1999 California Almond Board Report
Year One of Two Years

Project Number: 98-MM-o0

Project Title: Attempts to make a "compatible" virgin soil as a potential replacement for methyl bromide.

Principal Investigator: Michael V. McKenry
Nematology Department, UC Riverside

Executive Summary: In a third-leaf trial involving Mission Almond on Nemaguard there is no significant growth difference between trees growing in 100% virgin soil (NRPS), Methyl Bromide treated, or trees planted into ½ yard NRPS. All three treatments were significantly greater in size than those backhoed only or non treated. In an adjacent second-leaf orchard the ground had been fallowed one full year. Trees placed into sites that received ½ yard NRPS following a pre-plant drench of 250 ppm MITC (Vapam) grew significantly poorer than trees planted into ½ yd NRPS only. Essentially, roots moving out of NRPS and into the ecosystem that results after a Vapam treatment grew poorer than those that grew directly into replant problem soil.

Since we have had 10 years of experience growing Nemaguard in sites treated only with Vapam, we now believe that trees do not grow well as their roots move out of one ecosystem into a very different one. To test this hypothesis we have planted Butte/Nemaguard into sites containing ½ yard NRPS but surrounded by soil that has received a variety of pre-plant treatments. Pre-plant treatments included: Telone plus chloropicrin, methyl bromide, Telone at 30 gal/acre, 20 gal/acre plus ThioSol, 12 gal/acre drenched, 250 ppm MITC drenched, and non treated check. In the first year trees having roots that grew out of NRPS and into methyl bromide or Telone treated soil did not exhibit a growth lag. Trees growing out of NRPS and into Vapam or chloropicrin treated sites did exhibit a growth lag depending on the intensity of the replant problem across the site. We refer to this growth lag as an incompatibility. Additions of organic matter at planting time reduced tree growth in every case, but especially where no attempt was made to alleviate the replant problem.

Though growth differences were not significant, there was a benefit to applications of the same amount of organic matter (from the same piles) applied to a site that had previously been treated with methyl bromide. This latter soil was used in lieu of NRPS in order to try to make NRPS.

These results, further enumerated in Table 1, should not be relied upon until we see the conclusion of growth in fall 1999. We continue to recognize a lag in tree growth as root systems move out of one soil ecosystem and into another. As we attempt to put together three or four or five "softer" treatments in an attempt to replace one treatment of methyl bromide, it is clear that those softer treatments need to result in soil ecosystems with overall compatibility to plant growth.

Table 1

First Year (1998) Trunk Dia. in Cm
In a Severe or Moderate Replant Problem
Butte Almond on Nemaguard
2/16/99

	Severe Replant Problem				
	Treatments	Mean	% of ck	DMRT	
4g	NRPS>350 lbs/ac MB Tarped	2.96	136.8	a	*
6g	NRPS>100 gpa Vapam	2.92	134.7	a	*
5	325 lbs/ac 1,3-D + Pic ec	2.88	132.8	ab	*
2g	NRPS>30 gpa 1,3-D	2.81	130.0	abc	*
5h	325 lbs/ac 1,3-D + Pic ec >Compost>Suppressive Agent	2.81	129.9	abc	*
3g	NRPS>20 gpa 1,3-D + Thiosol	2.76	127.6	abcd	*
g	NRPS>RPS	2.74	126.7	abcd	*
4	350 lbs/ac MB Tarped	2.68	123.8	abcde	*
1g	NRPS>30 gpa 1,3-D + Vapam	2.67	123.4	abcde	*
b	100 gpa Vapam + 1yr Nemaguard Roots[Trt M]>RPS	2.64	122.1	abcdef	*
8g	NRPS>12 gpa 1,3-D ec	2.60	120.1	abcdefg	*
3	20 gpa 1,3-D + Thiosol	2.59	119.8	abcdefg	*
d	Telone+ Vapam + 1 yr Nemaguard Roots[Trt w]>RPS	2.50	115.5	bcdefgh	
5g	NRPS>325 lbs/ac 1,3-D + Pic ec	2.50	115.5	bcdefgh	
U	350 lbs/ac MB + Manure, Compost,Seaweed>RPS	2.49	114.9	cdefgh	
e	350 lbs/ac MB Tarped[Trt 4}>Compost>Suppressive Agent>RPS	2.48	114.3	cdefgh	
3h	20 gpa 1,3-D + Thiosol>Compost>Suppressive Agent	2.39	110.3	defghi	
1	30 gpa 1,3-D + Vapam	2.36	108.8	efghi	
2	30 gpa 1,3-D	2.31	106.8	efghi	
8h	12 gpa 1,3-D ec >Compost>Suppressive Agent	2.29	105.7	fghij	
c	100 gpa Vapam Soil[Trt 6]	2.27	104.8	fghij	
4h	350 lbs/ac MB Tarped>Compost>Suppressive Agent	2.25	103.9	ghij	
P/A	RPS>Butte on Peach Almond Hybrid	2.24	103.5	ghij	
a	100 gpa Vapam Soil[Trt 6] >Compost>Suppressive Agent	2.24	103.3	ghij	
7	RPS	2.17	100.0	hij	
2h	30 gpa 1,3-D>Compost>Suppressive Agent	2.13	98.3	hij	
6	100 gpa Vapam	2.13	98.2	hij	
h	RPS>Compost>Suppressive Agent	2.12	97.9	hij	
1h	30 gpa 1,3-D + Vapam>Compost>Suppressive Agent	2.08	95.8	ij	
8	12 gpa 1,3-D ec	2.03	93.8	ij	
6h	100 gpa Vapam Soil[Trt 6]>Compost>Suppressive Agent	1.91	88.4	j	
f	RPS>Compost>Suppressive Agent	1.91	88.3	j	
				P= .05	

	Moderate Replant Problem				
	Treatments	Mean	% of ck	DMRT	
8g	NRPS>12 gpa 1,3-D ec	3.06	128.0	a	*
4	350 lbs/ac MB Tarped	3.03	126.7	ab	*
U	350 lbs/ac MB + Manure, Compost,Seaweed>RPS	3.01	126.2	abc	*
1g	NRPS>30 gpa 1,3-D + Vapam	2.88	120.4	abcd	*
5g	NRPS>325 lbs/ac 1,3-D + Pic ec	2.88	120.4	abcd	*
4g	NRPS>350 lbs/ac MB Tarped	2.87	120.3	abcd	*
4h	350 lbs/ac MB Tarped>Compost>Suppressive Agent	2.85	119.4	abcd	*
e	350 lbs/ac MB Tarped[Trt 4}>Compost>Suppressive Agent>RPS	2.84	119.1	abcd	*
3g	NRPS>20 gpa 1,3-D + Thiosol	2.84	119.1	abcd	*
6	100 gpa Vapam	2.81	117.8	abcde	*
3	20 gpa 1,3-D + Thiosol	2.79	117.0	abcde	*
5	325 lbs/ac 1,3-D + Pic ec	2.78	116.5	abcde	*
2g	NRPS>30 gpa 1,3-D	2.73	114.3	abcdef	
P/A	RPS>Butte on Peach Almond Hybrid	2.72	113.9	abcdef	
g	NRPS>RPS	2.69	112.6	bcdefg	
8	12 gpa 1,3-D ec	2.68	112.3	bcdefg	
2	30 gpa 1,3-D	2.68	112.0	bcdefgh	
2h	30 gpa 1,3-D>Compost>Suppressive Agent	2.66	111.5	cdefgh	
5h	325 lbs/ac 1,3-D + Pic ec >Compost>Suppressive Agent	2.65	111.0	defgh	
1	30 gpa 1,3-D + Vapam	2.63	110.2	defgh	
b	100 gpa Vapam + 1yr Nemaguard Roots[Trt M]>RPS	2.59	108.4	defghi	
d	Telone+ Vapam + 1 yr Nemaguard Roots[Trt w]>RPS	2.58	107.9	defghi	
8h	12 gpa 1,3-D ec >Compost>Suppressive Agent	2.56	107.3	defghi	
3h	20 gpa 1,3-D + Thiosol>Compost>Suppressive Agent	2.56	107.1	defghi	
c	100 gpa Vapam Soil[Trt 6]	2.47	103.4	efghi	
1h	30 gpa 1,3-D + Vapam>Compost>Suppressive Agent	2.41	101.0	fghi	
7	RPS	2.39	100	fghi	
6g	NRPS>100 gpa Vapam	2.39	99.9	fghi	
6h	100 gpa Vapam Soil[Trt 6]>Compost>Suppressive Agent	2.34	98.1	ghi	
f	RPS>Compost>Suppressive Agent	2.32	97.2	hi	
h	RPS>Compost>Suppressive Agent	2.26	94.8	i	
a	100 gpa Vapam Soil[Trt 6] >Compost>Suppressive Agent	2.26	94.8	i	
				P= .05	

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DATE: March 24, 1999

TO: Almond Board of California, Chris Heintz
American Vineyard Foundation, Patrick Gleeson
California Table Grape Commission, Ross Jones
California Tree Fruit Agreement, Annee Ferranti
California Tree and Vine Improvement Advisory Board, Don Dilly
California Cling Peach Advisory Board, Diana Richards
California Raisin Marketing Board, Kathleen Boyd
California Walnut Board, Dave Ramos

FROM: Michael V. McKenry
Nematologist, UC Riverside

SUBJECT: **Summary of Methyl Bromide Alternatives Work Conducted from 1993 to 1998**

Enclosed is one copy of a text summarizing work funded by your agency and matched by the Nematology Department at University of California, Riverside. This text will indicate our small plot findings and directions for future studies in commercial settings. More importantly the text indicates criteria needed by any methyl bromide replacement. Over the next three months this text will go out for technical review by scientists engaged in similar studies. I wanted the original report to go to the people who funded the work, but expect improvements in the final version. I would also appreciate any critical comments you may have concerning this text.

I do not currently have a clear notion of where this text will eventually be published but my goal is to get the corrected text printed with quality color photos at a cost of about $35.00 each.

Thank you for your support of these studies.

MVM:ls

Enclosure

The Replant Problem and Its Management
by Michael V. McKenry

Abstract

A new working hypothesis for the replant problem affecting tree and vine crops is described with four distinct components characterized. The term “rejection component” is suggested to provide a specific description of the general replant problem. Field performance of more than 135 potential alternatives to methyl bromide soil fumigation are compared. Treatments include a diversity of cultural, physical, biological and chemical approaches to the problem. The loss of methyl bromide will result in a shift to 1,3-D nematicide, probably in combination with MITC liberating compounds or chloropicrin. Without methyl bromide there will be a shift to longer fallow periods and combinations of softer treatments which solve individual components of the replant problem. Combining of soft treatments will require accurate knowledge of their limitations as well as diagnosis of the specific problem and commonly add great complexity to the task of replanting. There will also be field situations where methyl bromide is not needed or replaceable by one or two soft treatments. Mistakes in proper assessment of the replant problem can greatly reduce production efficiency of the grower, frequently for the life of the new planting. Recipes for commercial evaluation of softer combination treatments are provided as are the best management practices currently available. New management methodologies including trunk treatments with systemic herbicides and use of transported non replant problem soil are described.

The Replant Problem and Its Management
by
Michael McKenry
March 1999

A. Introduction

Farmers of tree or vine crops often encounter growth problems when they replant within several years of removing the previous orchard or vineyard. This problem, herein described as the replant problem (RP), includes plant stunting and leaf yellowing in an uneven pattern across a field. While the problem occurs worldwide at varying intensity levels, there are locations and regions where it does not occur. For decades, scientists have tried to identify the key ingredients of this problem. But even today, we are only able to provide partial and usually discipline-biased theories on the source of RP.

Solutions to RP exist but they typically vary from region to region or from one woody crop to the next. For instance, on the northeast coast of US and Canada, fumigation is a reliable control of apple RP but was only recently accepted as a control for the RP that occurs on apples in Washington State (Smith, T. J. 1994). The methods used in Oregon on pear replants (phosphorous applications) are different from those known to be dependable in California. Since the 1960s, the practices for controlling RP in California include soil profile modification (i.e. soil ripping, backhoeing of individual tree sites, soil trenching or slip plowing) coupled with soil fumigation. When properly applied, this one-two punch is effective more than 95% of the time (McKenry et. al. 1994). A recent study of Sonoma County vineyards indicated that soil fumigation is only used in 43% of the new grape plantings (Liebman, J. and S. Daar, 1995). However, that report failed to note that growers were fumigating at least 90% of their replanted vineyards compared to only a few of their first-time vineyards.

These examples illustrate how even the recognition of RP is elusive. On some occasions, fumigation itself may result in poor growth of the subsequent crop. These situations are usually a result of one or more factors: replanting too soon after treatment; soil that is too cold or too moist; or killing of beneficial soil microbes such as Mycorrhizal Fungi. (Mycorrhizal inoculations are a good investment after any fumigation but especially after operations that included land-leveling or tarped fumigations.)

