The Replant Problem

AND ITS MANAGEMENT

by Michael V. McKenry

Acknowledgments

The author is indebted to many for their assistance in these studies. Foremost, there were many California commodity groups willing to support these studies. Second, the excellent assistance of Tom Buzo, Stephanie Kaku, Rulon Ashcroft, and Dave Dougherty was paramount to conducting and maintaining the field trials and laboratory studies. The typing and tabulation into readable format is a product of Lois Strole, photo arrangements by Gwen Conville, and additional editing by Perry Klassen. Formal review and helpful comments on the manuscript were provided by Dr. Andy Nyczepir, USDA and Dr. Greg Browne, USDA.

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First Printing: July 1999

Listing of Acronyms

1,3-D	1,3-dichloropropene nematicide (= Telone II)
BCC	Bacterial Canker Complex
BV	biological vacuum
CDFA	California Department of Food and Agriculture
CP	chloropicrin or "teargas"
DBCP	1,2-dibromo-3-chloropropane
D-D	1,3-dichloropropene nematicide (Shell Chemical); banned
DMSO	dimethyl sulfoxide
Ecto	ectoparasitic nematodes
Endo	endoparasitic nematodes
FS	fumigated soil
GFLV	grape fan leaf virus
IGR	increased growth response
IPM	Integrated Pest Management
MB	methyl bromide
MI	methyl iodide
MITC	methyl isothiocyanate
MS	metam sodium
NC	northern California
NRPS	non replant problem soil
ORF	oak root fungus, *Armillaria mellea*
PSDD	portable soil drenching device
Rej	rejection component of replant problem
RKN	root knot nematode
RL	root lesion nematode
RP	replant problem
RPS	replant problem soil
RS	rootstock
SP	soil pest and disease component of replant problem
UC	University of California

Note: Vapam is 3.2 lb ai (MS) per gallon which generates 0.566 lb MITC for every 1.0 lb of MS.

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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 150 potential alternatives to methyl bromide soil fumigation is 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 narrow spectrum treatments which solve individual components of the replant problem. Combining of more specific 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 specific 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 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. Depending upon soil characteristics, conditions, and equipment availability; certain low-volatility biocides can be effectively delivered to target pests using new drenching techniques.

The Replant Problem and Its Management
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A. Introduction

Farmers of tree or vine crops often encounter growth problems when they replant on sites 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, Appendix Item 2). 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, Appendix Item 3 and 11).

The expected phase out of MB by 2005 heightens the need to find solutions to RP. This author estimates a 25% loss in production efficiency 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 and elsewhere 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 symptoms usually initiate the first year after planting and follow the removal of some other woody perennial. Additionally, this soil problem can have physical, chemical and biological components, requiring that effective control 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 cover 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 (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 root knot nematode *Meloidogyne incognita*. 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 Root Knot Nematode influence on girth of peach trunks

First Fall Fall Year 3

RKN

RP with RKN

Dactylella + RKN

MB only

RKN

RP with RKN

Dactylella + RKN

MB only

normal irrigation

more frequent irrigation

Spring Year 3 Fall Year 5

Photo Array 2 Second-year growth of walnut nursery following walnuts

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 Array 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 Fungus, *Armillaria mellea*; 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 trees or vines and then replant trees or vines within months. 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; Historical Perspectives). This author does not believe that any of these pathogens or parasites per se is 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 greater 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 applied 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 still visible in the adjacent five rows that only received DBCP. Tree death due to Oak Root Fungus began to occur at six years and slowly enlarged across the orchard. By 14 yr tree death 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 because no pre-plant MB treatments were applied.

