replace an old almond orchard or an old vineyard. Our plant growth measurements to date suggest that most of the fumigation treatments will prove beneficial at the old almond site, but there is no current indication of benefit at the old vineyard site. The initial growth responses of the replanted almonds are consistent with peach-grape replant disease cross-specificity trials that we have conducted in pots and micro plots. Nevertheless, treatment effects may change as the experimental almond trees develop and plant parasitic nematode populations build (detected before planting at the old vineyard site but not the old almond site), and growth and productivity data will be collected in these orchard trials for several years.

It is important in the future to test alternative tree-site, row-strip, and broadcast treatments in high-risk replant scenarios. For example, a severe replant problem, referred to as replant disease, has occurred in the upper Sacramento Valley. There, almond trees replanted at old almond orchard sites have failed to establish (50 to 90% tree loss) in a few severely affected orchard blocks. Tree site or broadcast fumigation with chloropicrin and tree-site fumigation with several other fumigants has prevented replant disease. Another severe replant problem commonly occurs in course-textured soils of the upper San Joaquin Valley, where ring nematode populations can reach high levels and contribute poor tree vigor and development of bacterial canker disease.

Table 1. Fumigation treatments and mulching system by nursery.

Fumigant	Rate lb/acre	Mulch	Nursery			
			1 (peach/plum on loam soil)	2 (walnut on clay loam soil)	3 (almond on clay loam soil)	4 (almond on loam soil)
None	0	None	+	+	+	+
MB	400	HDPE	+	+	+	+
IM:Pic (50:50)	400	HDPE	+	+	+	+
Telone II	354	HDPE	+	0	+	+
Telone C35	560	HDPE	+	+	+	+
Telone C35	560	VIF	+	+	+	+
Inline	560	HDPE	0	0	+	+

Table 2. Final tree harvest data from Nursery 1.

Nemaguard peach

Fumigant	Rate lb/acre	Mulch	Marketable trees/meter	Diameter (cm)	Weight (kg/tree)	Seasonal average midday stem water potential (bars)
None	0	None	5.5	1.37	0.41	-17.6
MB	400	HDPE	5.7	1.35	0.45	-15.7*
IM:Pic (50:50)	400	HDPE	4.9	1.27	0.40	-14.3*
Telone II	354	HDPE	5.2	1.47	0.42	-15.6
Telone C35	560	HDPE	5.5	1.52	0.42	-18.0
Telone C35	560	VIF	5.0	1.57	0.35	-17.4*
			nsd	nsd	nsd	lsd=1.7

Prune/Myrobalan 29C

Fumigant	lb/acre	Tarp	Marketable trees/meter	Diameter (cm)	Weight (kg/tree)
None	0	None	5.8	1.40	0.54
MB	400	HDPE	5.9	1.37	0.62
IM:Pic (50:50)	400	HDPE	5.8	1.47	0.64
Telone II	354	HDPE	5.1	1.22	0.56
Telone C35	560	HDPE	5.7	1.14	0.56
Telone C35	560	VIF	5.8	1.14	0.55
			nsd	nsd	nsd

Table 3. Treatment descriptions, pest survival and emergence data for nursery trials.[a]

Trial	Pre-plant fumigation treatment	Mulch system	Survival of Pythium ultimum (cfu/g soil) at depths in soil[b]				Number. of surviving Citrus nematodes at depths in soil[b]				Emergence (#/meter)
			15cm	30cm	60cm	90cm	15cm	30cm	60cm	90cm	
1	None	None	309	378	406	481	-	1180	1108	1181	10.7
	MB 98:2	HDPE	0	0	0	81	-	0	0	0	11.7
	IM:Pic 50:50	HDPE	0	0	0	0	-	0	0	0	9.8
	Telone II	HDPE	0	0	5	122	-	0	0	0	10.8
	Telone C35	HDPE	0	0	22	47	-	0	0	0	10.0
	Telone C35	VIF	0	0	0	0	-	0	0	0	10.3
											lsd=1.2
2	None	None	431	466	481	556	1109	1204	1080	1219	6.7
	MB 98:2	HDPE	0	0	0	0	0	0	0	0	8.7
	IM:Pic 50:50	HDPE	0	0	50	137	0	0	0	0	9.0
	Telone C35	HDPE	0	0	0	218	0	0	0	0	9.2
	Telone C35	VIF	0	0	6	131	0	0	0	0	9.5*
											lsd=2.6
3	None	None	2775	3019	2755	3103	4859	5124	5426	5183	13.9
	MB 98:2	HDPE	0	0	163	0	0	0	0	0	13.8
	IM:Pic 50:50	HDPE	0	0	0	500	0	0	0	0	13.1
	Telone II	HDPE	191	653	1731	2311	1	0	399	585	13.5
	Telone C35	HDPE	0	0	972	1487	0	0	0	0	17.5*
	Telone C35	VIF	0	0	216	1397	0	0	0	1	13.6
	Inline	HDPE	272	1266	2013	2266	21	0	339	1039	15.7
											lsd=1.9
4	None	None	1631	1591	1519	1775	1890	1801	1687	1119	9.7
	MB 98:2	HDPE	0	0	0	0	0	0	0	0	9.8
	IM:Pic 50:50	HDPE	3	131	228	244	2	51	65	172	9.2
	Telone II	HDPE	0	0	0	22	0	0	0	0	10.7
	Telone C35	HDPE	0	0	0	6	0	0	0	0	12.0*
	Telone C35	VIF	0	0	0	0	0	0	0	0	9.6
	Inline	HDPE	0	13	916	1438	0	0	17	103	8.8
											lsd=2.0