An alternative to soil fumigation is leaving the land fallow prior to replanting. This alternative can be quite expensive because proper alleviation of RP in peach orchards, for example, requires up to 4 yr fallow or the rotation to non-woody rooted crops. The soil pest spectrum also dictates the fallow time period. For vineyards infected with Grape Fan Leaf Virus (GFLV), even 10 yr of fallowing or non-host crops may not be enough. Few California growers can afford leaving land out of production for so long.

Most tree and vine growers have shifted to soil fumigation with methyl bromide (MB) after use of Telone (1,3-D) soil fumigant was suspended in 1990. Prior to the suspension, 1,3-D was the preferred soil fumigant with MB a distant second choice because of its higher cost and associated nutritional problems. Vapam (a methyl isothiocyanate liberator) is not widely used due to its inconsistent performance. This product is not a true fumigant and is a poor root penetrant (McKenry, M., et. al., 1995).

The expected phase out of MB by 2001 heightens the need to find solutions to RP. This author estimates a 25% loss in production across California's 2.2 million acres of tree and vine crops should no viable replacement be found for MB.

A major drawback to finding a solution is the piecemeal approach taken in California when studying the problem. RP is typically blamed on a single factor such as a nematode problem, nutritional problem, root rot condition, overwatering, wind damage, nursery problem, flat headed borers problem or some other malady. Common to each of these individual problems is that they usually initiate the first year after planting and follow the removal of some other woody perennial. Additionally, when a soil problem is physical, chemical and biological, the most effective control method must be performed prior to planting, otherwise the malady can develop into a long-term problem.

B. Characterization of RP

B-1. Descriptions and Photographs

RP is a multi-component problem associated with a very complex medium, the soil. The severity of RP varies by region, field, cropping history, soil type, even row to row. Individual rootstock cultivars also have proven to be a source of RP intensity. For example, Marianna 2624 Plum is not as sensitive to RP as Nemaguard Peach.

A common symptom of RP is uneven growth across a field, especially in the first season of growth (see introductory photo). Plant chlorosis and stunting is usually visible by early summer. In severe RP situations, plants will die, especially if a young field is overwatered.

The array of trunk circumferences displayed below (on Photo Array 1) depicts actual trunk girths of Loadel on Lovell Peach rootstock grown over a 6-yr period at two different irrigation regimes (McKenry, M. V. et. al., 1987). A randomly selected tree was cut off 15 cm above ground from each of six replicates at first fall (designated as #1), spring of year 3 (#4), fall of year 3 (#5) and in fall of year 5 (#7). Trunks displayed on a green background received normal irrigation whenever soil moisture reached -50cb tension at the 45 cm depth. Those on the blue background received a more frequent irrigation at -25cb moisture tension or every 14 instead of 21 days during summer months. Treatments 4 and 8 were planted without addition of any soil organisms. Treatments 1 and 5 were planted and the soil inoculated with *Meloidogyne incognita* nematode. Treatments 2 and 6 received the same nematode inocula but supplied by adding 1 kg soil from a peach replant site to each tree at planting time. Treatments 3 and 7 received the same *Meloidogyne* population as above but were also inoculated with *Dactylella oviparasitica*, a fungus that infects *Meloidogyne* eggs (but was unsuccessful in this trial). Note the variability in trunk circumferences in all but treatments 4 and 8. Note that especially in the first few years the higher moisture regime was detrimental to tree growth but especially in the replant soil sites (treatments 2 and 6).

Growth of new feeder roots and primary roots is also limited. An unhealthy or restricted root system often translates into weak plants, especially if other stress factors exist. In commercial plantings, dead or poorly growing plants typically occur in a pattern traceable to a unique soil type within a field. In the first year, these growth problems can frequently appear in a random fashion with weak plants adjacent to seemingly strong plants. Where RP exists, usually none of the plants are growing as well as they could. This is especially apparent when comparable plants are growing nearby in a fumigated site.

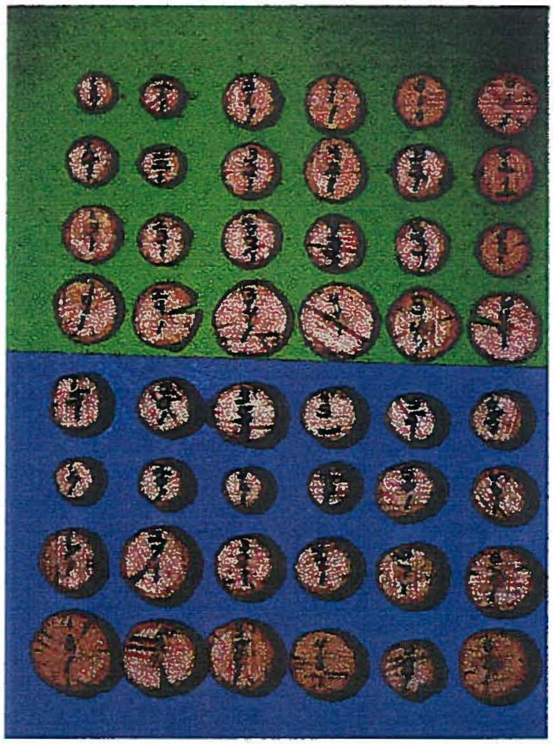
For example, peach on Nemaguard rootstock will grow poorly the first summer although some to many appear to grow out of the problem. This can be most noticeable in the second year (see treatment 2 displayed in Photo 1).

Replants of walnut and grape do not rebound as quickly as Nemaguard replants. Peach on Lovell rootstock can also exhibit apparent recovery in the second year. However, in the sandiest soils where *Meloidogyne* spp. are prevalent (the Achilles heel for Lovell) the trees may never be productive.

Unwittingly, California growers often neutralize RP by using soil fumigation in combination with soil profile modification without even realizing RP exists in their field. In fact, most of our knowledge about RP and key soil pests is based on comparisons between fumigated and non-fumigated treatments. While these studies have led to increased research

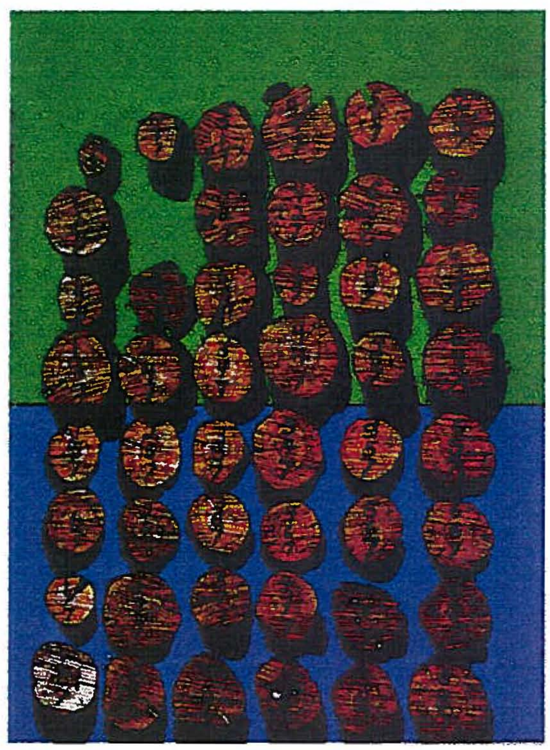
Photo Array 1

First Fall



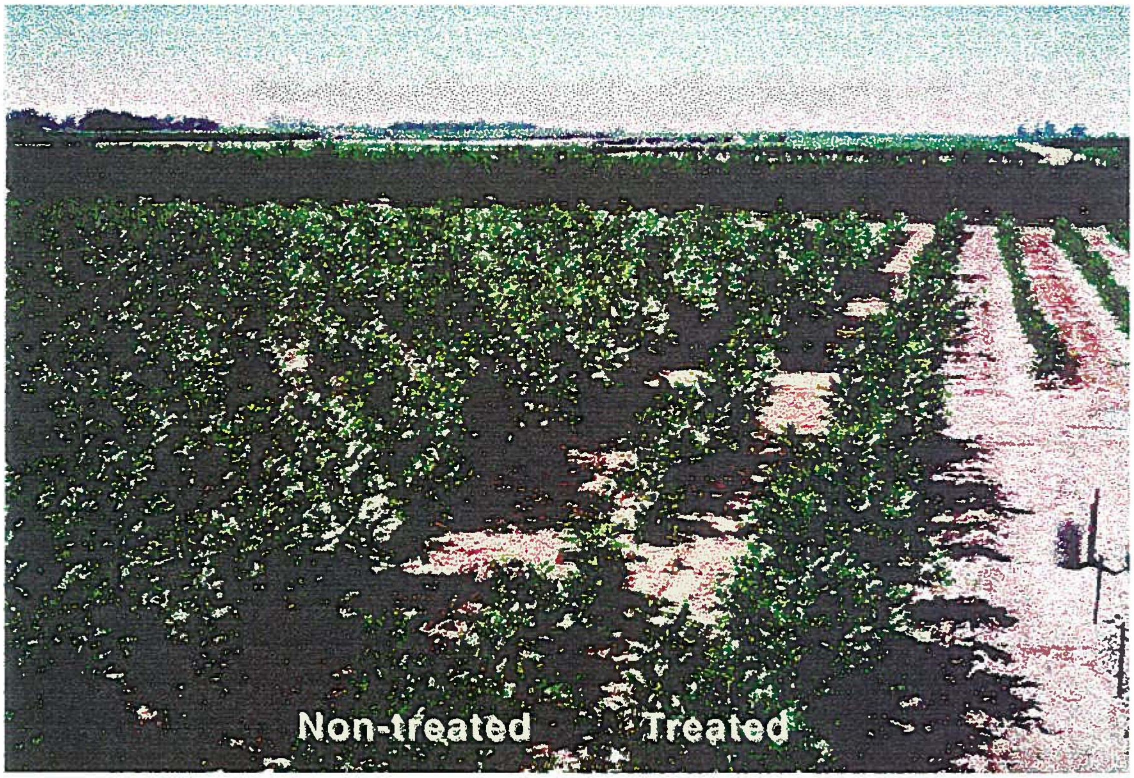
Fall Year 3

Spring Year 3



Fall Year 5

Photo Array 2



Non-treated checks (8 reps) indicated by lime check mark on outer portion of plot. Photo from 500 ft. elevation.

on specific soil microbes, few studies focus on the general problem, except in the form of general observations.

An example is a study of Northern California Black Walnut seedlings following various fumigation treatments (see Photo 2). This planting was in a walnut replant site infested with Root Lesion Nematode, *Pratylenchus vulnus*. Researchers wanted to determine which is the most important contributor to poor growth: nematodes, Oak Root Rot or RP. Adjacent to this planting in a non replant site were walnut seedlings inoculated with pieces of walnut root with and without *Pratylenchus vulnus*. These plants were compared to the nematode without roots. It was clear that the nematodes were more damaging than the presence of old roots transported into the site. However, soil from a replant site was not transported to the test site. When this is done, the presence or absence of the nematode is less distinguishable in the first year because none of the plants were growing very well.

RP is not a result of poor root condition per se, but something in the soil around those roots. Nematodes, it seems, are only one of the components. An early theory on the cause of RP was that exudates from old roots directly impacted new roots. Over the years, this theory proves correct only where growers remove then replant trees within months into soil with exudates. RP can be transferred by placement of old orchard soil (without roots) into a greenhouse pot and growing the proposed planting stock for 3 to 4 mo compared to a fumigated or non replant problem soil (NRPS) or virgin soil.