Photo Array 3 **The Replant Problem plus Oak Root Fungus**

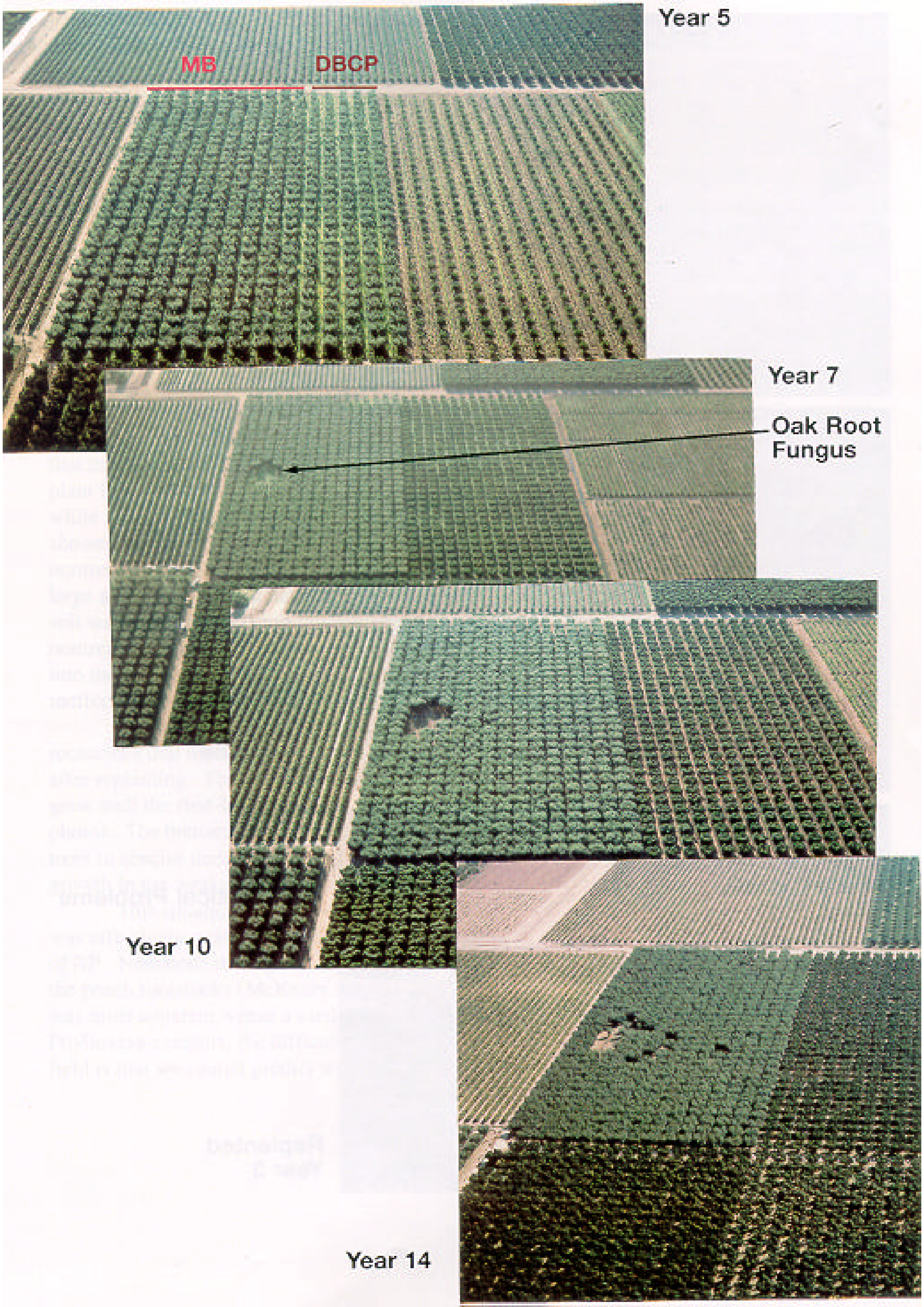


Photo Array 4 **The Replant Problem, plus soil physical problems plus oak root fungus**

Oak Root Fungus

30 yr. old orchard

strip fumigation MB

Soil Physical Problems

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 MS, 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 pre-plant fumigated with 1,3-D 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 **The Replant Problem plus Phylloxera plus soil physical problems**

