G. Experimental Methods and Materials

Typically when growers see RP, they see poor growth in their young plantings. In an effort to correct the problem, they apply fertilizers, amendments, nematicides, new techniques and elixirs. If that doesn't work, they question the health of their nursery stock and the quality of their soil preparation. After years of replanting fields plus gathering information from neighbors, the grower begins to recognize a pattern:

- RP is worse in sandier soil, alkaline soil or marginal soils in general.
- RP is worse when the planting follows peach.
- Walnuts grow better after almond (usually on peach rootstock) than after walnut.
- Apples have a specific RP (where soil pests receive blame) compared to a general RP.
- Citrus doesn't experience RP. This is not true!
- Many crops do well after grape except more grapes.
- In general, the greater RP problems typically involve replanting the same crop (referred to as specific replant problem). However, there is also a general replant problem when following perennials with more perennials.

The observations above are usually associated with negative experiences in a particular region. Within these observations lie confusion as well as the truths about RP. The problem is, these observations were selectively analyzed only at the visible level. RP damage occurs as a result of microorganisms and the ecosystems they develop overlain by differing influences of plants, soil textures and farming practices.

Many growers have also observed that fumigation almost always solves the problem, including controlling weeds. Once they had experienced the benefits of fumigation, they were not interested in experimenting with other ways to solve the problem, except for an occasional small acreage grower who wants to avoid the ever-increasing cost of fumigation.

G-1. Field Trials

Almost all studies we have conducted with RP involve replicated field trials set out in a randomized block design with at least four replicates of each treatment to be tested. Before the trials begin, we know the nematode populations, soil moisture content and temperature at time of treatment, and the obvious growth limiting pests or diseases coupled with a cropping history and soil map for the land. Nematode population levels are used to bioassay the rate of nematode buildup for the next 2 yr following a variety of treatments. At 30 to 60 days after treatment, soil samples are collected from each replicate of each treatment at 1-ft increments down to the 5-ft depth. A finding of 98% nematode control averaged across those samples is essential if nematode protection is to persist longer than 6 mo. If nematodes are found 30 days after any fumigation treatment, a backhoe is used to assess the viability of remnant roots.

Once replanted, the rate of nematode return is monitored at 6-mo intervals from the surface 18 inches of soil surrounding the new root system. Plant growth is measured annually by trunk circumferences, plant height, pruning weights, or by collecting total plant biomass annually for 2 yr after treatment. These field trials involve constant effort to limit contamination from one plot to another by building barriers, avoidance of vehicular traffic and the following of traffic patterns. There is always a MB or 1,3-D comparison and a nontreated check.

G-2. Small Experimental Plots

We have 650 macro and micro plots which involve open-bottomed containers with side walls reaching 4 to 5 ft deep with 30 to 435 sq ft of field surface area in each plot. These nematode-infested sites have permitted as many as a dozen replicates for treatments from biocides to cover crops to nematicides to biocontrol agents where grapes can be grown for up to 2 yr as a bioassay of performance.

G-3. Commercial Plots

Any references to drenching refer to delivery of products within 6 inches of water using a non-commercial device having a single dripper emitter placed on each sq ft of field surface delivering product slowly mixed into water for 8 hr. References to transported non replant problem soil (NRPS) involve a Vermeer tree spade (see top of Photo Array 10, page 17) capable of delivering an inverted cone of soil 3 ft deep and 50 inches across at the field surface. References to a backhoeing treatment refer to digging with a tractor-mounted, 18 to 24 inch bucket to the 5 to 6 ft depth and then caving in the four side walls. The spoil pile is then placed onto the remaining pit and packed down.

Drenching, transporting NRPS, backhoeing, and applications of systemic herbicides to old trees and vines are experimental methods we have evaluated in commercial settings. We never seem to have enough data from commercial plots but it is this type of work that is needed to field test the notions put forth in this text.

H. Results and Discussion

H-1. Comparison of More than 135 Potential Alternatives to Solve Components of RP

Listed in Table 1 is a comparison of the performance of various treatments having the potential to solve one or more components of RP. Most of these evaluations were conducted from 1993 to 1998 although some emanate from previous field trials conducted by the author.

In Table 1 the treatments are listed beneath sub headings for ease of finding but the first 70 evaluations, chemical and non-chemical treatments, were commonly evaluated side by side. The last 68 evaluations were conducted in a diversity of settings so resistant rootstocks, for example, were not compared in trials adjacent to sites where post-plant treatments or NRPS were evaluated. The cryptic treatment descriptions listed in Table 1 are described in greater detail within individual progress reports cited in the literature list at the end of this text.

MB solves three components of RP. Coupled with soil ripping or backhoeing, all four components can be resolved. We are aware that MB does not completely solve the rejection component where it occurs with greatest intensity. In such settings one full year of fallowing is also beneficial. Throughout Table 1 the value of each treatment toward improving plant growth, killing remnant roots, and controlling specific soil pest problems is indicated. Treatments that do not provide 98% nematode control across the surface 5 ft of soil profile when sampled 30 to 90 days after treatment will not provide nematode relief lasting longer than the first year. For treatments where this goal is not achieved, use of resistant rootstocks or post-plant nematicides must be calculated into the future costs of production. The only “softer” treatments to provide relief from the rejection component of RP were: 1) three to four years of alfalfa rotation 2) properly applied systemic herbicides plus fallow one full year (Appendix Items 11, 12 and 13) and 3) use of transported NRPS of at least ½ yd per planting site (Appendix Items 14 and 15). Another approach is to plant rootstocks having less sensitivity to the rejection component of RP. MITC liberators do not solve the more intense rejection component as well as MB but do solve the common rejection component. We have no methods of predicting where the rejection component will be in the field or its intensity, whereas soil pest incidence is generally predictable.

As “softer” soil treatments are evaluated there is practical value to identifying which components of RP they do or do not solve.

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem.

			RP Components			% Roots	Relative Plant Growth		First-Year Nematode Control			ORF	Weed
No.	Treatment Description	Test Situation	Rej	SP	IGR	Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	Relief	Relief
Standard Comparisons													
1.	Pull trees/vines, rip, replant.	6 mo fallow	0	0	0	20	1.x	1.x	20	20	20	3 yr	0
2.	Pull, rip, dry fallow 1 full yr (=18 mo out).	a) Grape	S	0	0	20	3.	2.	90	50	20	3 yr	Some
		b) Walnut	S	0	0	20	3.	2.	90	50	–	3 yr	Some
		c) Peach/Plum	S	0	0	40	3.	2.	90	50	–	3 yr	Some
3.	Pull, rip, barley, sorghum x Sudan, vetch rotation.	18 mo rotation	S	S ecto only	S	20-40	3.5	2.	95	70	20	3 yr	Some
4.	Pull, rip, dry fallow 4 yr.	a) Grape	S	0	0	40%	7.	3.2	95%	95%	40%	3 yr	99+%
		b) Walnut	√	0	0	90	7.	3.2	99	98	–	3 yr	99+
		c) Peach/Plum	√	√	0	100	7.	3.2	99	98	–	3 yr	99+
5.	Pull, rip, MB 400 lb/acre, nontarped.	6 mo fallow	√	G	√	99.+ to 6'	7.0	3.5	99.	99.	99.	6 yr	Some
6.	Pull, rip, MB 400 lb/acre at 14" tarped.	6 mo fallow	√	√	√	99.9 to 5' deep	7.0	3.5	99.9	99.9	99.9	6 yr +	99+
Biocides													
7.	Pull, rip, MB 350 lb/acre, nontarped.	6 mo fallow	√	G	√	99.+ to 6' deep	7.0	3.5	99.	99.	99.	6 yr	Some
8.	Nontarped MB plus root removal to 6" depth.	18 mo fallow	√	√	√	99.+ to 6' deep	7.0	3.5	99.9	99.9	99.9	+	Some
9.	Pull, rip, MB 225 lb/acre at 30" depth.	6 mo fallow	√	G	√	99.+ to 6'	6.0	3.2	99.	99.	99.	–	0
10.	Pull, rip, MB 350 lb/acre at 14" tarped.	6 mo fallow	√	√	√	99.9 to 5' deep	7.0	3.5	99.9	99.9	99.9	6 yr +	99+
11.	Pull, rip, MB 225 lb/acre at 20", flip surface in 2 wk, retreat at 100 lb/acre.	6 mo fallow	√	√	√	99.9 to 5' deep	7.0	3.5	99.9	99.9	99.9	–	99+
12.	Pull, rip, 1,3-D at 325 lb/acre shanked at 18" to dried soil.	18 mo fallow	√	√	√	99.9 to 5' deep	7.	3.5	99.9	99.9	99.9	Top 4' only	Some
13.	Pull, rip, 1,3-D at 1000 lb/acre shanked at 18" to dry soil.	18 mo fallow	√	√	√	99.9 to 6' deep	8.	3.8	99.9	99.9	99.9	Top 6' only	Some
14.	Pull, rip, 1,3-D shanked at 325 lb/acre to dry soil, flip top 12" 110 lb/acre at 12".	6 mo fallow	√	√	√	99.9 to 5' deep	7.	3.5	99.9	99.9	99.9 to 5' deep	Top 4' only	99.

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

No.	Treatment Description	Test Situation	RP Components			% Roots Killed	Relative Plant Growth		First-Year Nematode Control			ORF Relief	Weed Relief
			Rej	SP	IGR		Yr 1	Yr 2	Ecto	Endo	GFLV		
15.	Pull, rip, 1,3-D at 325 lb/acre drenched by PSDD in 4.5 acre inches then 1.5 acre inches with MS at 110 lb/acre.	6 mo fallow	√	√	√	99.9 to 5' deep	7.x	3.5x	99.9	99.9	99.9 to 5' deep	Top 4' only	75
16.	Pull, rip, 1,3-D at 325 lb/acre uniformly drenched by PSDD with tarp in 6 acre inches.	6 mo fallow replant	√	√	√	99.9 to 5' deep	6.	3.2	99.9	99.9	Top 4' only	Top 4' only	90
17.	Pull, rip, MS uniformly drenched at 325 lb/acre (=100 gal/acre 32.7% Vapam) in 6 acre inches water.	6 mo fallow	G	S	√	99 to 2.5' deep	6.	3.0	99 to 5'	99 except those in deep roots	Top 2.5' only	Top 2.5' only	95+
18.	Pull, rip, MS uniformly drenched at 325 lb/acre (=100 gal/acre 32.7% Vapam) in 6 acre inches water.	No roots larger than ½ inch	√	√	√	99 to 5' deep	7.	3.5	99.9 to 5'	99 except those in deep roots	Top 2.5' only	Top 2.5' only	95+
19.	Pull, rip, MS uniformly drenched at 650 lb/acre in 6 acre inches then 1 yr fallow.	18 mo fallow	√	√	√	99.9 to 4' deep	7.	3.5	99.9	99.9 to 4'	Top 4'	1 yr only	99
20.	Pull, rip, incorporate Basamid at 325 lb/acre to top 1" then intermittent sprinkling of 6 acre inches over 15 hr.	6 mo fallow	√	S	√	99 to 2.5'	7.	3.5	99	99 except in roots	Top 2.5'	Top 2.5'	95
21.	Pull, rip, shank 325 lb/acre 1,3-D at 18" dry soil then 110 lb MS in 2 acre inches.	6 mo fallow	√	√	√	99.9 to 5' deep	7.	3.5	99.9	99.9	Top 4.5'	Top 4'	50-95
22.	Pull, rip; 1,3-D at 500 lb/acre shanked at 18" depth.	6 mo fallow	√	√	√	99.9 to 5'	7.	3.5	99.9	99.9	99.9	To 4' only	0
23.	Pull, rip; chloropicrin at 325 lb/acre shanked at 18" depth.	6 mo fallow	√	S+	√	4'	8.	3.5	98	98	98	To 4' only	0
24.	Pull, rip, 500 lb Telone C35 shanked at 18" depth.	6 mo fallow	√	√	√	99.9 to 5'	7.5	3.5	99.9	99.9	99.9	Top 4'	Some
25.	Pull, rip, Acrolein drenched at 325 lb/acre pulsed in 6 acre inches water.	18 mo fallow	√	S	√ esp. walnut	99 in top 2.5'	7.	3.5	99.+	99 in top 2.5'	Top 2.5'	Top 2.5'	Some