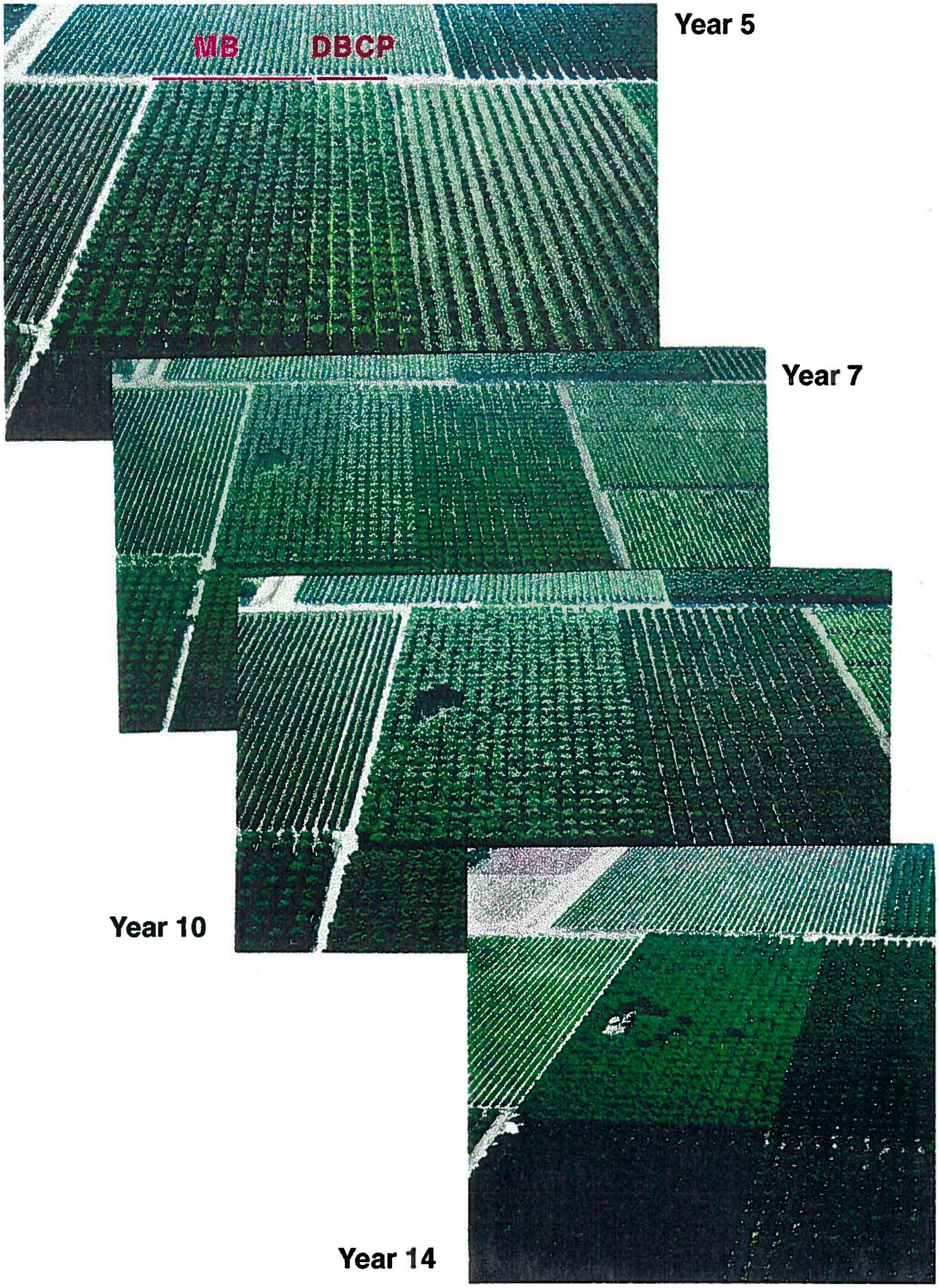
Many researchers agree that RP is caused by much more than the roots themselves (Yadava,U. L. and S. L. Doud, 1980). Over the years, scientists in many countries have pointed to nematodes, actinomycetes, fungi and certain bacteria as the greatest possible contributors of RP (refer to Section C). This author does not believe that any of these pathogens or parasites per se are the single cause of RP. These pathogens represent one important component of RP. However, RP also contains a much more general component.

The aerial photos in Photo array 3 depict a replanted plum/Nemaguard orchard which was known to be infested with Oak Root Fungus, *Armillaria mellea*. Prior to planting in 1974, the grower tarp-fumigated with MB the precise area where the fungal infection was located. Land outside the infected area was also treated pre-plant with 1,2-dibromo-3-chloropropane (DBCP) prior to its cancellation. This product was a useful nematicide but a poor pre-plant treatment because it did not penetrate and kill remnant roots of the previous crop. Over the next 14 yr, the orchard area treated with DBCP never matched the yield or vigor of the portion treated with MB, though the DBCP was likely better than no treatment at all.

The Oak Root Fungus-infested area treated with MB fared only slightly better. The MB treatment was made in late November after rains and although there was only 7 ft of soil depth above a hardpan layer, monitoring showed that the MB did not move through the entire soil profile.

The effects of not properly treating RP were especially apparent during the first 6 yr after planting (Photo Array 3). At 14 yr, poorer tree growth was also visible in the adjacent five rows that only received DBCP. Tree death due to Oak Root Fungus slowly moved across the orchard and after 14 yr, was also visible within the DBCP treated block. Many of the trees replanted within the declining area would also die within two years of replanting.

Photo Array 3



Year 5

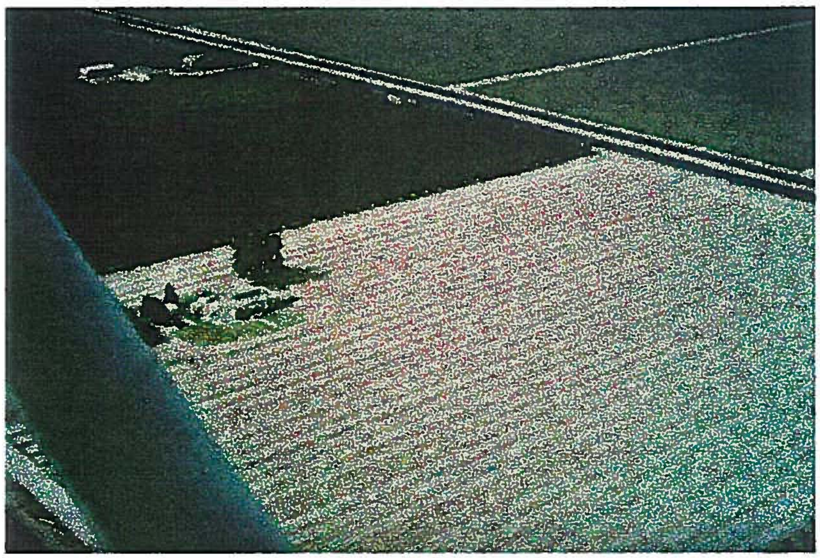
Year 7

Year 10

Year 14

Photo Array 4

30 yr. old orchard



strip fumigation MB

Replanted Year 3

In Photo Array 4, Photo 1 shows a weak, 30-yr-old peach orchard with trees missing due to Oak Root Rot to the left of the house. The farm was sold and the new owner removed the old orchard, ripped the soil 3 ft deep, strip treated with MB, and replanted peaches the next spring. Photo 3 shows the orchard in the third year of growth. Oak Root Rot has not yet reappeared but it will because a strip treatment is inadequate. The uneven growth is due to the grower's difficulty delivering water uniformly across the orchard. The field also has a range of soils, some with a hardpan layer 4 to 5 ft below the surface while other areas are underlain by deep sand.

Obviously, MB did not solve all the problems in this field. Better water management or soil ripping to shatter the hardpan layer is essential if peaches are planted in these conditions. While the first 2 yr of tree growth were excellent (photo not shown), the soil physical problems were not adequately managed with the shallow pre-plant soil ripping.

The cover photo of this text depicts RP in an adjacent nine row plum orchard with the same physical soil problems. The plum orchard was drenched with MITC, which controlled certain soil microbial components of RP but did not solve all components of RP.

Photo Array 5 depicts the growth of own-rooted Carnelian Grapes over a 7-yr period. The vineyard is infested with Phylloxera, *Daktulosphaeria vitifoliae,* another soil-borne pest that must be dealt with pre-plant, through selection of resistant rootstock and proper pre-plant fumigation. Most of the vineyard acreage was tarp fumigated with MB at 400 lb/acre while a check plot of five rows was left untreated. During the first years, aerial photos showed no apparent plant growth benefits from the MB treatment. Three yr later, the five nontreated rows showed the effects of RP, including Phylloxera. Six yr after treatment, a large area of Phylloxera damage had developed in the MB treated zone, especially where the soil was most conducive to Phylloxera development. Three yr after planting, the vines in the nontreated area were interplanted with Phylloxera resistant rootstocks and gradually grafted into the existing scions. The photo depicting growth at 7 yr shows this corrective action was ineffective.

The photos in Photo Array 6 show a Friar Plum orchard planted with a variety of rootstocks that received inoculation or no inoculation with *Pratylenchus vulnus* the first year after replanting. The soil was fumigated pre-plant with Telone at 100 gal/acre. The trees grew well the first 4 yr as the nematode populations quickly climbed to damaging levels (top photo). The bottom photo shows the result of an early November cold snap where the only trees to abscise their leaves were those infected by the nematodes. The photos depict tree growth in the weakest area of the orchard during summer and fall of the same year.

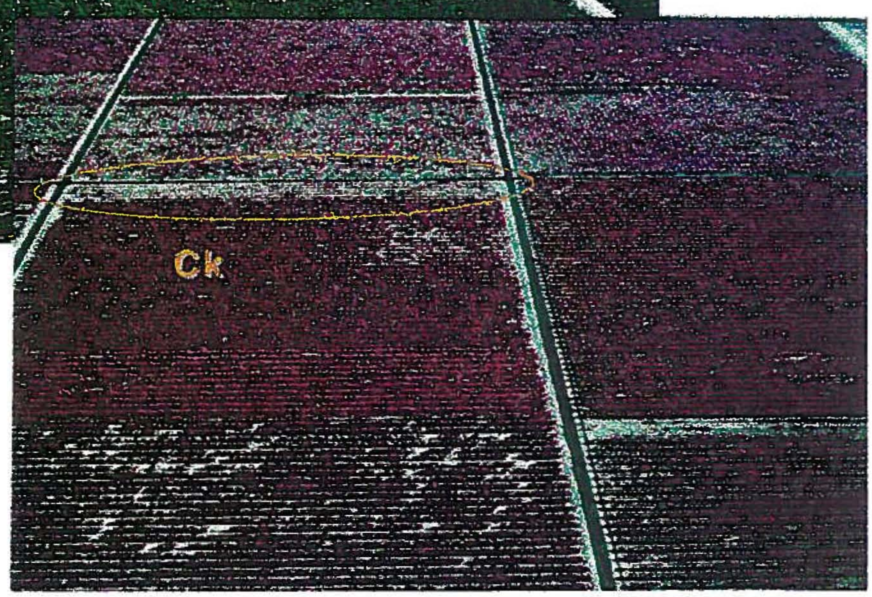
This situation was repeated again 3 yr later at another site. In this example, the RP was effectively treated but we wanted to know the role played by nematodes in the absence of RP. Nematode damage over a 15-yr period was 8% on the plum rootstocks and 16% on the peach rootstocks (McKenry, M. V., 1989). On this site, damage caused by nematodes was most apparent where a sandy subsurface also restricted root development. As with the Phylloxera example, the difficulty of trying to correct a pest problem in only a portion of a field is that we cannot predict with confidence where the problem will be greatest.

Photo Array 5

Year 1

Year 3

Year 6



Year 7
(Infrared)