*indicates significant difference in emergence from untreated control at 5% level
[a]Fumigation treatments were applied on 8/24/03, 9/11/03, 5/19-20/04, and 8/6/04 for Trials 1-4 respectively
[b]Survival of Pythium ultimum and citrus nematode was determined in artificially infested soil, buried in bags at soil depths indicated, then retrieved to determine viability.

Table 4. Preliminary plant growth data, Orchard Trials 1 and 2, almond replanted after almond, and almond replanted after grape, respectively

Site	Fumigant, rate	Plot area treated	Mulch system	Increase in trunk diam. (mm)[d]	2004 seasonal average midday stem water potential (bars)
1-A[a]	Control	None	None	24	-10.9
	Control	None	VIF row strip	23	-10.4
	MB, 448 kg/ha	Broadcast (100%)	None	25	-9.7*
	MB, 448 kg/ha	Row strip (38%)	None	25	-10.7
	MB, 448 kg/ha	Row strip (38%)	VIF row strip	21	-9.7*
	Telone II, 380 kg/ha	Broadcast (100%)	None	28	-10.1
	Telone II, 380 kg/ha	Row strip (38%)	None	27	-10.3
	Telone II, 380 kg/ha	Row strip (38%)	VIF row strip	24	-9.5*
	Telone C35, 600 kg/ha	Broadcast (100%)	None	31	-8.9*
	Telone C35, 600 kg/ha	Row strip (38%)	None	30	-9.0*
	IM:Pic (50:50), 448 kg/ha	Broadcast (100%)	None	31	-9.0*
	IM:Pic (50:50), 448 kg/ha	Row strip (38%)	None	28	-10.4
	Pic 448 kg/ha	Broadcast (100%)	None	26	-9.8*
	Pic, 448 kg/ha	Row strip (38%)	None	31	-9.2*
	Pic, 448 kg/ha	Rowstrip (38%)	VIF row strip	31	-9.4*
			95% confidence interval limits:	*+/-4*	*lsd = 1.1*
1-B[b]	Control	None	None	24	-10.9
	MB, 0.5 kg per tree site	Tree site[e]	None	23	-10.7
	Pic	Tree site	None	21	-10.3
	Telone II	Tree site	None	19	-10.4
			95% confidence interval limits:	*+/-3*	*lsd = 1.1*
2[c]	Control	None	None	34	-9.0
	Control	None	VIF row strip	34	-9.4
	MB, 448 kg/ha	Broadcast (100%)	None	32	-9.5
	MB, 448 kg/ha	Row strip (38%)	None	30	-9.4
	MB, 448 kg/ha	Row strip (23%)	None	31	-9.0
	MB, 448 kg/ha	Row strip (38%)	VIF row strip	31	-9.3
	Telone II, 380 kg/ha	Broadcast (100%)	None	32	-9.7*
	Telone II, 380 kg/ha	Row strip (38%)	None	32	-9.1
	Telone II, 380 kg/ha	Row strip (38%)	VIF row strip	30	-9.7*
	Telone C35, 600 kg/ha	Row strip (38%)	None	30	-9.4
	Telone C35, 600 kg/ha	Row strip (38%)	VIF	29	-9.5
	IM:Pic (50:50), 448 kg/ha	Broadcast (100%)	None	32	-9.1
	IM:Pic (50:50), 448 kg/ha	Row strip (38%)	None	33	-9.5
	Pic 448 kg/ha	Row strip (38%)	None	31	-9.3
	Pic, 448 kg/ha	Row strip (23%)	None	28	-9.0
	Pic, 448 kg/ha	Rowstrip (38%)	VIF row strip	31	-9.4
			95% confidence interval limits:	*+/-4*	*lsd = 0.7*

[a]Fumigants applied 27 October 2003
[b]Fumigants applied 10 November 2003
[c]Fumigants applied 11 November 2003
[d]From 16 March to 31 August 2004
[e]Applied at depth of ca 45 cm, one probe per tree site