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

			RP Components				Relative Plant Growth		First-Year Nematode Control				
No.	Treatment Description	Test Situation	Rej	SP	IGR	% Roots Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	ORF Relief	Weed Relief
26.	Urea (lobi) drenched at 650 lb/acre in 6 acre inches then straw amend or barley crop planted.	18 mo fallow	0	S	0	20	2.0	1.2	98	98 in soil only	–	–	Some
27.	Marigold extract at 1 lb fresh wt/10 gal water + 325 lb/acre urea in 6 acre inches then 3 acre ft after 30 days.	18 mo fallow	0	S	0	20	0.8	0.9	90	90 in soil only	–	–	0
28.	Enzone at 700 ppm uniformly drenched in 6 acre inches water (=300 gpa) then 1 gpa Tillam last hr.	Non replant	–	S	√	–			98	98 in soil only	–	–	75
29.	Enzone at 2100 ppm uniformly drenched in 6 acre inches water (=900 gpa).	18 mo fallow	√	√	√	?	10% over MB	–	99.+	99	–	–	Slight
30.	1,3-D shanked at 100 to 120 lb/acre at 12" depth.	18 mo fallow	S	S	0	Top 2' only	6.	3.	98	98	–	–	0
31.	CaOHCl uniformly drenched at 325 lb/acre in 6 acre inches water.	18 mo fallow	S	0	S	20	2.	1.2	20	0	–	–	
32.	Chlorine dioxide uniformly drenched at 6 ppm in 6 acre inches at night.	18 mo fallow				20			20	0	–	–	0
33.	Furfural drenched uniformly at 325 lb/acre in 6 acre inches.	Non replant site	–	S	–	0							
34.	Peroxyacetic acid drenched at 40 gpa + 40 gpa stabilizer uniformly or pulsed in 6 acre inches water.	Non replant site	–	0	–	0	–	–	0	0	–	–	Some when pulsed
35.	Ozone shanked at 2 std ft^3 per minute into 9 ft^3 sandy soil (note in dry sandy loam soil the ozone traveled along the shank).	NRPS Replant	– 0	0 0	– –	– 0	– –	– –	0 0	0 0	– –	– –	0 0
36.	Harvest, drench 500 ppm MS to old row, pull, replant after 1 yr.	18 mo fallow	√	S	√	Top 4'	7.	3.2	99.	99.	Top 4'	Top 3-4'	S
37.	Harvest, pull, rip, drench planting row at 250 ppm MS.	6 mo fallow	√	S	√	Top 2.5'	7.	3.2	99.	99.	Top 2.5'	–	S
38.	750°F steam at 2000 psi injected into sand at 240'/hr.	NRPS	–	S	–	Some	–	–	Some	Some	–	–	–
Soil Amendments and Additions													
39.	Pull, backhoe 10' x 6' deep hole	Sand	S	0	?	Some	1.2-3.	–	0	0	–	–	0
40.	6 mo after tree removal.	Fine sandy loam	0	0	0	Some	0.8	0.9	0	0	–	–	0

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

			RP Components				Relative Plant Growth		First-Year Nematode Control				
No.	Treatment Description	Test Situation	Rej	SP	IGR	% Roots Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	ORF Relief	Weed Relief
41.	Incorporate steer manure at 45 ton/acre – grape.	18 mo fallow	0	0	S	10	2.0	1.3	50	50	–	–	0
42.	Grow marigolds (var. spp.) spring to fall as a rotation crop.	18 mo fallow	0	S	0	0	0.8	0.9	90	90 in soil only	–	–	0
43.	Marigold extract drenched at 1 lb fresh wt/10 gal plus 325 lb/acre urea then after 30 days apply 40 acre inches water.	18 mo fallow	0	S	0	0	0.8	0.9	95	95 in soil only	–	–	0
44.	Water extract of 325 lb fresh wt/acre walnut hulls in 6 acre inches water.	18 mo fallow	–	0	–	0	–	–	0	0	–	–	0
45.	Solarization of 6' wide strip beneath planted trees for 2 yr.	Non replant site	–	0	S	Top 8" only	Check +15%		Top 8" only	Top 8" only	–	–	95+
46.	300 gal of 210°F water to tree backhoe site treated with naphthalene or not.	6 mo fallow	S	S	0	?			95	95	–	–	0
47.	Incorporate compost (New Era) at one shovelful/tree site.	Fallow 6 mo	0	0	S	0	1.5	1.3	20	20	–	–	0
48.	Addition of macro and micro	Fallow 6 mo				0	2.0	1.2	0	0	–	–	0
49.	nutrients at planting, small	Fallow 18 mo				20	4.0	1.5	50	50	–	–	0
50.	amounts.	Fumigated MB				99	8.0	3.7	99	99	Top 5'	Top 5'	0
51.	Replanting with new row	Fallow 6 mo	Initial S	0	0	20	2.5	1.2	0	0	–	–	S
52.	10 ft away from old row.	Fallow 18 mo	Initial S	0	0	40	3.0	1.3	0	0	–	–	S
53.	Forty-day flooding	Fallow 3 mo	0	0	0	Surface discoloration	0.8	1.0	0	0	–	–	S
54.	Dec.-Jan. tree site	Fallow 15 mo	S	0	0		3.5	1.3	0	0	–	–	S
55.	Aqua ammonia 5 times in first year at 10-15 lb N/acre each in presence of Root Knot Nematode.	NRPS	–	–	√	0	Better than check	–	0	0	–	–	–
56.	Hinder® ammonia soap dissolved and added to non-manured planting sites in first year.	NRPS	–	–	√	0	Better than check	–	0	0	–	–	–
57.	Pull, rip, 3 yr California alfalfa then replant sandy loam soil.	42 mo	√	Change	–	Same as #3	7.0	3.5	Changed		–	–	S

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

			RP Components			% Roots	Relative Plant Growth		First-Year Nematode Control			ORF	Weed
No.	Treatment Description	Test Situation	Rej	SP	IGR	Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	Relief	Relief
58.	Pull, rip, 3 yr California alfalfa, 1 yr sorghum x Sudan Hybrid then replant when sandy soil and Ring Nematode.	54 mo	√	Change	–	Same as #3	7.0	3.5	Changed		–	–	S
59.	Incorporated chaff of wild sesame in NRPS.	250 lb/acre	–	0	–	–	–	–	0	0	–	–	–
60.		20 ton/acre	–	S	S	–	–	–	20	20	–	–	–
61.		100 ton/acre	–	S	S	–	–	–	–	50	–	–	–
62.	Safflower stalks water extracted at 20 ton fresh wt/acre in 6 acre inches water.	NRPS	–	–	–	–	–	–	20	–	–	–	–
63.	8 ton fresh Cahaba White Vetch extracted in 6 inches water/acre plus 300 lb N from urea plus 325 lb/acre Clorox.	Fallow 30 mo	S	S	√	0	8.	–	95	95	–	–	–
64.	Pull, rip, Velvet Bean for 6 mo.	NRPS	–	S	–	–	–	–	–	90 RKN	–	–	–
65.	Pull, rip, Jack Bean for 6 mo.	NRPS	–	0	–	–	–	–	–	0	–	–	–
66.	Pull, rip, 20 ton/acre fresh cabbage tops incorporated preplant.	NRPS	–	S	–	–	–	–	–	50 RKN	–	–	–
67.	Pull, rip, grow Jupiter Rape for 6 mo.	NRPS	–	0	–	–	–	–	–	0	–	–	–
68.	Pull, rip, Black-Eyed Susans for 6 mo.	NRPS	–	S	–	–	–	–	–	90	–	–	–
Nemaguard + Systemic Herbicides													
69.	25 ml Roundup plus 13 ml diesel	Fallow 6 mo	0	0	0	20	1.	1.	0	–	–	–	–
70.	painted after mid-November, pull in 60 days, rip.	Fallow 18 mo	0	0	0	40	3.	–	0	–	–	–	–
71.	50 ml Roundup plus 100 ml MorAct by Sept. 1.	Fallow 18 mo	√	S	0	95	7.	–	–	–	–	–	–
72.	2% foliar Roundup by Aug. 1.	Fallow 6 mo	0	0	0	95	–	–	0	0	–	–	–
73.		Fallow 18 mo	√	S	0	95	7.	3.0	50	50	–	–	–
74.	Vapam into 5 drill holes on trunk.	Fallow 3 mo	–	–	–	0	–	–	0	0	–	–	–
75.	Vapam wicked to girdle on trunk.	Fallow 3 mo	–	–	–	0	–	–	0	0	–	–	–
76.	Roundup wicked to girdled trunk.	Fallow 3 mo	–	–	–	0	–	–	–	–	–	–	–
77.	50 ml Roundup plus 100 ml MorAct to cut trunks by Aug. 1	Fallow 18 mo	√	S	0	95	–	–	95	–	–	–	–