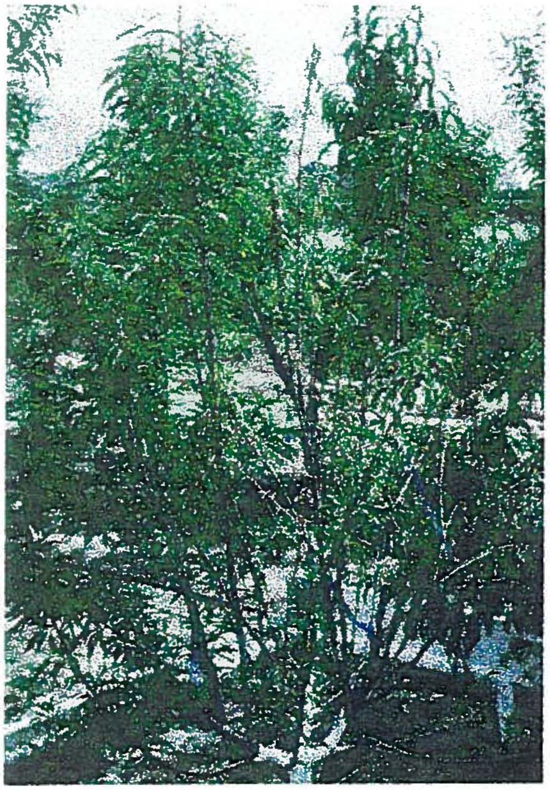
Photo Array 6

Summer
Year 4

non-inoculated inoculated

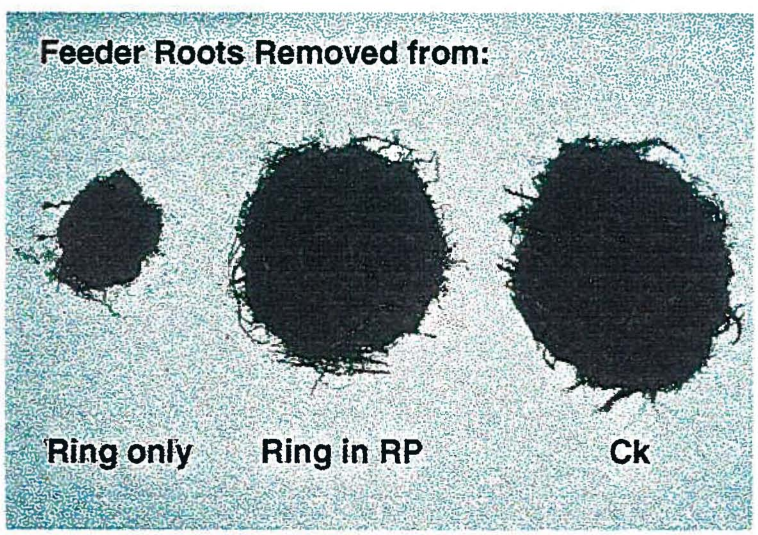
Fall
Year 4

Photo Array 7



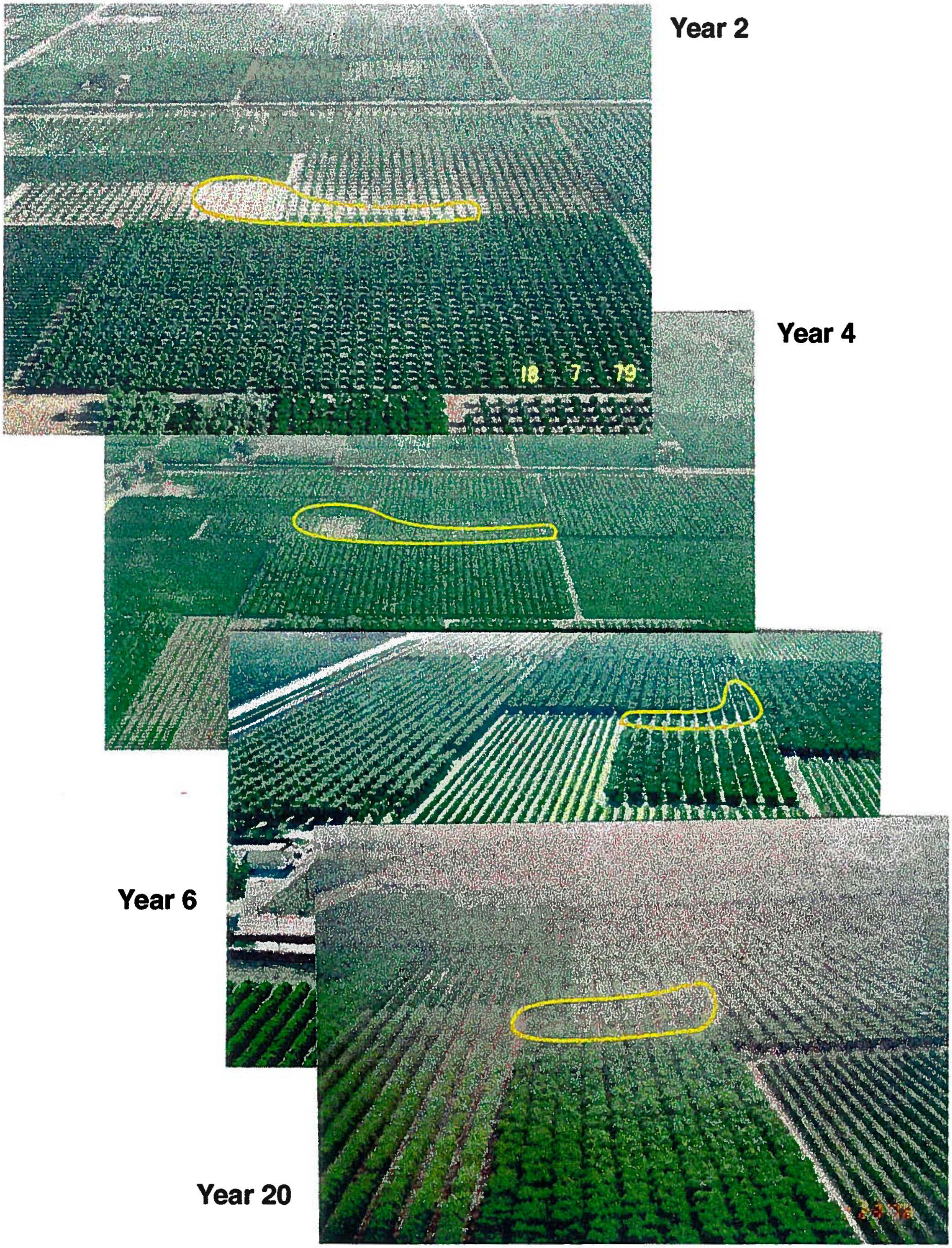
Fourth Year
Limb death

Overview Year 1



Roots from Ring Nematode Only

Photo Array 8



The orchard of Mission Almonds on Nemaguard rootstock in Photo Array 7 was planted into a relatively sterile sand soil brought in from a gravel pit. The trees were inoculated with *Criconemella xenoplax*, Ring Nematode only, the same number of Ring Nematode but present in 2 lb of peach replant soil or non-inoculated. As previously shown in Photo Array 2, only 2 lb of RP soil, without roots, is adequate to transfer RP to a new tree. In this case, the trees inoculated with RP soil grew the poorest and were most chlorotic in the first year but then grew well the remaining 3 yr. Interestingly, the Ring Nematode populations also developed slowly in the presence of the RP soil, indicating that the RP soil must also contain active biocontrol agents specifically effective against Ring Nematode. By the end of the fourth year of growth, there was Bacterial Canker Infection present in five out of six trees that received Ring Nematode only, one out of six that received RP soil and none detected where the nematodes were absent (McKenry, M.V., 1996). Here again, the nematode damage could be separated from some other component within RP soil that was only responsible for poor growth during the first year. Two of the photos indicate the paucity of fine feeder roots on those trees infested with Ring Nematode.

The photos in Photo Array 8 depict growth of a new orchard on Nemaguard rootstock following one full year of fallow after removal of own-rooted Thompson Seedless vineyard. The poor growth area appears to be associated with a sand streak but it is not that simple. Rather, the old vineyard land, which was not fumigated, continued to exhibit live grape roots for 8 yr after vine removal. These remnant roots continued to support Root Knot Nematodes, *Meloidogyne* spp. The resistance mechanism in Nemaguard permits juveniles of Root Knot Nematode to enter, feed and develop within the roots but halts their reproduction (Malo, 1967). In this example, a portion of the RP is attributable to feeding by Root Knot Nematodes despite the excellent resistance (no reproduction) present in Nemaguard.

Photo 9

Photo Array 10

Vermeer Spade in use

Year 1

Year 3

Photo 9 depicts the third year growth of Flame Seedless Grape planted after removal of a 70 yr-old Thompson Seedless vineyard. Before planting, a 3-ft wide trench was furrowed down each vine row. Vapam was water-run down the rows then the new vines planted. Before the end of the first year, the grower was experiencing growth problems in the sandiest areas of the drip irrigated vineyard. The photo depicts vine growth in replicated, single-row, 30-vine strips that had been treated for 1½ yr with post-plant nematicides via existing drip irrigation lines. In this example vine growth was initially good as a portion of RP was solved but the Root Knot Nematode surviving in the nontreated zone quickly surfaced as a growth limiting factor on this highly susceptible host.

Photo Array 10 depicts the relative tree size of Mission Almond on Nemaguard rootstock planted in NRPS (soil not farmed for more than 15 yr) compared to trees planted on a site where ½ yd of RP soil was transferred prior to planting. The RP soil was removed from a 15-yr almond orchard with the equipment shown in the top photo. In this example, the RP condition is not attributable to known pests or diseases yet there is gumming on the trunk, limited root development in the first year with noticeable stunting and chlorosis lasting more than 3 yr (McKenry, M. V. et. al., 1998). Although the new tree roots had migrated into the native NRPS within 5 mo after planting, much of the damage had already been done and the surrounding NRPS provided little growth benefit. The only soil pest known to be present in the replant soil was a population of *Paratylenchus hamatus*, Pin Nematodes, at 800/250cm3 soil sample. This is a nematode we do not consider to be pathogenic, but its feeding might provide a method to release greater volumes of root exudate into the rhizosphere.

Currently, the knowledge base for RP is based on data collected from trials involving soil fumigation and use of various rootstocks. For example, properly fumigated soils, in contrast to non-fumigated soils, do not have live remnant roots in the top 5 to 6 ft of soil. This simple observation raises several questions about some current thinking. First, the notion that nematodes are a major player in RP comes from success of using 1,3-D nematicides as a method of attaining effective control. However, 1,3-D doesn't just kill nematodes in soil and nematodes in remnant roots. It also kills the remnant roots and any microbes they sustain. Similarly, MB is a broad spectrum biocide that does not kill some microbes but does kill almost all the remnant roots. Just because it controls a wide variety of known pathogenic fungi does not mean that those fungi are the source of RP. In 1992, we began studies evaluating alternative methods of killing tree and vine roots prior to their removal (McDonald, D.,1992).

As researchers unravel the microbiological mysteries of RP, its multi component nature must not be ignored. Not only is there a range of intensities to RP but also a short-lived component and long-lived component. There is a tremendous history of observations associated with RP. The following two examples will aid the characterization of RP.

The first is from Livermore Valley where *Xiphinema index* and Grape Fan Leaf Virus (GFLV) are prevalent. In the mid-1960s, it was observed that vines replanted after applying 80 gal/acre D-D soil fumigant grew better than those planted where 40 gal/acre was applied. Similarly, 160 gal/acre produced even faster growing vines, but 250 gal/acre was even better. The additional cost of treatment could be reclaimed by faster development of an established vine. However, none of these treatments gave complete control of the last remaining *X. index* nematodes. Populations began rebounding within 2, 3, or 4 yr after replanting and the subsequent vineyard decline was sure and steady. By the time these vineyards reached 10 yr of age, the treatment rates were not distinguishable by vine vigor or yield, only by trunk size.

The message from this example is that the consequences of poor rootstock choices and the occurrence of a biological vacuum after fumigation cannot be ignored. An IPM-type approach is essential with soil treatments just as it is for control of above-ground pests. Soil pest and disease conditions need to be characterized for each new planting site if growers are to succeed in the long term.

A historical example supports this point even though it is based on observations from a single set of sites. Before replanting on what is now Kearney Agricultural Center began in the 1960s, soil samples were systematically collected by D. J. Raski of U C Davis. Nematodes of varying kinds and population levels were shown to be prevalent. Apparently, this confirmed local concerns that the university had bought a "nematode haven." Beginning in the early 1960s, every newly planted block at the Center was treated with 40 to 80 gal/acre of D-D or Telone. Usually this treatment occurred 2 to 3 yr after removal of the previous planting. Additionally, most of these blocks were either planted to Thompson Seedless Grape or Nemaguard Peach, both of which offer some degree of nematode protection.

In the mid-1970s, this author observed the lack of endoparasitic nematodes at the Center. Field assessments by biocontrol experts from U.C. Riverside indicated a wide variety of potentially important microbes, but no clues as to which "one" was most important. It wasn't until the early 1990s that this author catalogued nematode problems at the Center. From about 200 acres of land, there was an abundance of ectoparasitic nematodes but not more than two naturally occurring problem sites involving endoparasitic nematodes. The two naturally occurring nematode infestations both involved a very good host, while one also involved the presence of a sand streak.

Meanwhile, the author has no problem starting a nematode problem anywhere desired, whether RP soil, fumigated soil (FS) or non replant problem soil (NRPS). Additionally, on properties surrounding the Center, nematode problems are present on a variety of crops, but each is on non-fumigated sites. While conducting a nematode examination involving more than 50 soil samples adjacent to a nematode rearing facility, we noted that one to 10 Citrus Nematodes or Root Knot Nematodes could be found in four of the 50 soil samples. Why had these nematodes never developed to damaging levels in this 25-yr-old vineyard? The hypothesis of this author is that starting new plantings in partially sterilized soil plus unintentional filling of the biological vacuum before endoparasitic nematodes were actually reintroduced may be responsible for the low population levels.

Whatever is occurring, it is in spite of soil fumigation and the problems alluded to in the Livermore Valley example. More tests need to be conducted where soil is treated and then not replanted to a perennial for a full year. Then compare this approach to the current practice of treating in the fall just before a spring replanting. This approach may be necessary if Vapam becomes the replacement for MB.

The observations reported in this section are based on single replicate experiences over a number of years. While such observations may only have site specific value, I have included them so other researchers won't waste time stumbling around field problems (like this author) before coming up with reproducible data sets.

B-2. Symptoms of the Replant Problem

The symptoms of RP are clearly manifested across a field by mid July of the first year, sometimes even sooner. Growth is uneven with tall plants adjacent to poor plants. Foliage is chlorotic and sometimes a few plants have already died by mid-summer. In some situations, poor growth can be associated with soil texture changes across a field.