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

No.	Treatment Description	Test Situation	RP Components			% Roots Killed	Relative Plant Growth		First-Year Nematode Control			ORF Relief	Weed Relief
			Rej	SP	IGR		Yr 1	Yr 2	Ecto	Endo	GFLV		
Lovell + Systemic Herbicides													
78.	50 ml Roundup+ 25 ml diesel by	Garlon 3A	0	S	0	20	–	–	0	95 RKN	–	–	–
79.	Aug. 1 then 6 mo fallow.	Roundup	0	S	0	20	–	–	0	95 RKN	–	–	–
80.	25 ml Roundup + 25 ml diesel + 25 ml fosthiazate.	Fallow 6 mo	0	S	0	20	–	–	0	95 RKN	–	–	–
81.	2% foliar Roundup by Aug. 1.	Fallow 6 mo	0	0	0	50	–	–	20	0	–	–	–
82.		Fallow 18 mo	G	S	0	75	7.	3.0	75	50 RL	–	–	–
83.	Vapam into 5 drill holes on trunk.	Fallow 3 mo	–	–	–	0	–	–	0	0	–	–	–
Marianna 2624 + Systemic Herbicides													
84.	2% Roundup foliar by Aug. 1.	Fallow 6 mo	–	–	–	40	–	–	0	0	–	–	–
85.		Fallow 18 mo	G	S	0	60	7.	3.0	75	50	–	–	–
Myrobalan 29C + Systemic Herbicide													
86.	2% Roundup foliar by Aug. 1.	Fallow 6 mo	–	–	–	75	–	–	0	0	–	–	–
87.		Fallow 18 mo	G	S	0	85	7.	3.0	75	50	–	–	–
NC Black or Paradox Walnut + Systemic Herbicides													
88.	50 ml Garlon 3A + 25 ml diesel oil.	Fallow 6 mo	0	0	0	0			0	0	–	–	–
89.		Fallow 18 mo	√	S	0	95+	6.	3.	Some	97+	–	–	–
Grapes + Systemic Herbicides													
90.	Thompson Seedless + foliar spray of	Fallow 6 mo	–	–	–	10	–	–	–	–	–	–	–
91.	2% Roundup in Aug, Sept., Oct., or Nov.	Fallow 18 mo	–	–	–	10	–	–	–	–	–	–	–
92.	Cabernet Sauvignon + foliar spray 3% Roundup in Oct.	Fallow 12 mo	0	?	0	10	–	–	–	–	–	–	–
93.	Thompson Seedless	25 ml Roundup + 13 ml diesel	–	–	–	10	–	–	–	–	–	–	–
94.	painted to trunk with	25 ml 2,4-D + 13 ml diesel	–	–	–	10	–	–	–	–	–	–	–
95.	herbicide Aug. – Nov.	25 ml Goal + 13 ml diesel	–	–	–	10	–	–	–	–	–	–	–
96.	then 12 mo fallow.	25 ml Roundup + 13 ml DMSO	–	–	–	10	–	–	–	–	–	–	–
97.		25 ml Garlon 3A + 13 ml diesel	–	–	–	95% in top 18" soil	–	–	–	–	–	–	–
98.		25 ml Garlon 3A + 50 ml MorAct	–	–	–	?	–	–	–	–	–	–	–
99.	Repeated girdling of Sauvignon Blanc.	Fallow 6 mo	–	–	–	40	–	–	–	–	–	–	–

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

			RP Components				Relative Plant Growth		First-Year Nematode Control				
No.	Treatment Description	Test Situation	Rej	SP	IGR	% Roots Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	ORF Relief	Weed Relief
Transported NRPS													
100.	½ yd NRPS within RPS site.	Fallow 4 mo	Initial √ then G	S	0	0	7.5	3.0	(90)	(90)	–	–	–
101.	Pull, rip, backhoe then	Fallow 6 mo	Initial √ then S	S	0	0	?	–	(95)	(95)	–	–	–
102.	250 ppm MS then ½ yd NRPS.	Fallow 6 mo	Initial √ then S	S	0	0	?	–	(95)	(95)	–	–	–
103.	Pull, rip, backhoe then 25 gal NRPS.	Fallow 6 mo	Initial √ then S	S	0	S	Inadequate		–	–	–	–	–
Post-Plant Nematicides to NRPS Site													
104.	Post-plant (7) monthly Vydate 42	NRPS	–	Limited √	√	–	1.1	1.2	98	98	–	–	0
105.	treatments at 1 lb ai via drip.	After 25 gpa Telone	√	Limited √	S	95			99	99	–	–	0
106.	Post-plant (7) monthly Nemacur 3	NRPS	–	√	0	0	1.0	1.1	98		–	–	0
107.	treatments at 1 lb/acre via drip.	After 25 gpa Telone	√	Limited √	S	95			99	99	–	–	0
108.	Post-plant Enzone after first summer at 500 ppm via drip.	NRPS	0	S	0	0	–	–	90	50	–	–	0
109.	Post-plant Enzone 30 days after planting at 700 ppm via drip.	NRPS	0	S	0	10-25	0.9	–	50	50	–	–	0
110.	Post-plant Vapam at 10 ppm monthly 7 times.	NRPS	0	0	0	50	0.8	–	0	0	–	–	0
111.	Post-plant DiTera at 20 lb/acre 3 times/yr.	NRPS	0	S	0	0	1.0	–	50	50	–	–	0
112.	Post-plant peroxyacetic acid at 2000 ppm/mo 7 times/yr.	NRPS	0	0		0			0	0	–	–	0
113.	Post-plant urea or UAN_{32} at 10-15 lb N/acre in 3-5 successive mo.	NRPS	0	S	0	0	1.0	1.1	50	50	–	–	0
114.	More frequent irrigations.	Begin first year in RPS	0	0	0	0	0.8	0.9		0	–	–	Aggravates
115.	More frequent irrigations.	Begin second year	0	0	0	0	–	1.1	0	0	–	Aggravates	

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

			RP Components				Relative Plant Growth		First-Year Nematode Control				
No.	Treatment Description	Test Situation	Rej	SP	IGR	% Roots Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	ORF Relief	Weed Relief
Resistant Rootstocks													
116.	Nemaguard.	Peach	0	S	0	0	–	–	0	Root Knot	–	0	0
117.	Marianna 2624.	Plum	S	S	0	0	–	–	0	Root Knot	–	95+	0
118.	Lovell seedling.	Peach	0	S	0	0	–	–	Some Ring	0	–	0	0
119.	Myrobalan 29C.	Plum	0	S	0	0	–	–	Some Ring	Root Knot	–	0	0
120.	Deep Purple.	NRPS	–	0	–	0	–	–	0	0 RL	–	–	–
121.	Bruce.	NRPS	–	S	–	0	–	–	0	RL RKN	–	–	–
122.	English Walnut.	Walnut	–	0	0	0	–	–	0	0	–	0	0
123.	NC Black Walnut.	Walnut	0	S	0	0	–	–	Some Pin – Dagger	Root Knot	–	S	0
124.	Paradox Hybrid.	Walnut	S	S	0	0	–	–	Some	Some Root Knot	–	S	0
125.	*Pistacia atlantica*.	Pistachio	–	S	0	0	–	–	0	RL, RK, Citrus	–	–	0
126.	Hayward Kiwifruit.	Kiwi	0	0	0	0	–	–	0	0	–	–	0
127.	Citrus Trifoliate.	Citrus	S	S	0	0	–	–	0	Citrus Nema	–	S	0
128.	Malus M-111.	Apple	0	0	0	0	–	–	0	0	–	0	0
129.	Thompson Seedless.	Grape	S	S	0	0	–	–	0	Some RKN	0	Some	0
130.	Freedom RS.	Grape	0	S	S	0	–	–	0	Some RKN RL Citrus	0	Some 0	0

Table 1. Relative Efficacy of Various Treatments and Strategies Against Three Components of the Replant Problem – (continued)

			RP Components				Relative Plant Growth		First-Year Nematode Control				
No.	Treatment Description	Test Situation	Rej	SP	IGR	% Roots Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	ORF Relief	Weed Relief
131.	Teleki 5C.	Grape	0	S	0	0	–	–	0	Some RKN, RL	0	Some	0
132.	6-19B.	Grape	0	√	0	0	–	–	98+	98+	0	–	0
133.	10-17A.	Grape	S	√	0	0	–	–	98+	98+	0	–	0
134.	10-23B.	Grape	S	√	?	0	–	–	98+	98+	0	–	0
135.	RXS-9.	Grape	–	G	–	0	–	–	98+	98+	–	–	–
136.	RXS-3.	Grape	S	G	0	0	–	–	?	98+	0	–	0

Table Legend:

RP Components:
√ = can solve.
G = good solution.
S = some solution.
0 = no solution.

Relative Plant Growth: Growth compared to untreated or 1 x

First-Year Nematode Control: % control compared to untreated

BV = Biological Vacuum.
PSDD = Portable Soil Drenching Device delivery 6 inches water.
Rej = Rejection Component of Replant Problem
SP = Soil Pests and Disease Component of Replant Problem
IGR = Increased Growth Response
RKN = Root Knot Nematode
RL = Root Lesion Nematode
Citrus = Citrus Nematode
GFLV = Grape Fan Leaf Virus
ORF = Oak Root Fungus

H-2. Characteristics of Specific Treatment Approaches Evaluated

1,3-dichloropropene nematicide (Telone II, Telone C-17, Telone C-35)

Until 1990, Telone II was the most utilized fumigant in California at 16 million lb/yr. Methyl bromide was in second position at 6 million lb including all uses (CDFA). The 1990 suspension of Telone use was followed by its reintroduction for perennial crops in 1996. It was reinstated with at least three very restrictive regulations:

- Rates not to exceed 35 gal/acre.
- Presence of high soil moisture content (in excess of –60 cb) at the field surface.
- Treatments prorated on a township basis so that not more than 350 acres per township (23,040 acres) could be treated each year.

The purpose of the restrictions was to reduce the volatilized portion released into the atmosphere following any treatment. In 1978, this author published a schematic that indicated the treatment rates of Telone necessary to effectively kill remnant roots and nematodes present within the surface 5 ft of soil profile. Using shanks our lowest rate for success was 40 gal/acre applied at 6 to 12-inch depth. The important point was that dry soil is key to being able to reduce treatment rates. Nothing has changed the dry soil requirement and in Fig. 1 of this text is depicted the same basic chart for shank treatments. The new Telone II formulation plus the requirement for treatment depths at or below an 18-inch depth enables a further rate reduction so that 35 gal/acre is an acceptable level of treatment. We have been able to verify this rate in at least two field experiments involving fine sandy loam soil, properly dried, following a year of fallow. This rate reduction does, however, limit the long lasting benefits of Telone II treatments to coarser-textured soils.

One major difficulty with the current label is the need for surface application of moisture prior to Telone treatments. First of all, most tree and vine growers in California would have to rent sprinkler pipe to apply the proper moisture required. Even more important is the fact that these growers almost always rip their soil from 30 inches to 7 ft deep prior to fumigation. This extensive soil ripping remedies any soil lenses, plow pans or chemical residues that accumulated in the previous crop. These physical and chemical factors are a component of RP and are best dealt with prior to replanting. However, the first irrigation after such a ripping job will penetrate deeply even if only 1 or 2 inches of water are applied.

This author has serious reservations that 1,3-D, with its current label, will not be a viable replacement for MB, except for a very narrow grouping of coarser-textured soils.

Emulsified Telone or Cordon, although not yet registered in California, is in commercial use abroad and has had substantial field testing in California. Thus far, drenching with Telone EC at 330 1b ai/acre provides kill of remnant roots and the degree of nematode relief equivalent to a shanked application of the standard Telone formulation. Air monitoring after treatment shows that once the drench water is beneath the field surface, there is a substantial locking in of the 1,3-D to reduce its volatilized percentage (McKenry, M. V., 1995, Yates, S. et. al. 1997). The downside is that drenching applications are limited to buried drip lines, which usually do not provide adequate emitter spacings for an effective treatment. In contrast to shanked treatments where we want the complete soil profile to 5 ft at less than -60 centibars moisture (see Fig. 1), the emulsified treatments would occur in moist soils between -30 and -60 centibars (see Fig. 1).

Telone C-17 and more recently, Telone C-35 products, which include chloropicrin, appear to provide improved first-year growth of trees on Nemaguard and Lovell rootstocks, but not because of a nematode control advantage. These products should only be considered at treatment rates containing the full 1,3-D active ingredient of 330 lb/acre.

Finally, we have found one treatment involving Telone and Vapam that is equivalent in performance to tarped MB. In Washington State, this is referred to as the over/under method. The application received Washington registration in 1997, but at rates slightly lower than those needed for control of RP.

For RP situations, Telone is applied at 35 gal/acre (330 lb/acre) by shanking the product to the 18-inch depth. Then, Vapam is applied via sprinklers in 1 to 2 inches of water at 15 to 30 gals/acre (250 ppm MS) on days 1 through 4 after the Telone treatment. We suggest that sandy soils might require sprinkling on day 1 and 4 (1-inch per application). In finer-textured soils, apply the full 2 inches of water during each application. Splitting the irrigation into intervals 3 days apart does provide weed seed kill that is not normally achieved with Telone alone. This procedure requires either sprinkler lines in place during the Telone injection or perhaps a remote delivery device (we are in the process of constructing a prototype). Not only does this method provide replants with excellent growth and a nematode-free condition lasting many years (2 + years) but it has the potential to reduce volatilization. This method could increase the total acreage treatable per year with Telone. In finer-textured soils, the quantity of water containing Vapam may have to be increased.

MITC Liberators-Liquids (Vapam, Soil Prep)

The most consistent attribute of methyl isothiocyanate liberators has been the inconsistency of their performance. Shank delivery devices with nozzles pulled through the soil at 5 inch increments did not provide nematode control beyond 6 mo and on many occasions, the rate of nematode return was remarkably fast. The use of basin treatments had failures even when everything was done right. Furthermore, basin applications require a worker exposure level that we prefer to avoid.

By 1994, we were reporting back to back successes with applications of MS when delivered to soil using a portable drenching device (McKenry, M. V. et. al., 1994, Appendix Items 1 and 2). Use of these devices enabled us to look deeper into the limitations associated with products such as Vapam. To begin, an 8-hr drenching of 6 inches water uniformly injected with 250 ppm MS and delivered across a properly prepared soil profile at one dripper emitter per sq ft can provide long-lasting nematode control as well as relief from the rejection component of the replant problem. Except in the sandiest soils, weed control is equal to a tarped MB treatment and replanted trees or vines frequently grow better than following a tarped MB.

There are reasons why the delivery method is so complicated and why treatments sometimes do not provide adequate nematode control.

First, MS is a poor soil fumigant. The compound does not “fume” or move beyond the wetted front. It must be transported through the soil in water for it to reach the nematodes, which reside in every nook and cranny. If the soil profile contains areas that are already saturated, those sites can be missed. If the soil profile contains a lens or plow pan layer that slows the water movement, the Vapam may release the MITC before all destinations are reached. Poor results can also result if inadequate water is applied or the water moves through too fast due to a fluffed soil condition.

MS is also a relatively poor root penetrant. When Vapam is applied at 100 gal/acre in 6 inches water (or 250 ppm MS), there is essentially complete kill of remnant roots in the surface 30 inches of soil profile. In the next 12 inches, root kill may only be 75% with reduced kill of deeper roots.

The Root Lesion Nematode, *Pratylenchus vulnus*, lays eggs within the cortex of roots as well as in the soil. After treatments, some eggs may actually survive within roots in the surface 30 inches, and they assuredly survive in roots that are not killed. The Root Knot Nematodes are also endoparasitic. Their eggs are usually considered to be at the root surface but they do occur deeper in many grape or fig roots, as do the females. Also, Root Knot Nematodes have a long list of host plants including nutgrass, Bermuda grass, and others which actually support nematode populations within the nut or rhizome (Thomas, S. et. al., 1996).

The brief answer, although not legal, is raising rates: 250 ppm MS is not a high enough dose when such refugia occur in the soil. Increasing the delivered dose to 500 ppm MS can achieve essentially complete kill of roots down to 4 ft. This, plus the additional nematode control provided to the 5 ft depth has been enough to give control of endoparasitic nematodes that is equivalent to a tarped MB. However, we quickly learned that none of the woody perennials we replanted grew much better than the nontreated comparison. When we treated at the high rate (200 gpa Vapam is double the current registered rate) and then fallowed the field for one full year, plant growth was equivalent to that achieved with MB tarped. The trees also remained essentially nematode free for 2 yr.

The chlorosis and stunting that occurs when replanting too soon can be mostly overcome with applications of macro and micro nutrients at planting (Appendix Item 8) However, fertilization also helped plants grown in MB treated sites. Additionally, the poor root penetrating quality of MS precludes its use against Oak Root Fungus, *Armillaria mellea*. In a field trial with Vapam applied at 212 gal/acre in 10 inches of water, Oak Root Fungus had killed some of the replanted vines within 1 yr after replanting (unpublished results).

This brings up a third and very important consequence of MS treatments. All fumigants, including MS, create a biological vacuum. However, the broad spectrum effectiveness of MS plus the above-mentioned opportunities for missing a few soil pests are big drawbacks for this product. The first microbes reintroduced into a biological vacuum can be highly successful. Before using this product as a pre-plant for perennials, we need to learn how to properly fill such a vacuum. In one of our experiments, we replanted roses that were accidentally infected with *Paratylenchus hamatus*, which is an endoparasite in rose. In this experiment, plant growth was similar between treatments but the *P. hamatus* populations were threefold at the end of a year when planted into MS treated soil (see Appendix Item #4).

These shortcomings of MS liberating compounds are reasons why MS will continue to be a source of frustration and surprise to its users. There is also a narrower range of conditions for its effective use compared to MB or 1,3-D. The question remains: Where will it be used?

On the plus side, MS does kill shallow roots and simultaneously destroys the rejection component of RP without the lengthy waiting period of an extensive fallow period.. This occurs only within the MS delivery zone, which is adequate to give at least one full year of good root growth. MS can also be a useful choice as a strip or spot treatment applied via a low-volume irrigation system if the replanted crop is on a rootstock with resistance to the dominant nematodes as well as some tolerance of the rejection component. An example is Marianna 2624 Plum, which possesses resistance to Root Knot Nematode and Oak Root Fungus and a degree of tolerance to *P. vulnus* and the rejection component of RP. This choice has its problems since Marianna 2624 can badly sucker and should not be planted in sandy soils where Ring Nematode buildup can result in Bacterial Canker Complex.

Many own-rooted grapes also possess tolerance to the rejection component of RP but are susceptible to a wide array of nematode species. Teleki 5C is an example of a rootstock with high sensitivity to the rejection component, while carrying a degree of resistance to endoparasitic nematodes. More information is needed on rootstocks and their sensitivity to the rejection component of RP.

Since only 1/3 of the California peach, plum and almond acreage is infested with *P. vulnus*, and most of it is planted to Nemaguard, which possesses durable resistance to *Meloidogyne* spp., these acres also present opportunity for MS treatments. We have not yet conducted enough MS field trials in sandy orchard ground where Ring Nematode is the major problem. We do know that Ring Nematode population buildup is influenced by the presence of a biological vacuum. In a 4-yr study, we found a 10-fold buildup of this nematode in sterilized soil compared to sites inoculated with a small amount of RP soil containing Ring Nematode. Although we don’t know all the biological control mechanisms, they make up part of the rejection component of RP.

The importance of a quick delivery of Vapam into soil also may hinder the product’s future use. Two hours after Vapam is mixed with water, it begins releasing the active ingredient, MITC. Since Vapam must be delivered uniformly throughout 5 ft of soil profile, it must be done quickly. We have had successes with Vapam when it is fully delivered in 8 hr or less. A soil that will not take 6 inches of water in 8 hr or less has not been properly prepared or should never have been a candidate for Vapam use. By contrast, the time limitation we use for emulsified 1,3-dichloropropene drenches is about 12 to 15 hr while for Enzone, a quickly degrading product, we would want to drench within hours.

Obviously, there are soils that can be drenched and those that cannot. Non-drenchable soil conditions include plow pans, fine-textured lenses, or sites where the profile has saturated areas and do not infiltrate 6 inches water in 8 hr or less. Under these conditions, the MS would not be uniformly dispersed. Soils more conducive to success with MS are deep sands, loamy sands, coarse sandy loams and some of the finer sandy loams. These tend to be more drenchable soils. However, some studies show that excessive macropores can result in inadequate residence time of the MS at the target site.

MS need not always be applied with a drenching device. Basin irrigations that take 5 to 6 inches in 2 to 3 hr can be successfully treated but there must be good mixing of the Vapam with the water before delivery. Sprinklers with low-atomizing heads can also be used as long as the wind is below 5 mph. But again, the goal should be complete delivery in 8 hr, not 15 hr. And, the Vapam must be uniformly delivered into the flowing water for the duration of the run, with a final ½ hr watering to rinse out the system.

MITC Liberators – Granules (Basamid or Dazomet)

These granules release nearly 100% MITC when the granules are dissolved in water. To apply, the small granules are evenly spread onto the soil surface and incorporated. Water is then applied uniformly to dissolve the granule and transport the MITC deep into soil. One major difficulty with this product is our lack of data on the dissolution rate of the granules, which vary in size. Our most successful trial was incorporating the granules in the surface 1 inch then sprinkler irrigating on a 2 hr on, 2 hr off cycle for a total of 14 hr and 6 inches of water. The lethal effect was transported down 5 ft. However, by the end of 1 yr, we found a nematode control level of 75% compared to the 99% control achieved with a drenching of Vapam at 325 lb/acre rate in 6 inches water. Before this product is practical, the granule dissolution rate must be known and predictable or there must be a formulation providing slow release of MITC over a known period of time. Uniformity of distribution of granules to the soil surface also poses a problem.

Chloropicrin (CP)

Tear gas was studied even before MB but additional interest was kindled when S. Wilhelm found a synergistic growth response to strawberries when used in association with MB. In California, CP was used almost exclusively in combination with MB or 1,3-D to broaden their spectrum of activity. Other minor uses include control of Verticillium of pistachio and control of Pox of sweet potatoes where treatment rates of 200 to 400 lb/acre are occasionally applied.