Where there is RP, everything that can go wrong seems to go wrong, and usually without a single identifiable reason. Even though the trees are smaller, it is those with RP that blow over during a fall windstorm. By October, the presence of Western Flat-Headed Borer is usually apparent among *Prunus* replants. Also by this time, the presence of Phytophthora Root Rot might be evident, usually due to drowning out of poorer growing trees as the healthy trees require greater moisture. When the advice of experts is sought, the nematologist can usually find some damaging nematodes present while the horticulturalist detects nutritional deficiencies.

In the second year, plantings of *Prunus* spp. may begin to flourish, depending on the intensity of soil pest problems. If not, the poor area appears to follow a soil-related pattern as the damage lessens in other areas across the field.

Where new vineyards replace older vineyards, the poor growth persists for a longer period since live roots are typically abundant and grapes are host to a wide variety of nematodes.

In orchards where spot or strip fumigation in used to control high nematode populations, the trees may grow remarkably well for the first 2 yr but by the beginning of the third year, growth stops altogether. This can occur where the plant is a very good pest host, such as: *P. vulnus* in the presence of walnuts; Lovell Peach in the presence of *Meloidogyne* spp.; or Cabernet Sauvignon Grape in the presence of *Meloidogyne* spp. in a warm climate. For *Prunus* spp., early fall tip strikes by Peach Twig Borer can stop tree growth whereas adjacent fumigated trees seem to not be bothered by their presence.

RP can easily be transported to fumigated or virgin soils with as little as 1-2 lb of soil from an old orchard adjacent to the new planting. There is no need to transfer roots along with the soil.

C. Historical Perspectives

"Don't plant pip after pip or stone after stone or by refilling the planting hole with fresh soil."

This maxim provides a grower perspective of RP in the apple and cherry growing regions of England. The East Malling scientists who cited this maxim then demonstrated repeatedly that related and unrelated crops could indeed be replanted in a RP field if the soil was treated pre-plant with chloropicrin. They further demonstrated that planting pip after pip was possible in certain locations even without fumigation (Way and Pitcher, 1971).

These authors listed four important properties of RP: 1/ Specificity – difficulty in replanting to a crop of similar species. 2/ Persistence – Five or even 10 yr between removing the first crop to replanting the second may not be enough time. 3/ Symptoms – While there is no reliable diagnostic symptom, the root system is usually reduced and discolored with stunted shoots. 4/ Recovery – Affected plants transplanted to fresh soil soon resume normal growth i.e. the causal factor(s) are not systemic. The authors also noted that

Malling IX rootstock of apple was more sensitive to RP and more responsive to chloropicrin treatments than other rootstocks.

In the decade prior to the above study, RP had already been divided into two types: specific RP and general RP. Specific RP referred to situations where a known soil pest or pathogen was implicated. General RP referred to situations where the etiology was less clear (Savory,1967; Hoestra, 1965). In the mind of this author, these definitions are inadequately flexible and can be a limitation to researchers.

In California, early studies of RP were primarily carried out by A. E. Gilmore in the Department of Pomology at U.C. Davis. His studies focused on substances secreted by peach roots which could sicken and kill another peach root. In a June 1949 issue of *The Grower*, Gilmore summarized field survey results conducted by numerous California farm advisors in counties where peaches might be grown (Gilmore, A. E., 1949). In Merced, Yuba and Contra Costa counties, no RP had been observed. In Solano County, the only problem area was around Winters where RP was severe. RP was also noted in San Diego, San Bernardino, Riverside and Stanislaus counties but not severely and probably not more than 5% to 10% of the time. In Fresno, Tulare, El Dorado, Kings, Sutter and Sacramento counties, the problem was acute. In Fresno County, the problem was most severe on sandy soil. In Tulare County, it could occur on any soil type and in one location, occurred after 10 yr of alfalfa and grain crops. In Kings County, the problem was most severe on fine textured soils.

Gilmore eventually concluded that more was going on with RP than simply influences from root substances. He further noted that soil microbiology is in a constant state of change and exclusive of the organisms that directly attack plants, may have marked and in some cases little understood influence on the plants growing in a soil.

Apple researchers in Northeastern United States showed that RP could be solved by pre-plant soil fumigation (Mai and Abawi, 1981). In this region, there appeared to be a common connection between RP and the Root Lesion Nematode, *Pratylenchus penetrans*. However, they were not ruling out a role played by soil fungi (Jaffee, Abawi and Mai, 1982 a and b).

Apple researchers in Washington State indicated that RP was a result of soil accumulation of lead arsenite applied as a fungicide (Benson, Covey, Haglund, 1978). A decade later, Washington researchers suggested pre-plant fumigation as a solution to RP (Smith, T. J., 1994). In recent years, several fungi have been implicated with RP while pathogenic nematodes are usually absent (Mazzola, 1998).

German grape researchers reported that Teleki 5C rootstock is more sensitive to RP than own-rooted stocks (Waschkies, et. al., 1993). Following up to inarching experiments at California State University, Fresno, an Italian viticulturalist indicated that placement of young resistant rootstocks on either side of a diseased plant for eventual grafting was a useful procedure for correcting certain pest problems (Fregoni, 1993). However, if a replant problem exists, activities like inarching would not be useful. The inarching experiments at Fresno were conducted in the five check rows depicted in Photo Array 5.

A number of factors have been implicated as a possible source of RP in various crops:

- *Thielaviopsis basicola* on cherry (Hoestra, H, 1965)
- Rhizosphere microorganisms on apple (Catska et. al., 1982)
- Deficiency of Vesicular-Arbuscular Mycorrhizae on grape (Deal, D. R., 1972)

- *Pratylenchus penetrans* on apple (Jaffee, B. A. et. al., 1982)
- Various fungi on apple (Jaffee, B. A. et. al., 1982)
- Toxic substances from microbial decomposition products of peach roots (Patrick, Z. A. 1955)
- Pythium species on apple (Sewell, G. W. F., 1981)
- Root-derived inhibitors on grape (Brinker, A. M., 1988)
- *Pratylenchus vulnus* on peach (Ricciardi, P. et. al. 1975)
- Rhizosphere organisms on apple (Catska, V., 1982)
- Nematodes (Zehr, E. I., 1981)
- Waterlogging of peach (Mizutani, F.,1980)
- Citrus Nematode on citrus (Burger, W. P. and Bruwer, W. J., 1979)
- Fusarium spp. on asparagus (Schofield, P. E. et. al., 1996)
- Microbial antagonism on fruit trees (Catska, V., 1993)
- Actinomycetes on apple and rose (Otto, G., et. al.,1994)
- Actinomycetes (Locci, R., 1994)

Methods proposed to control RP are as diverse as the list of potential causal agents:

- Monoammonium phosphate fertilization of apple (Nielsen, G. H. and Yorston, J. 1991
- Correction of potassium deficiency on apple (Merwin, I. A. and Stiles, W. C., 1989)
- Planting-hole amendments including combinations with fungicides and peat on apple (Nielsen, G. H., et. al., 1994)
- Formaldehyde applications on fruit tree sites (Daemen, E. 1994)
- Mancozeb on sugarcane and apple sites (Magarey, R. C., Bull, J. I., 1994)
- Planting of antagonistic plants on apple ground (Edwards, L. et. al. 1994)
- Cover crops on grapes (Halbrendt, J. M., 1995)
- Biological control agents (Catska, V. and Taube-Baab, H., 1994)
- Soil fumigation (many authors since the 1950s)

The listings above by no means represent an exhaustive literature search but are indicative of recent research activities and individuals who might be contacted for additional information. For older literature, refer to a review of the subject written in 1980 by Yadava, U. L., and Doud, S. L. An encouraging development is the occurrence of international meetings focused on RP. These conferences provide the forum needed to sharpen the focus on solving RP around the world.

D. A Working Hypothesis for RP – Four Components Described

RP has at least four distinct but interlocking components: the rejection component; the soil physical and chemical components; the soil pathogens and pests component; and the initial nutritional needs component. Each component need not be in every RP site so the appearance of RP need not be the same in every location. Additionally, while effects of the rejection component and the nutritional component are apparent the first year, the other two components may occur at any time, but usually later. There are also many different kinds of soil pests, soil physical conditions and nutritional deficiencies that can occur.

Most confounding are the factors that can accentuate or diminish the intensity of RP. For example:

- Marianna 2624 Plum, whether planted after peach or plum, is not as sensitive to RP as Nemaguard Peach.
- Own-rooted grapes frequently do not experience RP as much as some of the Phylloxera tolerant rootstocks such as Teleki 5C.
- RP doesn't appear to affect replanted peaches in the Yuba City area, but is a problem with peaches almost everywhere else. However, RP is associated with replanting walnuts near the Yuba City area.
- Northern California growers report that almonds follow well behind walnuts, but as with the Yuba City peach growers, the typical rootstock is Lovell rather than Nemaguard.
- Some Central California growers report that their own-rooted grapes follow peach rather well except in sandy streaks. Growers on the best soils do not experience as striking of RP as those on more marginal soils. However, there are also situations where growers recall that the intensity of RP is greatest where the best growing trees were before.
- An observation made years ago by Norm Ross from the Modesto area was that for Nemaguard rootstock, each full year of fallow alleviated half of the remaining RP. After 4 yr of fallow, RP incidence was so slight, it was not measurable.
- Walnut growers near Modesto believe that 4 yr is not a long enough fallow period. Conversely, some walnut growers farming the best silt soils near Visalia, CA, do not fumigate and may not wait even a full year before replanting.
- At the Kearney Agricultural Station in Parlier, RP is not as damaging following Paradox Hybrid rootstock compared to following Northern California Black Walnut. Additionally, RP can be more damaging and longer lasting in one location than it is in adjacent areas, even when the entire field received a proper soil fumigation.

The question remains: What is the source of this more serious RP compared to the common RP that is solved with soil fumigation?

These accounts illustrate how the intensity of RP can change under different situations. Also note that a long-term RP effect can be noticeable decades after planting. Conversely, a short-term RP effect can disappear in 6 mo to 1 yr.

RP is a very serious problem, it is common, and the higher costs of soil fumigation plus the future loss of those products has prompted the writing of this manual. My working hypothesis is just a start, but it serves as a point to begin finding solutions to RP.

The rejection component of RP is likened to the human rejection of transplanted organs. With humans, the rejection may not be caused by a single specific causal agent that is a known pathogen but instead, an ecosystem of diverse microbes or metabolites of microbes that are inhospitable to new introductions into their territory. In human medicine, antibiotics assist to suppress groups of microbes until the patient's system adjusts to the new organ. For tree and vine crops, the highest success seems to be from manipulating the soil profile followed by general biocide treatments that affect the top 5 ft of soil. When treating known soil pathogens, we have also partially eliminated non-pathogenic microbes, providing a "default" control of the rejection component. More importantly, these biocides also kill the live remnant roots of the previous crop. Once the energy source for the live root soil ecosystem is destroyed, there is a major shift in the ecosystem to those microbes that survive on decaying roots. When soil is fumigated, the rejection component of RP is destroyed along with a multitude of diverse microorganisms. This makes it difficult to pinpoint the actual source of a subsequent plant growth benefit.

My proof for the rejection component is described this way: when a plant and its roots are killed with systemic herbicides (and the plant removed) without killing normal soil pathogens, tree and vine crops planted in that same spot grew as well in their first year as if the soil had been fumigated. It follows that the varying intensity of RP across a newly planted, non-fumigated field is a result of the varying ecosystems that also occur across the field.

In one peach orchard devoid of known soil pathogens, the non-fumigated, non-ripped planting site grew poorly for about 6 mo, after which the growth rate paralleled that of the trees planted in soil that was ripped and fumigated. In other words, some sites exclusively exhibit the rejection component of RP. Although systemic herbicides were used to kill the root system in our peach orchard test, the same task could be accomplished in a similar non soil pathogen site by using a backhoe to dig each new tree site. Then, let the soil pile sit in the open sunshine for several months with occasional stirring in order to kill the old roots.

The rejection component could be a result of specific microbes surviving on the old roots. But it also could be a result of activities and defense mechanisms of the entire ecosystem with its intensity amplified by high populations of microbes capable of promoting or leaking a greater volume of normal root exudate into soil. In the realm of nematodes, Pin Nematode and Ring Nematode are candidates for study, but so is any microbe capable of causing a leaky root.

A second component of RP involves presence of soil physical or chemical barriers to root development. Chemical barriers include accumulation of salts, herbicide residues, or other chemicals. Physical barriers include hardpans, plow pans, or soil lenses. The role these factors play in RP may be twofold. First, these problems will serve to intensify the rejection component and perhaps lengthen its duration. Second, these soil problems will persist to some degree for the life of a new orchard or vineyard. Both physical and chemical soil problems are best resolved through pre-plant manipulations of the soil profile.

A third component of RP is the presence of known soil pathogens and pests. Deal with these components before planting by first identifying that they exist or could soon build up in the field. Post-plant treatments are capable of controlling some soil pest problems but they are best alleviated prior to replanting. Proper soil fumigation can give 6 yr of relief from nematodes or Phylloxera. The use of a resistant rootstock can also give long-term protection. Unfortunately, most rootstocks are resistant to only one or two soil pests but not the multitude of pests that can occur. Additionally, the resistance mechanisms may last only a decade or two before new pest biotypes develop. However, a rootstock possessing resistance to Root Knot Nematodes or Phylloxera may in fact also be quite susceptible to the rejection component of RP.

The downside to broad spectrum biocides is they also kill beneficial soil microbes, which can be important for long-term pest suppression. A good example is the loss of soil pest suppression provided by ectoparasitic nematodes including Pin Nematode (McKenry, M. V., et. al., 1995), *Xiphinema index* and Ring Nematode.

A fourth component to solving RP relates to the initial nutrient needs of young trees and vines. It's difficult to separate the RP effects caused by nutrient deficiencies from those resulting from a changed soil ecosystem, which may or may not be compatible with good plant growth. Our work indicates that newly planted bare root plants benefit from receiving trace amounts of a broad range of macro and micronutrients. Soil fumigation generally provides a "growth response" to subsequently planted crops, whether they are perennials or annuals. The source of this increased growth response can emanate from the presence of more suitable nitrogen forms (Millhouse, D. and D. E. Munnecke, 1979a) as shown for MB treatments. However, following MITC treatments, the increased growth response may result from the cascade of microbial populations that reinhabit soil after fumigation, some of which are more compatible with plant growth.

E. Relative Incidence of the Four Components of RP in California

E-1. Crop-Related Incidence of Specific Soil Pests and Diseases

At this writing, as much as 85% of the California walnut acreage is infested with one or more of three nematode genera, *Pratylenchus vulnus*, *Criconemella xenoplax*, or *Meloidogyne* spp. Currently, no rootstock has uniform resistance to the pests and there are no post plant nematicides currently available (Westerdahl, B. B. and M. V. McKenry, 1998). Pre-plant protection is the only nematode control method available in walnut.

About 60% of California vineyard lands are infested with one or more plant pathogenic nematode species. Rootstocks can provide resistance to one or two nematode species but none are commercially available with broad nematode resistance (McKenry, et. al. 1995).

Approximately 35% of the almond acreage is infested with either *Criconemella xenoplax* and/or *Pratylenchus vulnus*. The main rootstock used by almond growers has resistance to *Meloidogyne* species only (McKenry, M. V. and J. Kretsch, 1987).

At least 60% of the cling peach acreage is infested with *Criconemella xenoplax*. Another 35% of the fresh peach, plum and nectarine plantings are infested with *P. vulnus* with a lesser amount infested with *C. xenoplax* (McKenry, M. V. 1989).

There are vineyards infested with Phylloxera, orchards and vineyards infested with Armillaria Root Rot. Kiwifruit plantings are at least 75% infected by various species of *Meloidogyne* and no rootstocks are currently resistant to the pest.

Citrus plantings are 75% infested with Citrus Nematode while Phytophthora can be just as common. The use of resistant rootstocks limits the field incidence of Citrus Nematode damage and good water management practices limit the incidence of root rots. These infestations are generally insidious. Poor irrigation practices or inclement weather are not the sole cause of these maladies but their damage level is influenced by such factors.

Soil pest problems can be aggravated by soil physical characteristics such as salts, chemical residues or irrigation problems, all of which limit root development. Correcting the soil pest and physical problems prior to planting can ensure development of a good far-reaching root system. A proper pre-plant fumigation can provide 99.99% control of pests throughout the top 5 ft of soil. Equally importantly, fumigation kills remnant roots of woody perennials down to 5 or 6 ft in depth. By contrast, a good post-plant nematicide treatment via drip irrigation can only provide 50 to 75% control of pests for 6 to 9 mo within the treated zone but does not kill roots.

E-2. Spatial and Regional Incidence of Soil Pests and Diseases

Soil borne organisms such as *Armillaria mellea* can survive for decades on dead roots. The pathotypes of this pathogen include a wide range of agressive to less-agressive populations. Dead roots of many plants can be found at a depth of 20 ft. Remnant roots of riparian perennial plants are common along old stream beds where they once flourished but they may also occur elsewhere. Oak tree roots can be found 40 ft deep. It's common for walnut roots to grow down 10 ft and spread laterally for 40 ft, even growing under and beyond country roads.

Soil organisms such as nematodes survive by relying on resting stages, cysts or egg stages within their life cycle. These life stages serve the nematode well in the presence of annual crops or weeds. In addition to thriving where live roots are present year around, they can subsist for years even after the aboveground portions of a plant have been removed or killed.

Roots of Nemaguard Peach can remain alive up to 2 yr after the trunk has been removed. Live plum roots can survive even longer. Roots of Northern California Black Walnut appear alive 3 to 4 yr after tree removal. Grape roots have been reported to remain alive up to 8 yr after trunk removal and soil ripping. These grape studies were conducted in connection with studies of the longevity of the soil borne virus, Grape Fan Leaf Virus and its vector *Xiphinema index*. This author working in peach orchards was able to find the Citrus Nematode *Tylenchulus semipenetrans* supported by live grape roots as long as 10 yr after the vines had been removed. In citrus orchards, this author has found the starchy roots of Scalebroom, *Lepidospartum squamatum*, a native plant of the *Compositaceae*, surviving up to 20 yr of disking, rouging, and repeated treatments with contact and pre-emergence herbicides. This survival is due to the plant's lengthy, deep, and robust root system.

Killing or neutralizing remnant roots of a previous crop prevents obligate parasites such as pathogenic nematodes from using them as a support system. It also disrupts the established ecosystem of non-pathogenic microbes that they directly and indirectly support.

<u>E-3. More on the Rejection Component of RP</u>

The textbook of Baker and Cook (1982) points out that there are soils both conducive and suppressive to pathogen development. This author recently demonstrated that fumigated soils may be conducive to rapid development of soil pests, especially when the pest is introduced to the soil within 6 mo of the fumigation. Those who have observed this phenomenon have referred to it as a biological vacuum (McKenry et. al., 1995). A fumigated soil, however, should not be thought of as biologically inactive (Wensley, R. N., 1953; Millhouse, D. and D. E. Munnecke, 1982). Rather, it is a soil that is missing enough components of the previous ecosystem to render it conducive to pest development for a period of months to a year. During this same time period, the soil is conducive to the addition of beneficial organisms and to the fast development of plants. Observers have referred to this plant growth phenomena as the increased growth response (IGR) associated with fumigation.

When a soil is suppressive to specific soil pathogens, it is not a direct result of one or two specific microbes but the entire supportive compliment of microbes that make up that soil ecosystem. It appears that at least right after fumigation, the ecosystem most conducive to development of soil pathogens is also conducive to the best plant growth.

Another way of describing this phenomena is that there are soil ecosystems compatible to organism development, others that are incompatible, with a wide range of situations in between. The two soil conditions most compatible to growth of replanted tree and vine root systems involve NRPS (virgin soils) and well fumigated soils.

We can also identify a number of soil situations incompatible to root system development:

(1) The "rejection component" of RP is our best example of a soil ecosystem that is incompatible to root system development. But, the root system does adjust to the ecosystem after 6 mo to a year and resumes development at a rapid rate. It is this apparent adjustment to the incompatibility that is fascinating and raises several questions. Is this adjustment made along the entire length of the root system? Is it a result of a physiologically changed root system? Are root exudates encouraging a more compatible ecosystem for the new rootlets to grow into? Is the rejection component less significant when nursery soil travels along with the planted root system? Where else have we seen these incompatibilities that result in 6 mo to a year of growth lag? We need to find answers to these and many more questions. Dr. Robert M. Aikens has indicated that growth of corn is slowed if new root tips are not produced in sufficient abundance to send hormonal signals to the plant top. What governs production of root tips?

(2) Planting a new tree into ½ yd of RPS surrounded by NRPS produces a tree that after 3 yr, still has not adjusted to the rejection component of RP (McKenry, M. V., et. al., 1998). In this example, the roots migrate into the NRPS 4 to 6 mo after tree planting.

(3) Root systems expanding out of ½ yd NRPS into RPS adjust to the incompatibility faster than root systems expanding out of NRPS and into soil surrounded by 250 ppm MITC (unpublished).

(4) Soil treated at 500 ppm MITC is less compatible to new root system development than soil treated with 250 ppm MITC (McKenry, M. V., et. al., 1995).

(5) It is common for trees or vines planted into MB treated sites to grow well the first year. However, for the first 6 mo, they do not keep up with trees growing in NRPS.

The above situations are examples of where reduced growth for 6 to 12 mo may actually be the result of a root system enlarging into a foreign ecosystem. We have recently been looking into the impact of organic amendments on the rejection component of RP. It is possible that the addition of organic substrates to a setting that is incompatible to root development may prolong the incompatibility. Studies need to identify whether inoculations or amendments of specific organic ingredients increase or reduce these incompatibilities.

A personal note: I'm becoming amused at my efforts to study new biocontrol agents applied to established orchards and vineyards when in reality, these introduced microbes also have to defend themselves against the incompatibilities of an established ecosystem.

In summary, there are replantings that after 2 to 10 yr appear as though they will never become economically viable, at least in certain portions of the field. This damage is caused by soil pathogens or physical problems coupled with plants that never started out right in the first place. There are also situations where second year replantings grow well after 1 yr of mediocre to poor growth (peaches) or by the third or fourth year (grapes) without a known soil pathogen in the field. Meanwhile, none of these RP affected plantings grow as well as if they had a good first year of growth. In the spots with poor growth, they can still be noticeable 20 yr after replanting.

F. Current Management Methods of RP

F-1. Absence of an IPM Approach with Predictability

IPM is a knowledge-based approach. The cornerstones of this system include:

- Ability to sample for the pest(s)
- Ability to quantify pest/disease presence
- Ability to identify a biofix by which to gauge treatment worth and timing
- Knowledge of compatible and antagonistic ecosystems
- Knowledge of damage thresholds, etc.

There are very few examples of where soil pests in perennial crops are successfully managed with IPM, primarily because the above points are difficult to attain with soil as the media. For soil-borne problems, the focus has been on "pest avoidance" through quarantines, assurances of clean nursery stock, pre-plant soil fumigation, resistant rootstocks, and more recently, suppressive soils. In general, the approach has been prevention rather than therapy.

From 1979 to 1984, this author was involved in a search for an alternative to DBCP. That solution involved the use of drippers, knowledge of the root flush characteristics of grapevines, and knowledge of the sub-lethal capabilities of organophosphates and carbamates when applied at very low soil treatment rates. Although the final control method still involved chemicals, we learned how to use the products at 1/3 to 1/10 their previous rates through better timing, placement and avoiding situations where they would not perform. This IPM approach is still in use today as a post-plant therapy for nematodes in vineyards. However, it only works well in drip irrigated vineyards.

In replant situations, we need to reduce or neutralize a multiplicity of microbial populations. Many of these organisms do not have names, since they reside in foreign habitats as deep as 5 ft in soil. IPM has minimal value against RP today because of our lack of knowledge about soil inhabitants and because of our inability to deliver or encourage the active agent (preferably those environmentally benign) to the targeted site. Additionally, the microbial make-up of one field is not necessarily similar to that of another field.

F-2. Fallow Periods

California growers typically invest $5,000 to $50,000/acre of capital borrowed at 10% per annum. Such an investment is justifiable only because the land has the potential to return $2,300/acre annually from previous perennial crops. Once planted, it takes 3 to 7 yr before any crops are harvested. Then along comes a university professor or environmentalist suggesting he leave the ground unplanted for 4 yr or plant a $500/acre/yr gross return crop (such as grain). Of course, few fruit growers have the equipment or market savvy to handle grain. For grape growers, the field could lie fallow for 1 yr then along comes a rootstock salesman indicating he doesn't need fumigation if he just buys this fancy rootstock at $1500/acre. Or, use a certain post-plant nematicide (at $150/acre) that must be applied the entire life of the vineyard. Peach growers can plant more trees per acre and put them on low-volume irrigation. Some peach growers will accept 1 yr of fallow, then replant without fumigation and remove poor growing trees the second year, then replant that portion the following spring. For walnut growers, disaster awaits unless they allow a lengthy fallow (depending on the quality of the soil).

Simply put, the overriding limitation of leaving land fallow is its excessive cost.

F-3. Soil Profile Modification and Fumigation

The decision to rip, slip plow, backhoe or even trench soil to 3, 5, or 7 ft in depth is usually based on previous problems with water infiltration or deep root penetration. In replant settings, this procedure followed by laser leveling presumably pays for itself. However, there are almost no quantitative data to support the practice. It can also break up and dislodge remnant roots but most remain alive after the process.