CP is a relatively expensive soil fumigant that does not provide adequate relief from nematodes. It is generally not used on tree and vine crops but in 1996 was included in several field trials with and without 1,3-D (McKenry, M. V., B. Hutmacher and T. Trout, 1998 and McKenry, M. V., T. Buzo and D. Dougherty, 1998). If nematode control is essential, the treatment rate of 1,3-D cannot be reduced by substituting CP. As a pre-plant treatment for peach and plum rootstocks, CP when applied in excess of 125 lb/acre rate produces a dramatic growth response the first few months after planting, which places it ahead of the IGR provided by MB. For more information, refer to the review article by Wilhelm and Westerlund (1996).

Carbon Bisulfide Liberators (ENZONE)

One of the first soil fumigants was carbon bisulfide, a broad-spectrum biocide. In 1981, the only currently available CS_2 product became available experimentally as GY-81 and later under the name Enzone, or sodium tetrathiocarbonate. A century ago, the treatment rates for CS_2 were 2000 lb/acre. Today, each gallon of Enzone liberates only 3.2 lb of CS_2 so it would take many gallons of product to provide the biological activity of the old CS_2. Enzone provides a slower, less flammable release that is more suitable to post-plant treatments. As a post-plant treatment, its effectiveness has primarily been against ectoparasitic nematodes and Phylloxera at rates of 5 to 7.5 gal/acre.

In one trial, a loamy sand vineyard nursery site was drenched with Enzone at the rate of 900 gal/acre. This treatment was compared to Vapam at 100 gal/acre in 6 inches of water and a tarped MB treatment at 350 lb/acre. Grape cuttings were planted 21 days after treatment and harvested 14 mo later. Control of Ring Nematode and Root Lesion Nematode was excellent for all treatments but the best growing plants were those planted to the Enzone site.

In a later experiment where no roots larger than pencil-sized were present, we made a second treatment at 300 gal/acre in 6 inches of water in the presence of Root Lesion Nematode and Pin Nematode. This rate of 700 ppm sodium tetrathiocarbonate in sandy loam soil was a failure. In a separate effort to identify products that promote an IGR, we applied a 2100 ppm rate to individual tree planting holes 45 days before planting and a month after strip treatments of MB or Vapam. This too was a failure due to a phytotoxic response which can occur in cold soils but apparently not in warmer soils.

This product is a poorer root penetrant than Vapam. Additionally, the liberation of the CS_2 may be even faster than MITC is liberated from Vapam, thus restricting its use to the coarser-textured soils and even faster deliveries of the drench water. This product needs future testing in backhoed treatment sites involving Ring Nematode and in comparison to Vapam and Telone. Its influence on successive recolonization of treated soil may be quite different from the other two products.

Formaldehyde

This product is a known biocide reported to be a carcinogen but nematode control had been reported with a natural occurring formaldehyde known as Furfural. Our only test was at an application rate of 325 lb ai/acre in a Root Knot Nematode infested site where grape roots from 2-yr old plants were still present. Since this product does not penetrate roots, it did not control the nematodes within these young roots (Appendix Item 1).

Acrolein

This allyl alcohol product has current registrations in California as a control for water weeds and algae in waterways and for spot treatments of squirrel holes. It has a long history of being difficult to handle. We applied it through our drenching device by pulsing its delivery during the fourth hour of an 8 hr delivery. The aldehyde off-gassing was quite noticeable, but in a sandy soil may have been acceptable. A subsequent attempt to work with a pre-Acrolein product was not successful.

The one treatment at 325 lb ai/acre rate pulsed into soil was impressive in that it gave about 1 yr of protection and was on a par with Vapam at that same dose. Most impressive was the growth of Northern California Black Walnut seedlings in that treatment compared to any other. This product should not be forgotten. For example, we now know how to kill walnut roots with systemic herbicides but still have a problem with the nematodes remaining in soil around the remnant dead roots. Perfection of formulations and application equipment will be critical.

Ozone

Delivery of gaseous ozone by shanks into a porous sand at the rate of 2 std. cu ft per minute did not give control of Root Knot or Ring Nematodes sampled 10 days later. This same rate of delivery into a dried sandy loam soil revealed that the gas was more likely to come out the shank trace than to move through pore spaces.

Hydrogen Peroxide

This rapidly oxidizing agent delivered within water was ineffective in small plots. In a larger field site, we delivered peroxyacetic acid plus a stabilizer agent to protect the active ingredient for a longer period. At 40 gal/acre plus 40 gal of stabilizer applied as a pulsed or uniform injection into 6 inches water, there was no nematode control 30 days later. This site was a nursery setting with remnant roots no larger than pencil-sized.

Chlorine Dioxide

Nighttime delivery of 7 ppm chlorine dioxide dissolved in a 6-inch water application gave some nematode relief. The level of control was not adequate but neither was the treatment rate when soil is the medium being treated.

Calcium Hypochlorite

Swimming pool chlorine at 325 lb ai/acre in 6 inches of water resulted in poor nematode and root kill. Trees and vines grown after the treatment grew no better than the nontreated except for Nemaguard Peach which grew quite well until midsummer of the first year when the nematode component of RP made its presence known. It should be noted that peach rootstocks specifically appear to grow better than normal when they follow treatments containing chlorine. This product was pulsed into a 6-inch water application. Soil samples collected 30 days after treatment from each foot down to 5 ft showed that adequate delivery of the product had occurred. This product is not a root penetrant.

Methyl Iodide (MI)

Although we have only examined this product in a single large trial, it appears to live up to the claim of performance equivalent to or better than MB, but it is not a direct replacement. We achieved excellent nematode control at 325 lb ai/acre rate shanked at 20 inch depth on 4 ft centers. The control was as good as that achieved with a tarped MB but we didn't tarp the MI. A comparative non-tarped MB at 240 lb/acre had failed within a year, not because of root presence but because of late summer rains of 7.5 cm creating too much soil moisture for this treatment rate. In this trial, our planting included Nemaguard Peach and Marianna 2624 Plum seedlings. Forty-five days after planting or 5½ mo after treatment, the lower leaves developed a tattered marginal necrosis and abscised. The Nemaguard Peach, after another 4 mo, appeared to grow past the problem and had actually regained leaves in the lower tree. The plums were more sensitive and a full year after treatment as much as 1/3 of the leaves had abscised and not grown back. Additionally, many of the remaining leaves exhibited a tattered margin and were smaller in size. Then in the second spring after treatment, the plum trees once again exhibited tattered basal leaves as soon as temperatures began to warm. There did not appear to be a kill of leaf buds, only a tattering and abscission of leaves. In the second year the tattered leaves could also be found in the tops of the trees.

A full range of plant cultivars needs to be evaluated to determine specific sensitivities to MI treatments. Our concern for the nursery industry is that land is replanted at 3 yr intervals and if the problem is due to an accumulation of iodide, it could be several cropping cycles before the full effects of MI are known. Development costs and registration are major hurdles to any product that is to replace MB. When such products become available and full costs are known, it is the growers who will decide if it is a direct replacement.

Ammonia Liberators

Ammonia is nematicidal at sufficient quantities. It is reported to affect egg stages as well as juveniles. If these life stages or the adults are within roots, they will escape control because ammonia does not have root penetrating ability. There are several methods and products that will release ammonia once delivered into soil. Certain microorganisms, including bacteria growing along the root surface, release ammonia naturally and there have been studies to select and utilize such organisms as a means of nematode management (Zavaleta-Mejia and Van Gundy, 1989).

Anhydrous ammonia has been shanked into soil as a pre-plant treatment by growers trying to avoid the high costs of conventional fumigants. There have been almost no follow-up studies that prove the nematicidal value of such treatments. A method we have studied involves drenching with urea at 300 lb nitrogen per acre in 6 inches of water. This is followed by either soil incorporation of straw or growing barley which is turned under prior to replanting of perennials.

The release rate of ammonia from urea is influenced by a urease enzyme which is present in soils, probably at shallow depths where biological activity is already greatest. Urea is drenchable by sprinklers and our drenching devices but there may be other practical methods of delivery. In none of our experiments, including applying 600 lb nitrogen per acre, were we able to discern relief from the rejection component of RP. Additionally, it does not appear to create a biological vacuum like conventional fumigants. The rate of 300 lb nitrogen per acre seems adequate and this is the amount present in Clandosan, a shrimp shell product being sold as a nematicide to organic growers.

Ammonia is a relatively non-mobile molecule in soil but once metabolized to the nitrate form, it is mobile and capable of leaching into groundwater or used by plants as a nutrient. Proper management of this product would be required but for field settings without endoparasitic nematodes and where remnant roots can be killed by some other means. Ammonia release can provide 95% control of ectoparasitic nematodes in the surface 5 ft of soil without creating a biological vacuum and with excellent plant growth in settings where the rejection component does not occur.

Organic Amendments

Nematodes that attack perennials lie deep in the soil and can reside deep within roots. The first difficulty controlling nematodes with organic amendments is delivery to the site where plant parasitic nematodes populate.

The plant growth benefits of organic amendments are almost universally accepted. This author frequently recommends organic materials as a means of avoiding stress between lengthy irrigation periods, but this is a post-plant treatment. There is plenty of disagreement as to the best form of organic matter, from green manures to animal manures, composts, urban wastes, seaweeds and on and on.

More than 20 yr ago, this author participated in a 45 acre replicated experiment comparing a Telone application at 40-gal/acre with spreading steer manure at 45 tons/acre. The replanted grapes included several rootstocks. By July of the first year, plant growth differences were evident. By the following spring, most of the vines planted to the manure treatment had been removed, the ground fumigated and replanted. After another year, the remainder of vines planted to the manured site were removed.

Manures, composts, cover crops and other organic amendments do not solve the rejection component or nematode component of RP. Organic treatments can double the growth over that of the nontreated replants but proper preplant fumigation can give seven times the growth of nontreated.

In 1992, we initiated a field trial comparing the value of 18 mo fallow with growing nematode antagonistic cover crops for 18 mo. I had long believed that a wet fallow would be better than dry fallow because nematodes would be enticed to come out of the roots and maybe even some of the remnant roots would become rotted sooner. A peach/plum planting was removed, shallow-ripped, planted to barley, turned under and planted to sorghum x Sudan Hybrid, turned under and then planted to Cahaba White Vetch. Other treatments included dry fallow, flooding 40 days, MB and many others (McKenry, et. al., 1995). The replants included seven types of 1-yr-old perennials.

Use of dry fallow for 18 mo produced plants three times larger than those receiving dry fallow for 6 mo (nontreated). Cover cropping for 18 mo produced plants 3.5 times larger than the nontreated, not a significant benefit over the dry fallow. The plants in the cover cropped area appeared to start out better but by the end of the first year, differences were not discernible. The effects of the rejection component and nematode component of RP were discernible when compared to the fumigated. It is noteworthy that growth of each of the three rotation crops was excellent, providing no clue that the rejection component was still there. However, uneven growth of rotation crops can reveal the presence of physical or chemical problems.