Fumigation injection chisels are easier to pull through soil that is deep ripped, but MB can move through soil whether it is deep ripped or not. Some soil drying can result from deep ripping, which is an advantage especially when 1,3-D is applied. However, the current 1,3-D label requires high soil moisture 12 inches above the chisel outlets. It's difficult to limit the addition of moisture to the field surface if that field has been deep ripped unless sprinklers are used, which most growers aren't set up to handle. Sprinklers can be rented but water must be applied uniformily with no leaky fittings. It is also important that surface clods left after ripping be broken up or buried beneath the surface or the clods will not receive the fumigant.

A fumigant is typically applied by pulling steel shanks through the soil with a metal tube attached just behind each shank for delivery of the product. Currently, 1,3-D can be applied at no more than 35 gal/acre Telone (335 lb ai) in California. Twenty-five yr ago, these products were being applied at rates from 400 to 2500 lb of C3 chlorinated hydrocarbons/acre with the average rate being closer to 500 lb/acre. MB has consistently been applied at rates of 300 to 600 lb/acre with an average closer to 350 lb/acre. For tree and vine crops in the Central Valley, the most common treatments have been non-tarped but applied at a 20-inch depth. Non-tarped treatments perform well if there are no pests of concern in the surface 5 inches of soil or the crop to be planted carries resistance. The use of a tarp doubles the cost of a fumigation but is a requirement in certain counties.

F-4. Strip, Spot or Solid Treatments

Tree growers have the option of treating only where the new trees will be planted or treating the entire field surface. A strip or spot treatment has shown to provide relief from the rejection component of RP. A typical non-tarped strip treatment can cost $275/acre and provide 1 yr of nematode relief. Deciding whether to treat in strips or a solid field depends on the soil pests and availability of resistant rootstocks. Strip or spot treatments are not recommended where Oak Root Fungus is a problem. Strip or spot treatemtns are viable , for example, if the only soil pest is Root Knot Nematode and Nemaguard Peach is to be planted.

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) 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 125 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 five 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 waiting one full year 3/ and use of transported NRPS of at least ½ yd per planting site. 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'	7.0	3.5	99.	99.	99.	6 yr	Some
8.	Nontarped MB plus root removal to 6" depth.	18 mo fallow	√	√	√	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 in. then 1.5 acre in. with MITC at 110 lb/acre.	6 mo fallow	√	√	√	99.9 to 5' deep	7.	3.5	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 in.	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, MITC uniformly drenched at 325 lb/acre (=100 gal/acre 32.7% Vapam) in 6 acre in. water.	6 mo fallow	G	S	√	99 to 2.5' deep	6.x	3.0x	99 to 5'	99 except those in deep roots	Top 2.5' only	Top 2.5' only	95+
18.	Pull, rip, MITC uniformly drenched at 325 lb/acre (=100 gal/acre 32.7% Vapam) in 6 acre in. water.	No roots larger than ½ in.	√	√	√	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, MITC uniformly drenched at 650 lb/acre in 6 acre in. 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 in. 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 methyl iodide at 20" at 325 lb/acre, no tarp.	6 mo fallow peach	√	√	√	99.9	7.	3.5	99.9	99.9	–	–	95
22.	Pull, rip, shank methyl iodide at 20" at 325 lb/acre, no tarp.	6 mo fallow plum	√	√	√	99.9	Limited	Limited	99.9	99.9	–	–	95
23.	Pull, rip, shank 325 lb/acre 1,3-D at 18" dry soil then 110 lb MITC in 2 acre in.	6 mo fallow	√	√	√	99.9 to 5' deep	7.	3.5	99.9	99.9	Top 4.5'	Top 4'	50-95
24.	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
25.	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

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
26.	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
27.	Pull, rip, Acrolein drenched at 325 lb/acre pulsed in 6 acre in. 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
28.	Urea (lobi) drenched at 650 lb/acre in 6 acre in. then straw amend or barley crop planted.	18 mo fallow	0	S	0	20	2.0	1.2	98	98 in soil only	–	–	Some
29.	Marigold extract at 1 lb fresh wt/10 gal water + 325 lb/acre urea in 6" acre in. then 3' acre ft after 30 days.	18 mo fallow	0	S	0	20	0.8	0.9	90	90 in soil only	–	–	0
30.	Enzone at 700 ppm uniformly drenched in 6 acre in. water (=300 gpa) then 1 gpa Tillam last hr.	Non replant	–	S	√	–			98	98 in soil only	–	–	75
31.	Enzone at 2100 ppm uniformly drenched in 6 acre in. water (=900 gpa).	18 mo fallow	√	√	√	?	10% over MB	–	99.+	99	–	–	Slight
32.	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
33.	CaOHCl uniformly drenched at 325 lb/acre in 6 acre in. water.	18 mo fallow	S	0	S	20	2.	1.2	20	0	–	–	
34.	Chlorine dioxide uniformly drenched at 6 ppm in 6 acre in. at night.	18 mo fallow				20			20	0	–	–	0
35.	Furfural drenched uniformly at 325 lb/acre in 6 acre in.	Non replant site	–	S	–	0							
36.	Peroxyacetic acid drenched at 40 gpa + 40 gpa stabilizer uniformly or pulsed in 6 acre in. water.	Non replant site	–	0	–	0	–	–	0	0	–	–	Some when pulsed
37.	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
38.	Harvest, drench 500 ppm MITC 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

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

No.	Treatment Description	Test Situation	RP Components Rej	SP	IGR	% Roots Killed	Relative Plant Growth Yr 1	Yr 2	First-Year Nematode Control Ecto	Endo	GFLV	ORF Relief	Weed Relief
39.	Harvest, pull, rip, drench planting row at 250 ppm MITC.	6 mo fallow	√	S	√	Top 2.5'	7.	3.2	99.	99.	Top 2.5'	–	S
40.	750°F steam at 2000 psi injected into sand at 240'/hr.	NRPS	–	S	–	Some	–	–	Some	Some	–	–	–
Soil Amendments and Additions													
41.	Pull, backhoe 10' x 6' deep hole	Sand	S	0	?	Some	1.2-3.	–	0	0	–	–	0
42.	6 mo after tree removal.	Fine sandy loam	0	0	0	Some	0.8	0.9	0	0	–	–	0
43.	Incorporate steer manure at 45 ton/acre – grape.	18 mo fallow	0	0	S	10	2.0	1.3	50	50	–	–	0
44.	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
45.	Marigold extract drenched at 1 lb fresh wt/10 gal plus 325 lb/acre urea then after 30 days apply 40 acre in. water.	18 mo fallow	0	S	0	0	0.8	0.9	95	95 in soil only	–	–	0
46.	Water extract of 325 lb fresh wt/acre walnut hulls in 6 acre in. water.	18 mo fallow	–	0	–	0	–	–	0	0	–	–	0
47.	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+
48.	300 gal of 210°F water to tree backhoe site treated with naphthalene or not.	6 mo fallow	S	S	0	?			95	95	–	–	0
49.	Incorporate compost (New Era) at one shovelful/tree site.	Fallow 6 mo	0	0	S	0	1.5	1.3	20	20	–	–	0
50.	Addition of macro and micro	Fallow 6 mo				0	2.0	1.2	0	0	–	–	0
51.	nutrients at planting, small	Fallow 18 mo				20	4.0	1.5	50	50	–	–	0
52.	amounts.	Fumigated MB				99	8.0	3.7	99	99	Top 5'	Top 5'	0
53.	Replanting with new row	Fallow 6 mo	Initial S	0	0	20	2.5	1.2	0	0	–	–	S
54.	10 ft away from old row.	Fallow 18 mo	Initial S	0	0	40	3.0	1.3	0	0	–	–	S
55.	Forty-day flooding	Fallow 3 mo	0	0	0	Surface dis-	0.8	1.0	0	0	–	–	S
56.	Dec.-Jan. tree site	Fallow 15 mo	S	0	0	coloration	3.5	1.3	0	0	–	–	S
57.	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	–	–	–

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	Relative Plant Growth		First-Year Nematode Control			ORF	Weed
			Rej	SP	IGR	Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	Relief	Relief
58.	Hinder® ammonia soap dissolved and added to non-manured planting sites in first year.	NRPS	–	–	√	0	Better than check	–	0	0	–	–	–
59.	Pull, rip, 3 yr California alfalfa then replant sandy loam soil.	42 mo	√	Change	–	Same as #3	7.0	3.5	Changed		–	–	S
60.	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
61.	Incorporated chaff of wild sesame in NRPS.	250 lb/acre	–	0	–	–	–	–	0	0	–	–	–
62.		20 ton/acre	–	S	S	–	–	–	20	20	–	–	–
63.		100 ton/acre	–	S	S	–	–	–	–	50	–	–	–
64.	Safflower stalks water extracted at 20 ton fresh wt/acre in 6 acre in. water.	NRPS	–	–	–	–	–	–	20	–	–	–	–
65.	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	–	–	–
66.	Pull, rip, Velvet Bean for 6 mo.	NRPS	–	S	–	–	–	–	–	90 RKN	–	–	–
67.	Pull, rip, Jack Bean for 6 mo.	NRPS	–	0	–	–	–	–	–	0	–	–	–
68.	Pull, rip, 20 ton/acre fresh cabbage tops incorporated preplant.	NRPS	–	S	–	–	–	–	–	50 RKN	–	–	–
69.	Pull, rip, grow Jupiter Rape for 6 mo.	NRPS	–	0	–	–	–	–	–	0	–	–	–
70.	Pull, rip, Black-Eyed Susans for 6 mo.	NRPS	–	S	–	–	–	–	–	90	–	–	–
Nemaguard + Systemic Herbicides													
71.	25 ml Roundup plus 13 ml diesel	Fallow 6 mo	0	0	0	20	1.	1.	0	–	–	–	–
72.	painted after mid-November, pull in 60 days, rip.	Fallow 18 mo	0	0	0	40	3.	–	0	–	–	–	–
73.	50 ml Roundup plus 100 ml MorAct by Sept. 1.	Fallow 18 mo	√	S	0	95	7.	–	–	–	–	–	–

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

No. Treatment Description	Test Situation	RP Components: Rej	RP Components: SP	RP Components: IGR	% Roots Killed	Relative Plant Growth: Yr 1	Relative Plant Growth: Yr 2	First-Year Nematode Control: Ecto	First-Year Nematode Control: Endo	First-Year Nematode Control: GFLV	ORF Relief	Weed Relief
74. 2% foliar Roundup by Aug. 1.	Fallow 6 mo	0	0	0	95	–	–	0	0	–	–	–
75.	Fallow 18 mo	√	S	0	95	7.	3.0	50	50	–	–	–
76. Vapam into 5 drill holes on trunk.	Fallow 3 mo	–	–	–	0	–	–	0	0	–	–	–
77. Vapam wicked to girdle on trunk.	Fallow 3 mo	–	–	–	0	–	–	0	0	–	–	–
78. Roundup wicked to girdled trunk.	Fallow 3 mo	–	–	–	0	–	–	–	–	–	–	–
79. 50 ml Roundup plus 100 ml MorAct to cut trunks by Aug. 1	Fallow 18 mo	√	S	0	95	–	–	95	–	–	–	–
Lovell + Systemic Herbicides												
80. 50 ml Roundup+ 25 ml diesel by	Garlon 3A	0	S	0	20	–	–	0	95 RKN	–	–	–
81. Aug. 1 then 6 mo fallow.	Roundup	0	S	0	20	–	–	0	95 RKN	–	–	–
82. 25 ml Roundup + 25 ml diesel + 25 ml fosthiazate.	Fallow 6 mo	0	S	0	20	–	–	0	95 RKN	–	–	–
83. 2% foliar Roundup by Aug. 1.	Fallow 6 mo	0	0	0	50	–	–	20	0	–	–	–
84.	Fallow 18 mo	G	S	0	75	7.	3.0	75	50 RL	–	–	–
85. Vapam into 5 drill holes on trunk.	Fallow 3 mo	–	–	–	0	–	–	0	0	–	–	–
Marianna 2624 + Systemic Herbicides												
86. 2% Roundup foliar by Aug. 1.	Fallow 6 mo	–	–	–	40	–	–	0	0	–	–	–
87.	Fallow 18 mo	G	S	0	60	7.	3.0	75	50	–	–	–
Myrobalan 29C + Systemic Herbicide												
88. 2% Roundup foliar by Aug. 1.	Fallow 6 mo	–	–	–	75	–	–	0	0	–	–	–
89.	Fallow 18 mo	G	S	0	85	7.	3.0	75	50	–	–	–
NC Black or Paradox Walnut + Systemic Herbicides												
90. 50 ml Garlon 3A + 25 ml diesel oil.	Fallow 6 mo	0	0	0	0			0	0	–	–	–
91.	Fallow 18 mo	√	S	0	95+	6.	3.	Some	97+	–	–	–
Grapes + Systemic Herbicides												
92. Thompson Seedless + foliar spray of	Fallow 6 mo	–	–	–	10	–	–	–	–	–	–	–
93. 2% Roundup in Aug, Sept., Oct., or Nov.	Fallow 18 mo	–	–	–	10	–	–	–	–	–	–	–
94. Cabernet Sauvignon + foliar spray 3% Roundup in Oct.	Fallow 12 mo	0	?	0	10	–	–	–	–	–	–	–
95. Thompson Seedless	25 ml Roundup + 13 ml diesel	–	–	–	10	–	–	–	–	–	–	–
96. painted to trunk with	25 ml 2,4-D + 13 ml diesel	–	–	–	10	–	–	–	–	–	–	–