How could crop rotations solve the rejection component? Many of the old peach/plum roots were still alive 18 mo after tree removal. Even 2 yr after the roots were finally dead, *P. vulnus* was still emerging alive from the roots. The cyanides, glycosides, nonhost status and other naturally occurring attributes of such crops did not penetrate the nematode refuge. This type of work needs to be repeated in settings where endoparasitic nematodes are not present and the rejection component has been controlled by some other means (e.g. systemic herbicides).

I. Methods that Kill Remnant Roots and the Implications

I-1. Anaerobic Conditions

In a recent trial, peach/plum trees were removed and the ground was saturated for 40 days and nights during the months of December-January. A total of 16½ acre ft of water was applied to the deep sandy loam soil throughout the 40 days in an effort to maintain 2-4 inches of water above the wetted basins at all times. While anaerobic conditions do not kill aquatic organisms such as nematodes, our goal was to kill the remnant roots. Sixty days after the treatment, the epidermal surfaces of the peach/plum roots were darker than the nontreated. The darkening reached a few layers of cells deep.

Half the treated basins were planted 3 mo after the flooding and the remainder were planted to sorghum x Sudan for the summer and then replanted 15 mo after the winter-time flooding. Trees planted 3 mo after the flooding were smaller than the nontreated check with no change in the nematode populations. Replanted grapes grew similar to the nontreated checks. Trees planted 15 mo after the flooding initiated very good growth and by the end of the first year, growth was similar to sites receiving dry fallow for 18 mo. In the second year, development of nematode populations was high while tree and vine growth declined and was no better than the nontreated.

Marigolds also create anaerobic soil conditions. They can be: 1) grown as a summer rotation crop, 2) chopped and incorporated into the site, or 3) chopped and processed with cold water extract, with the extract applied by drench to the field. Marigolds have long been reported as nematicidal (Daulton, 1963) but they also actively remove available oxygen from soil (McKenry, 1991). In a field plot, we applied adequate doses of marigold extract in 6 inches of water and 30 days later applied 40 inches of water in an attempt to wash any residues from the soil. This treatment was planted 4 mo later and produced trees and vines no better than the nontreated but with fewer nematodes present. Phytotoxicity has been common to every replant site this author has utilized Marigolds or their extracts.

In summary, anaerobic conditions do not kill remnant roots or nematodes and can result in poor plant growth if planted within less than 6 mo of the anaerobic treatment.

I-2. Physical Removal of Remnant Roots

It is completely unrealistic to physically remove the bulk of remnant roots from the surface 5 or 10 ft of soil depth. When using non-tarped MB treatments, we have long recommended that a spring tooth or similar tractor-mounted device be used to bring the surface 6 inches of remnant roots to the surface for gathering and removal from the field. This activity is important because across the soil profile the performance of MB is poorest along a non-tarped surface. The use of very coarse screens to separate remnant roots from the spoil soil in a backhoed or trenched site is cumbersome but worth trying as long as there is also an 18 mo waiting time after their complete removal.

I-3. Root Penetrating Soil Fumigants

The killing of old roots is a natural consequence of proper soil fumigation. Although 1,3-D at 350 lb/acre is referred to as a nematicide, it does penetrate and kill roots to 4 or 5 ft depth. Once the roots are dead, the microbiological transformations responsible for halting RP can also be expected to occur just as they do following MB. In other words, the biological spectrum of activity for 1,3-D is increased due to the associated root kill it provides among remnant roots. To assess the value of a soil fumigation, search the surface 5 ft of soil for live and dead roots about 30 to 45 days after treatment. Using 325 lb/acre of active ingredient in a sandy soil under optimal soil and delivery conditions for that product MB, MI, 1,3-D, MS and CS_2 would provide 99% root kill to the 6 ft,5 ft,4 ft, 2½ ft and 0 ft depth, respectively.

The condition of soil at time of treatment is the most important factor in determining if a treatment will control soil pests for 6 mo or 6 yr. For the soil pest component of RP, the primary goal with all these products is the same. The active ingredient must be delivered to the site of the target pest(s). For the rejection component of RP, best plant growth results occur when remnant roots are completely killed and adequately high dosages have been delivered throughout the soil.

In this text, there has been discussion of two very different methods of fumigant delivery. Drenching involves uniform addition of the biocide within a large volume of water and then delivering that dosage uniformly and deep enough into the soil profile for an adequate exposure time. Conventional soil fumigation, by contrast, involves addition of a fuming ingredient into a dried soil profile, thus providing adequate open pore space for the gaseous product to reach the targeted soil pest.

Presented in Fig. 1 are the optimal soil conditions for product delivery via drenched or shanked applications to a range of soil textures. Fig. 1a indicates the relatively narrow range of soil situations where the current label for 1,3-D of 35 gal/acre can be 99.9% successful as a nematicide when infected remnant roots exist in the soil. If an emulsifier is added to the same quantity of 1,3-D, which is then uniformly added to 6 acre-inches water and delivered across the soil profile, the optimal soil conditions are indicated in Fig. 1b.

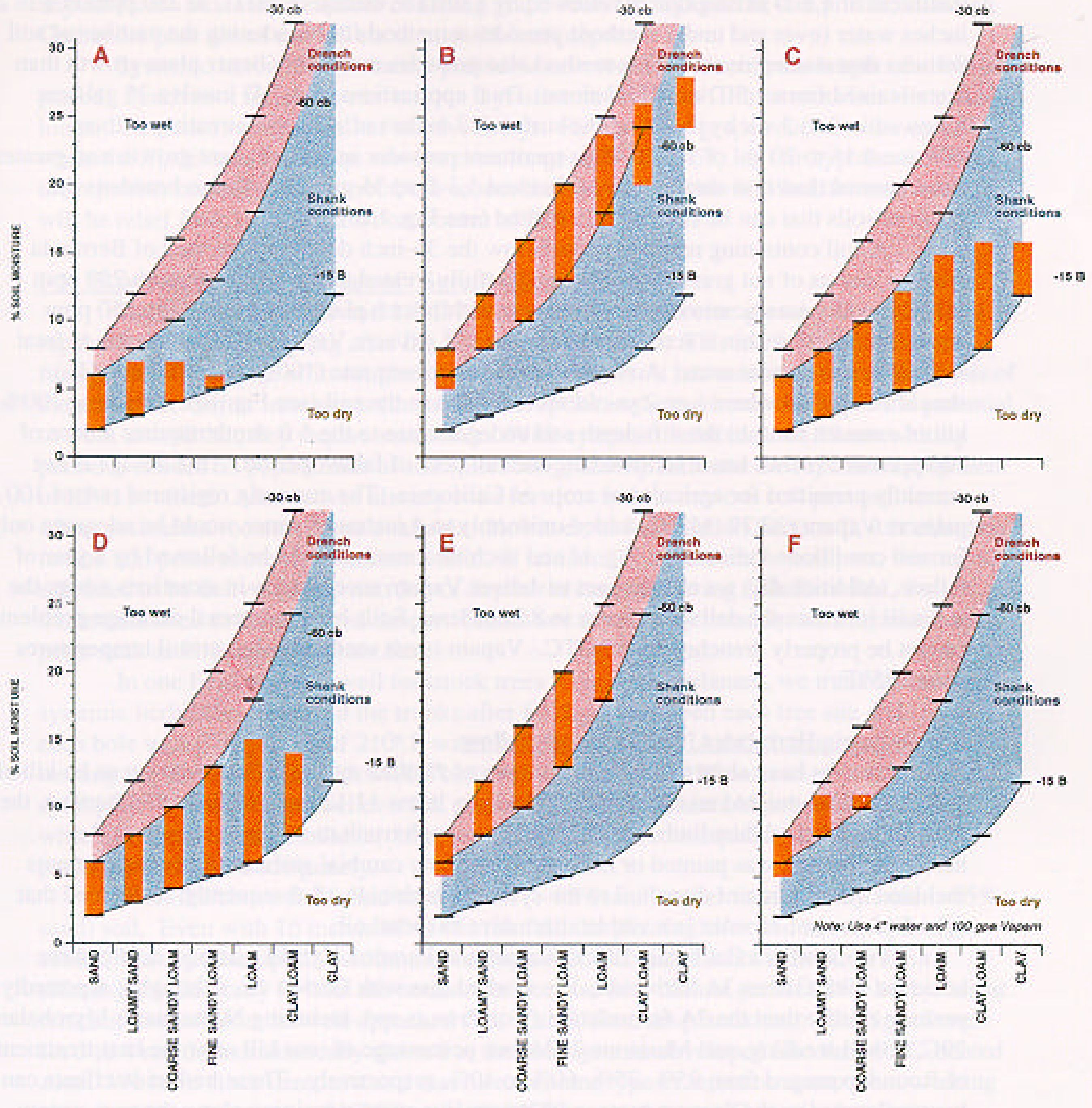

Fig. 1a. Optimum Treatment Conditions for 35 gpa 1, 3-D to soil with moistened surface.

Fig. 1b. Optimum Treatment Conditions for drenching 1, 3-D EC in 4-6" water.

Fig. 1c. Optimum Treatment Conditions for shanking 1, 3-D EC and to be followed by MITC drench.

Fig. 1d. Optimum Treatment Conditions for dual application 1, 3-D started at 18"d 35 gpa. flip in 2-4 weeks, retreat at 15 to 20 gallon at 18".

Fig. 1e. Optimum Treatment Conditions for drench delivery of Vapam where no roots larger than pencil-sized occur.

Fig. 1f. Optimum Soil Moisture Conditions for drench delivery of Vapam where a perennial woody root had been planted.

These two treatments provide uniform nematode control and root kill but the shanked treatment will generally provide a higher level of plant growth than the drenched. A shanked treatment of 1,3-D at 35 gal/acre followed by a surface drench of MS at 250 ppm in 1 to 2 inches water (over and under method) provides a method for broadening the number of soil textures that can be treated. This method also provides noticeably better plant growth than that obtained from 1,3-D or MS alone. Dual applications of 1,3-D involve 35 gal/acre followed in 2 to 3 wk by inverting the surface 12 inches of soil and retreating with an additional 15 to 20 gal of 1,3-D. This treatment provides improved plant growth and greater weed control than that obtained from shanked 1,3-D at 35 gal/acre. It also broadens the range of soils that can be successfully treated (see Fig. 1d).

A soil containing remnant roots below the 36-inch depth or rhizomes of Bermuda grass or nutlets of nut grass cannot be successfully treated to the 5 ft depth with 250 ppm MS if endoparasitic nematodes also occur within such plant structures. The 250 ppm dosage of MS within 6 acre inches of water (75 gal/acre Vapam HL) is adequate to treat soils without remnant roots. A slightly higher treatment rate (100 gal/acre Vapam HL) should be applied where 1 or 2 yr-old roots remain in the soil (see Fig. 1e). Attaining 100% kill of remnant roots to the 4 ft depth and endoparasites to the 5 ft depth requires a dose of 500 ppm in 6 inches water followed by one full year of fallow period. This dosage is not currently permitted for agricultural crops in California. The currently registered rate of 100 gal/acre Vapam (32.7% MS) added uniformly to 4 inches of water would be adequate only for soil conditions indicated in Fig. 1f and such treatments should be followed by a year of fallow. Additionally, we only expect to deliver Vapam successfully in situations where the soil will infiltrate the delivered water in 8 hr or less. Soils having internal drainage problems cannot be properly drenched with MS. Vapam is not recommended at soil temperatures below 45º F.

I-4. Systemic Herbicides Plus 18 Month Fallow

Studies have shown that remnant roots of *Juglans* spp. and *Prunus* spp. can be killed with herbicides painted on tree trunks (Appendix Items 11,12 and 13) Just after harvest, the trees were irrigated then limbs cut off leaving enough trunk to facilitate removal. An herbicide mixture was painted or hand sprayed to the cambial surface. Early experiments included the addition of diesel oil to the systemic herbicide. Subsequently we learned that four-fold rates of MorAct is a viable alternative to diesel oil.

For Northern California Black Walnut and Paradox Hybrid, our best results were achieved with Garlon 3A herbicide. We worked less with Garlon 4E, although it reportedly performs better than the 3A formulation. For *Prunus* spp. including Nemaguard, Myrobalan 29C, Lovell seedling, and Marianna 2624, our percentage of root kill after the best treatment of Roundup ranged from 95%, 75%, 60% to 40%, respectively. These herbicide effects can be translocated to the deepest roots, with spotty live roots remaining along the root system. Do not evaluate root death of walnut until 1 yr after treatments.

With Lovell seedlings, Root Knot Nematodes present in roots can be reduced by 95% within 60 days after treatment, which is long before the roots appear dead (Appendix Item 10). However, the Root Lesion Nematodes present as eggs within *Prunus* spp. can continue to come out of the roots for more than 2 yr after the roots appear completely dead. With walnut roots, root death initiates a moist decay that 18 mo after treatment can reduce root populations of Root Lesion Nematode to 3% of nontreated roots. By itself, this 97 % level of control provides nematode relief lasting only 6 mo. At this writing, we have not found any herbicide treatments capable of killing grape roots throughout the soil profile, although Garlon 3A plus diesel can kill roots to an 18-inch depth.

Systemic herbicide treatments provide a new tool for reducing the length of a fallow period. Peach root remnants can survive 2 yr after tree removal. Plum roots last somewhat longer. Remnant roots of walnut survive 3-4 yr. Remnants of grape roots survive up to 8 yr while the *Xiphinema index* can survive even longer (Raski, 1967). If our hypothesis about the rejection component is correct, the sooner the old root system is killed, the sooner there will be relief from the rejection component of RP.

I-5. Experiences with Packages of "Specific Treatments"

Fumigating with MB and 1,3-D have enabled tree and vine growers to remove and replant their fields the spring after the last crop is harvested. This attribute of soil fumigation will be one of its toughest to replace, however it has remained one of the goals of these studies. Softer treatments (those less disruptive to the environment) have the potential to work as well but they require more time. With systemic herbicides, an 18 mo waiting period is needed as populations of soil microbes gradually shift and the rejection component of RP is avoided. Alternatives already exist for sites with no serious soil pest problems or where resistance rootstocks are available. However, as indicated in Section E, it is common to find soil pests somewhere across a field. If nematodes are the major soil pest, treatments still need to be delivered down to 5 ft of depth. In cases involving Oak Root Rot, the treatments need to be delivered deeper. Shallower depths may be adequate for certain soil pests such as Phytophthora Root Rot.

In one field where Lovell rootstock trees were to be replanted, we trunk-treated with systemic herbicides, removed the trunks after 60 days, backhoed each tree site and filled each hole with 350 gallons of 210º F water before replanting. Another treatment involved treating the backhoed site with MS before refilling with NRPS instead of soil from the spoil pile. We continue to believe that packaging such treatments together can be useful when MB is no longer available. However, it is instructive to explain why none of our packages performed adequately.

First, the above fields had sandy loam (~65%sand) rather than a loamy sand (~85% sand) soil. Even with 16 inches of winter rainfall, the planting sites had not completely settled, leaving macropores within the rooting zone. Second, the hot water treatment effectively killed only 95% of the nematodes because heat did not penetrate the soil clods or remnant roots within the well-drenched site. Third, the trees planted into NRPS grew well for 3 to 4 mo then dramatically slowed as the root systems developed into the MS-treated zone. We have since demonstrated that there is some type of rejection component working as root systems move out of NRPS and into MS-treated zone. This rejection does not occur when the roots are started out in a soil completely treated to 5 ft deep with MS. However, as root systems grow out of MS treated zones into RPS, a similar rejection effect occurs.

It is imperative that researchers and regulators understand that soft treatments require multiple field trials before declaring the practice a viable alternative to standard practices. These trials require time and objectivity. Each soft tool has its limitations and the practical limitations of each must be understood before growers can be assured that it is a reliable MB replacement. For example, the application of organic materials to solve RPS situations can sometimes give a growth lag, thus there needs to be sub-plots involving such treatments.

J. Best Management Methods for Specific Tree/Vine Situations

Field Situation #1A	*Armillaria mellea* fungus present but limited to the surface 7 ft of profile.
Solution 1/	Tarped MB at 400 to 500 lb/acre to dried soil, slight surface moisture OK.
Field Situation #1B.	*Armillaria mellea* fungus present in a soil deeper than 7 ft.
Solution 1/	Tarped MB at 400 to 500 lb/acre to dried soil will only provide 6 yr relief.
Solution 2/	Plant crops with rootstocks having resistance to *A. mellea* e.g. Marianna 2624 Plum, persimmon, own-rooted grapes in San Joaquin Valley only.
Field Situation #2	Virus infected remnant roots with nematode vector present e.g. Grape Fan Leaf Virus plus *Xiphinema index* present.
Solution 1/	Tarped MB 400 to 500 lb/acre to dried soil then wait 1 yr before replanting.
Solution 2/	35 gal/acre Telone shanked at 18 inches to dried soil followed by 1-2 inch irrigation or drenching with 250 ppm MS, then wait 1 yr before replanting.
Solution 3/	35 gal/acre Telone shanked at 18 inches to dry soil followed in 2-4 wk with a complete inversion of the surface 12 inches then retreat with 15 to 20 gal/acre Telone. Wait 1 yr before replanting.
Field Situation #3	Remnant roots which contain endoparasitic nematodes or Phylloxera.
Solution 1/	Tarped MB at 350 to 450 lb/acre to dried soil.
Solution 2/	35 gal/acre Telone shanked at 18 inch depth to dried soil followed by 1 to 2 inches drenching with 250 ppm MS.
Solution 3/	200 gal/acre Vapam (32.7% MS) uniformly injected and delivered within 8 hr (coarse-textured soils only). Wait 1 yr before replanting.
Field Situation #4A.	Remnant roots with ectoparasitic nematodes present in coarse-textured soils, e.g. Ring Nematode in sandy soil conducive to Bacterial Canker Complex.
Solution 1/	Tarped MB 300 to 350 lb/acre to dried soil.
Solution 2/	Nontarped MB at 350 1b/acre at 18+ inches to a dried soil with surface 6 inches of soil gleaned of roots.
Solution 3/	Telone shanked at 35 gal/acre at 18 inch depth to dried soil followed by 1-2 inch drenching or sprinkling of 250 ppm MS.
Solution 4/	Telone EC at 35 gal/acre applied in the first 4½ inches water then 30 gal/acre Vapam in 1 inch water followed by ½ inch water containing 1 qt/acre Tillam.

Solution 5/ Telone at 35 gal/acre shanked at 18 inches depth to soil with moistened surface.

Solution 6/ Vapam HL at 100 gal/acre uniformly drenched or sprinkled within 8 hr in 4 to 5 inches water.

Note that all six of these treatments must be accompanied with an annual October treatment of a post-plant nematicide where BCC is serious.

Field Situation #4B Remnant roots with ectoparasitic nematodes present in finer-textured soil.

Solutions 1, 2, 3, 4 in situation #4A above.

Field Situation #5 Remnant roots present but no serious soil pests/diseases present or a resistant rootstock has been selected.

Solution 1/ Spot or strip treat with MB at 350 lb/acre rate, or Telone (35 gal) or Vapam (100 gal of 32.7% MS) then replant the next spring.

Solution 2/ Before removing trees and in the months of July through October irrigate, cut trunks and immediately paint cut surface with: *Prunus* spp. – 50 ml Roundup plus 100 ml. MorAct; *Juglans* spp. – 50 ml Garlon 3A plus 100 ml MorAct. Wait 60 days before tree removal. Push trees, rip and level and then in July of the following year examine remnant roots for life (*Prunus* spp. may only show slight darkening beneath outer root layer). Fallow or use nonhost crops during the waiting year.

K. Future Management Methods that Need Field Evaluation with *Juglans, Prunus* and *Vitis*

Field Situation #1 Walnuts with Root Lesion Nematode present.

Potential solution 1/ Harvest the last crop, irrigate, cut trunks and immediately paint with 50 ml Garlon 3A plus 100 ml MorAct. Wait 60 days before tree removal, rip, level. Midsummer to November of the next year treat soil as indicated in Solutions 4A #3, 4, 5, or where solid set sprinklers are available #6.

Potential solution 2/ Harvest last crop, irrigate, cut trunks and immediately paint with 50 ml Garlon 3A plus 100 ml MorAct. Wait 60 days before tree removal, rip, and level. Replant 18 mo after the last harvest planting a rootstock resistant to *P. vulnus*. (No such rootstocks currently exist for walnut).

Potential solution 3/ Harvest last crop and Garlon-treat as indicated above. Replant after 18 mo into backhoed sites treated with a biocide and then at least ½ yd of “non replant problem soil” (i.e. virgin soil) placed at each planting site. One-yr old seedlings or the planting of 3 seeds/site could permit planting the orchard 1 yr earlier. We do not yet know how to create soil that simulates NRPS, but it can be found in locations at least 100 ft away from existing walnut roots where no perennials have been growing and *P. vulnus* does not occur.

Field Situation #2 Peach/Plum/Almond replanting into a Root Lesion Nematode *P. vulnus* infested site.

Potential solution 1/ Harvest last crop, irrigate, cut trunks between July and November 1. Immediately paint the cut trunks with 50 ml Roundup and 100 ml MorAct/tree. Wait 60 days before tree removal then push tree stumps, rip and level. This treatment will not reduce populations of *P. vulnus* within remnant roots but after 18 mo fallow will give control of the rejection component of RP. Plant rootstock with resistance. The only known resistance occurs in pistachio. If resistant rootstocks are available plant 1 yr earlier by placing ½ yd NRPS at each tree site before replanting.