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		
97.	herbicide Aug. – Nov.	25 ml Goal + 13 ml diesel	–	–	–	10	–	–	–	–	–	–	–
98.	then 12 mo fallow.	25 ml Roundup + 13 ml DMSO	–	–	–	10	–	–	–	–	–	–	–
99.		25 ml Garlon 3A + 13 ml diesel	–	–	–	95% in top 18" soil	–	–	–	–	–	–	–
100.		25 ml Garlon 3A + 50 ml MorAct	–	–	–	?	–	–	–	–	–	–	–
101.	Repeated girdling of Sauvignon Blanc.	Fallow 6 mo	–	–	–	?	–	–	–	–	–	–	–
Transported NRPS													
102.	½ yd NRPS within RPS site.	Fallow 4 mo	Initial √ then G	S	0	0	7.5	3.0	(90)	(90)	–	–	–
103.	Pull, rip, backhoe then	Fallow 6 mo	Initial √ then S	S	0	0	?	–	(95)	(95)	–	–	–
104.	250 ppm MITC then ½ yd NRPS.	Fallow 6 mo	Initial √ then S	S	0	0	?	–	(95)	(95)	–	–	–
105.	Pull, rip, backhoe then 25 gal NRPS.	Fallow 6 mo	Initial √ then S	S	0	S	Inadequate		–	–	–	–	–
Post-Plant Nematicides to NRPS Site													
106.	Post-plant (7) monthly Vydate 42	NRPS	–	Limited √	√	–	1.1	1.2	98	98	–	–	0
107.	treatments at 1 lb ai via drip.	After 25 gpa Telone	√	Limited √	S	95			99	99	–	–	0
108.	Post-plant (7) monthly Nemacur 3	NRPS	–	√	0	0	1.0	1.1	98		–	–	0
109.	treatments at 1 lb/acre via drip.	After 25 gpa Telone	√	Limited √	S	95			99	99	–	–	0
110.	Post-plant Enzone after first summer at 500 ppm via drip.	NRPS	0	S	0	0	–	–	90	50	–	–	0
111.	Post-plant Enzone 30 days after planting at 700 ppm via drip.	NRPS	0	S	0	10-25	0.9	–	50	50	–	–	0
112.	Post-plant Vapam at 10 ppm monthly 7 times.	NRPS	0	0	0	50	0.8	–	0	0	–	–	0

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	Relative Plant Growth		First-Year Nematode Control			ORF	Weed
			Rej	SP	IGR	Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	Relief	Relief
113.	Post-plant DiTera at 20 lb/acre 3 times/yr.	NRPS	0	S	0	0	1.0	–	50	50	–	–	0
114.	Post-plant peroxyacetic acid at 2000 ppm/mo 7 times/yr.	NRPS	0	0		0			0	0	–	–	0
115.	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
116.	More frequent irrigations.	Begin first year in RPS	0	0	0	0	0.8	0.9		0	–	–	Aggra-vates
117.	More frequent irrigations.	Begin second year	0	0	0	0	–	1.1	0	0	–	Aggra-vates	
Resistant Rootstocks													
118.	Nemaguard.	Peach	0	S	0	0	–	–	0	Root Knot	–	0	0
119.	Marianna 2624.	Plum	S	S	0	0	–	–	0	Root Knot	–	95+	0
120.	Lovell seedling.	Peach	0	S	0	0	–	–	Some Ring	0	–	0	0
121.	Myrobalan 29C.	Plum	0	S	0	0	–	–	Some Ring	Root Knot	–	0	0
122.	Deep Purple.	NRPS	–	0	–	0	–	–	0	0 RL	–	–	–
123.	Bruce.	NRPS	–	S	–	0	–	–	0	RL RKN	–	–	–
124.	English Walnut.	Walnut	–	0	0	0	–	–	0	0	–	0	0
125.	NC Black Walnut.	Walnut	0	S	0	0	–	–	Some Pin – Dagger	Root Knot	–	S	0
126.	Paradox Hybrid.	Walnut	S	S	0	0	–	–	Some	Some Root Knot	–	S	0
127.	*Pistacia atlantica.*	Pistachio	–	S	0	0	–	–	0	RL, RK, Citrus	–	–	0
128.	Hayward Kiwifruit.	Kiwi	0	0	0	0	–	–	0	0	–	–	0
129.	Citrus Trifoliate.	Citrus	S	S	0	0	–	–	0	Citrus Nema	–	S	0

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	Relative Plant Growth		First-Year Nematode Control			ORF	Weed
			Rej	SP	IGR	Killed	Yr 1	Yr 2	Ecto	Endo	GFLV	Relief	Relief
130.	Malus M-111.	Apple	0	0	0	0	–	–	0	0	–	0	0
131.	Thompson Seedless.	Grape	S	S	0	0	–	–	0	Some RKN	0	Some	0
132.	Freedom RS.	Grape	0	S	S	0	–	–	0	Some RKN RL Citrus	0	Some 0	0
133.	Teleki 5C.	Grape	0	S	0	0	–	–	0	Some RKN, RL	0	Some	0
134.	6-19B.	Grape	0	√	0	0	–	–	98+	98+	0	–	0
135.	10-17A.	Grape	S	√	0	0	–	–	98+	98+	0	–	0
136.	10-23B.	Grape	S	√	?	0	–	–	98+	98+	0	–	0
137.	RXS-9.	Grape	–	G	–	0	–	–	98+	98+	–	–	–
138.	RXS-3.	Grape	S	G	0	0	–	–	?	98+	0	–	0

Table Legend:

√ = 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.

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:

1/ rates not to exceed 35 gal/acre

2/ presence of high soil moisture content at the field surface

3/ 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 Figure 1 of this text is depicted the same basic chart for shank treatments. The new 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 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 Condor, 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 MITC) 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, 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 MITC when delivered to soil using a portable drenching device (McKenry, M. V. et. al., 1994). 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 MITC 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, MITC 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.

MITC is also a relatively poor root penetrant. When Vapam is applied at 100 gal/acre in 6 inches water (or 250 ppm MITC), 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 MITC is not a high enough dose when such refugia occur in the soil. Increasing the delivered dose to 500 ppm MITC 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. However, fertilization also helped plants grown in MB treated sites. Additionally, the poor root penetrating quality of MITC 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.

This brings up a third and very important consequence of MITC treatments. All fumigants, including MITC, create a biological vacuum. However, the broad spectrum effectiveness of MITC 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 MITC treated soil.

These shortcomings of MITC liberating compounds are reasons why MITC 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, MITC does kill shallow roots and simultaneously destroys the rejection component of RP without the lengthy waiting period of other techniques. This occurs only within the MITC delivery zone, which is adequate to give at least one full year of good root growth. MITC 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 sucker badly 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 MITC treatments. We have not yet conducted enough MITC 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 tenfold 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 MITC would not be uniformly dispersed. Soils more conducive to success with MITC 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 MITC at the target site.

MITC 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 1 b/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.

Carbon Bisulfide Liberators

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.

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 1 b 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

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 pulled.

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 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, MITC 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.

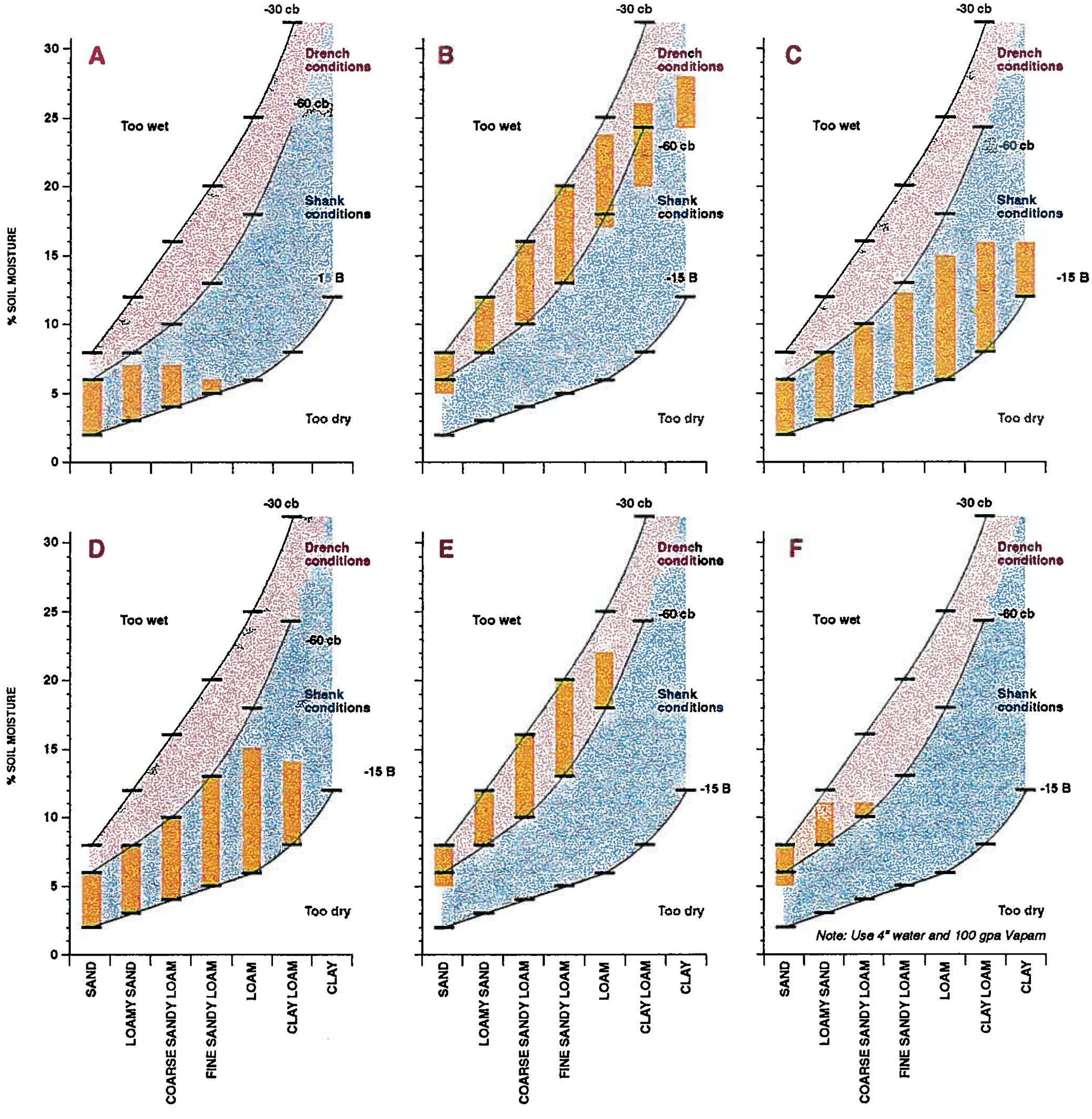


Fig. 1a. Optimum Treatment Conditions for 35 gpa 1, 3-D to soil with moistened surface.

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 MITC 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 MITC 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 MITC if endoparasitic nematodes also occur within such plant structures. The 250 ppm dosage of MITC 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% MITC) 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 MITC. Vapam is not recommended at soil temperatures below 45° F.

<u>I-4. Systemic Herbicides Plus 18 Month Fallow</u>

Studies have shown that remnant roots of *Juglans* spp. and *Prunus* spp. can be killed with herbicides painted on tree trunks. 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. 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. 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, 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 "Soft 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 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 210° F water before replanting. Another treatment involved treating the backhoed site with MITC 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 rather than a loamy 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 MITC-treated zone. We have since demonstrated that there is some type of rejection component working as root systems move out of NRPS and into MITC-treated zone. This rejection does not occur when the roots are started out in MITC soil. However, as root systems grow out of MITC 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 MITC, 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 MITC.

Solution 3/ 200 gal/acre Vapam (32.7% MITC) 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 MITC.

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% MITC) 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 *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 *Criconemella xenoplax* infested site.

Potential solution 1/ Harvest last crop, irrigate, cut trunks between July and November 1. Push tree trunks after 60 days, 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 MITC then pull the drip line a distance of half the emitter spacing and continue another 4 to 5 hr with the MITC. 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 MITC 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 MITC. 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 1/ 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). 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/ac 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. 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 l b/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 MITC 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.

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		Tree Growth (kg) 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 MITC.	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: MITC 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 MITC.	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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