Field Situation #2A Peach/Plum/Almond replanting into a Ring Nematode *Criconemella xenoplax* infested site.

Potential solution 1/ Harvest last crop, irrigate, cut trunks between July and November 1. Push tree trunks after 60 days, adjust pH, rip, and level. When new tree planting sites are known, treat the sites with a biocide and reestablish an ecosystem compatible with young woody perennials. It is unknown how to accomplish this. NRPS is the best medium we know of but spot treatments of Vapam, for example, are not very compatible with NRPS.

Potential solution 2/ Harvest last crop, irrigate, cut trunks between July and November 1. Push tree trunks after 60 days, rip, and level. Do not use a biocide but wait 18 mo after tree removal and replant into ½ yd NRPS. Via existing drip or microsprinkler deliver an effective nematicide treatment in mid-October of each of the first 7 yr of the planting. Additionally, irrigation methods that deliver water frequently can reduce the incidence of Bacterial Canker Complex, as compared to basin irrigation.

Field Situation #3A. Coastal grapes planted to shallower soils (2 to 4 ft of soil depth).

Potential solution 1/ Harvest, perhaps cane cut and then pull down the existing dripper system. Use the existing dripper system (emitters spaced 4 ft or less) to deliver at least 4 to 5 hr water containing 500 ppm MS then pull the drip line a distance of half the emitter spacing and continue another 4 to 5 hr with the MS. This should provide a wetted zone 3 to 4 ft wide and uniform down the planted row. Sixty days later remove the vines and stakes and lines if necessary. (If the soils are only 2½ ft deep 250 ppm MS is adequate.). Wait a full year before replanting, attempting to fill the biological vacuum and awaiting reduction of the plant growth problems associated with the 500 ppm rate of MS. This treatment provides soil pest relief lasting 8 to 12 mo. Do not consider this method without planting rootstocks with resistance to the known soil pests present and having some tolerance to the rejection component of RP. For example Teleki 5C should not be the replant. Growers wanting to continue treatments out into the drive row should move the dripper line out 3 ft from the trunk then progressively repeat the treatment as before until 3 ft away from the adjacent row. Don't assess the root kill pattern for at least 2 mo after the treatment. At 60 to 90 days prior to replant, soil lost from the new planting row should be replaced and the dripper system reinstalled to again deliver a low treatment rate of Vapam or Enzone to the replaced soil.

Field Situation #3B. Nematodes and/or Phylloxera present in soils deeper than 5 ft.

Potential solution l/ Follow the same process as outlined for shallow soils but substitute Telone EC for the Vapam. Deliver at 250 ppm 1,3-D and place a 3 ft-wide strip of polyethylene tarp over the surface of and fastened to the dripper line. A shorter replanting interval is possible following Telone EC.

L. Field-Grown Nursery Crops

Every potential replacement for MB involves a more complicated process than MB. With nursery crops, the goal is nematode-free stock (~100%) utilizing a combination of site selection, fallow period and treatment with biocides. For more than 30 yr, this goal has been accomplished by applying high treatment rates of MB or 1,3-D following a full year of fallow and a longer wait if the nursery is to follow removal of an old orchard or vineyard.

Potential soil treatments received evaluation in a nursery trial conducted from 1995 through 1998 (McKenry, et. al., 1997, Appendix Items 7 and 9). These most recent results have identified the shortcomings of potential MB replacements plus the direction we must now go with commercial evaluations (see Table 2). Table 2 indicates the relative value of various biocidal agents applied as a drench (PSDD), as a shank injection or when incorporated followed by irrigation. Five of these treatments provide nematode control adequate for a two-year nursery crop, at least in this single setting where we utilized mostly non-commercial equipment. These plots involved four replicates with each planted to 13 Nemaguard Peach and 13 Marianna 2624 Plum rootings. Treated replicates were 105 ft in length and 10 ft wide and efforts were taken throughout the three-year experiment to avoid soil contamination.

In addition to current standards of tarped MB at 400 lb/acre rate and a dual application of shanked 1,3-D (data not included); we can identify at least six products and/or delivery methods which provide 14 mo of nematode relief. These treatments must be coupled with proper attention to cropping history and 1 yr of fallow. Five of these treatments provided two years of adequate nematode relief. No treatment provided tree growth with the consistency of MB.

Methyl iodide treatments were most notable in this regard but additionally the drench treatments, particularly with 1,3-D alone, did not provide plant growth comparable to the shanked treatments. In this trial we were intentionally conservative with nitrogen fertilization and that shortage indicates the increased growth response (IGR) associated with various treatments and methods of delivery. It is also apparent in comparison to the tree growth attained with the urea drench (treatment K). As these potential treatments now receive commercial evaluation there will need to be supplementary nitrogen treatments with some.

Nontarped methyl iodide at 325 lb/acre performed adequately relative to nematode control and broad spectrum soil pest control is expected. We have reported phytotoxicity to Marianna 2624 Plum and to a lesser degree with Nemaguard Peach. If the phytotoxicity is due to abundance of native iodide already in the soil, it could mean differences in different locations but more importantly, repeated treatments to the same soil could create a buildup of iodide. This treatment cannot be recommended for nursery crops at this time.

Telone treatments at 330 lb/acre also performed adequately regardless of whether they were shanked or drenched as long as a surface treatment of Vapam was also sprinkled or drenched onto the surface in 1 to 2 inches of water. The current label for shanked Telone and the requirement for moisture at the field surface will require regulatory attention to soil moisture content present within each field (see Fig. 1). Even with such scrutiny, there may well be some failures in silty or clay loam soils. Successful treatments with Telone have included: Telone at 35 gal/acre shanked at 18-inch depth followed in 2 to 4 wk with an inversion of the surface 12 inches of soil and retreatment with 15 to 20 gal of Telone. The new surface soil moisture requirements could present a problem with this excellent soil treatment that also provides weed control. The shanked application of 35 gal/acre Telone at 18-inch depth coupled with delivery of 1-2 inches sprinkling or drenching of 250 ppm Vapam is also an excellent treatment with security that surface nematodes will not escape (McKenry, M. V., 1996).

This combination treatment will provide weed control if the Vapam drenches are split up by 3 to 4 days to allow imbibing by the seeds prior to the final 1-inch drench. Any sprinkler-applied Vapam treatment will require attention to wind conditions at time of treatment as well as attention to worker reentry periods for Telone but the combination treatment also provides an opportunity to reduce volatilization percentages of Telone.

Telone EC drenched by itself or with additional Vapam at the surface also provides adequate nematode control but there will need to be attention to the total gallons of water applied to each acre to insure efficacy. There is no currently available single piece of equipment to deliver such drenches and if developed commercially, there would likely be benefit from having some type of moving tarpaulin over the field surface to reduce volatilization that comes from the puddles during application. These puddles do not necessarily occur in sandier soils. The application of 4 to 6 inches water containing 250 ppm MS can also provide adequate nematode control when conducted in soils that can infiltrate the water in 8 hr or less.

In settings where the previous nursery crop had been walnuts or other 26-mo crops, there will need to be some attention to the roots remaining after digging but physical methods may suffice when completed soon after the digging. Vapam treatments should be made well in advance of planting in order to provide opportunity for filling the biological vacuum by cover cropping or soil amendments. Commercial evaluations are needed to determine if this is possible and how it is best accomplished while avoiding pest contamination of the field.

Basamid treatments will not be successful until more is known about the dissolution rate of the granules. The powdery nature of Basamid granules requires that attention be given to adequate granule distribution and incorporation prior to irrigation. A positive feature of the granules is the added growth benefit they seem to provide.

In this section and others throughout this text the goal has been to provide direction for future field evaluations involving larger plots, varied planting materials and commercially available chemicals and equipment. To adequately accomplish commercial evaluations will require that all stakeholders approach them in a cooperative manner (Appendix Item 16).

Table 2. Nematode control and tree growth following various pre-plant soil treatments for nematode-free nursery stock.

		Control of *P. vulnus* Expressed as % of nontreated			Tree Growth (kg)			
					Peach		Plum	
		90 day	12 mo	24 mo	Yr 1	Yr 2	Yr 1	Yr 2
P.	Uniform PSDD: 1,3-D ec at 325 lb/acre.	100.	99.9	99.92	1.49	5.22	1.73	6.08
D.	Stacked PSDD: 4.5" at 250 ppm 1,3-D ec then 1.5" of 250 ppm MS.	99.4	100.	99.90	1.78	5.38	1.79	5.56
O.	Shanked methyl iodide at 325 lb/acre, no tarp.	100.	100.	99.80	2.04*	6.17	1.14*	4.37
M.	Uniform PSDD: MS at 325 lb/acre.	99.8	100.	99.65	1.97*	6.81*	2.17*	6.63
W.	Shank 1,3-D at 325 lb/acre then PSDD 2" at 250 ppm MS.	90.0[1]	100.	97.00[1]	2.13*	7.30*	1.65	6.01
A.	Shank methyl bromide at 240 lb/acre, no tarp.	100.	92.1[1]	83.5[1]	1.96*	7.23*	1.76	7.11
S.	Uniform PSDD: ec of 1,3-D + Pic at 325 lb/acre.	100.	99.2	59.5	2.23*	7.47*	2.17*	6.63
U.	Incorporate 325 lb/acre Basamid then sprinkle 6" intermittently for 15 hr.	100.	74.0	39.4	2.28*	6.30	1.81	5.89
H.	Stacked PSDD: 300 gal/acre Enzone in 5.5" then Tillam in 0.5" then five post-plant treatments via drip.	66.	45.6	28.5	1.75	5.18	1.82	5.69
K.	Uniform PSDD: 650 lb/acre lobi urea then plant barley.	60.	22.1	8.4	1.70	6.44	1.93	6.98
I.	Uniform PSDD: 40 gal/acre peroxyacetic acid + 40 gal/acre stabilizer.	0	0	47.0	1.48	4.11	1.58	4.48
L.	Uniform PSDD: 18 lb/acre phenamiphos + 200 lb/acre urea.	0	30.0	54.0	1.28	4.27	1.58	5.90
Q.	Nontreated check, PSDD water only (actual *P. vulnus*) per 250 cm^3 soil.	(2.5)	(448.)	(929.)	1.29	4.16	1.58	5.62

[1] Designated treatments where only a single replicate became nematode infested.

* Designates plant growth significantly different ($P = 0.05$) from nontreated.

Note: PSDD refers to a “Portable Soil Drenching Device” consisting of a drip emitter on each square foot of field surface through which 6 inches water is delivered to every treated acre. Uniform PSDD refers to injection of product into the full 6 inches of water. Stacked PSDD refers to injection of one product followed by a different subsequent product.

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M. Literature Cited

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