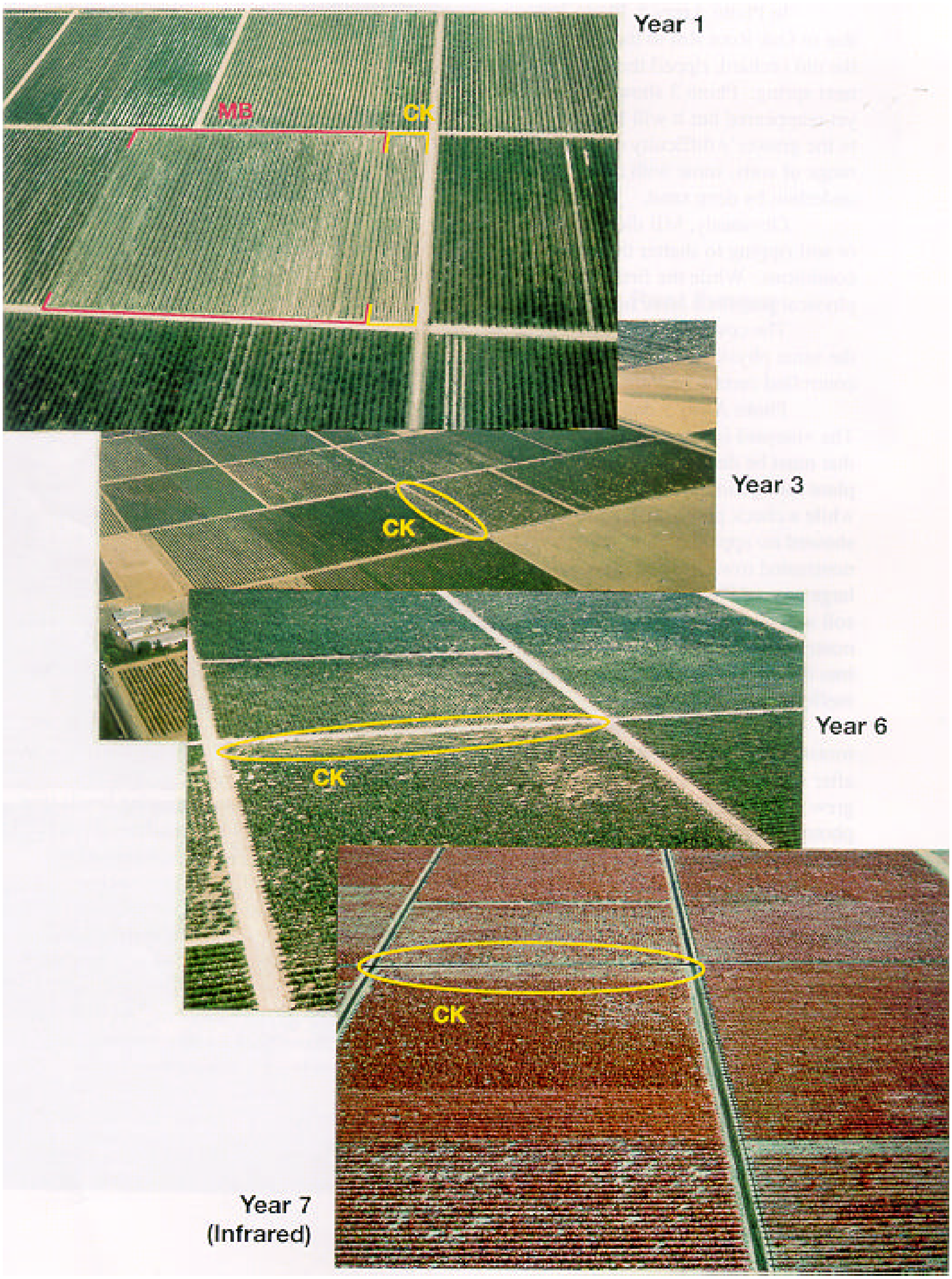


Photo Array 6 **A fumigated site inoculated with Root Lesion Nematode**

Summer Year 4

non-inoculated **inoculated**

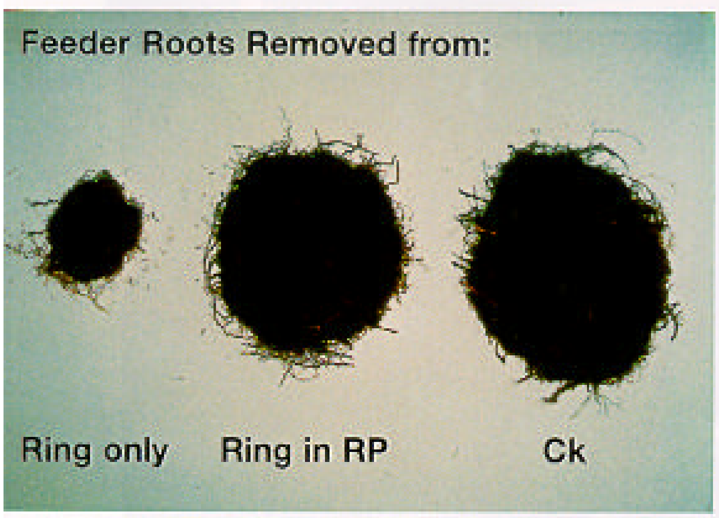
Fall Year 4

Photo Array 7

Replant problem soils can also harbor biocontrol agents

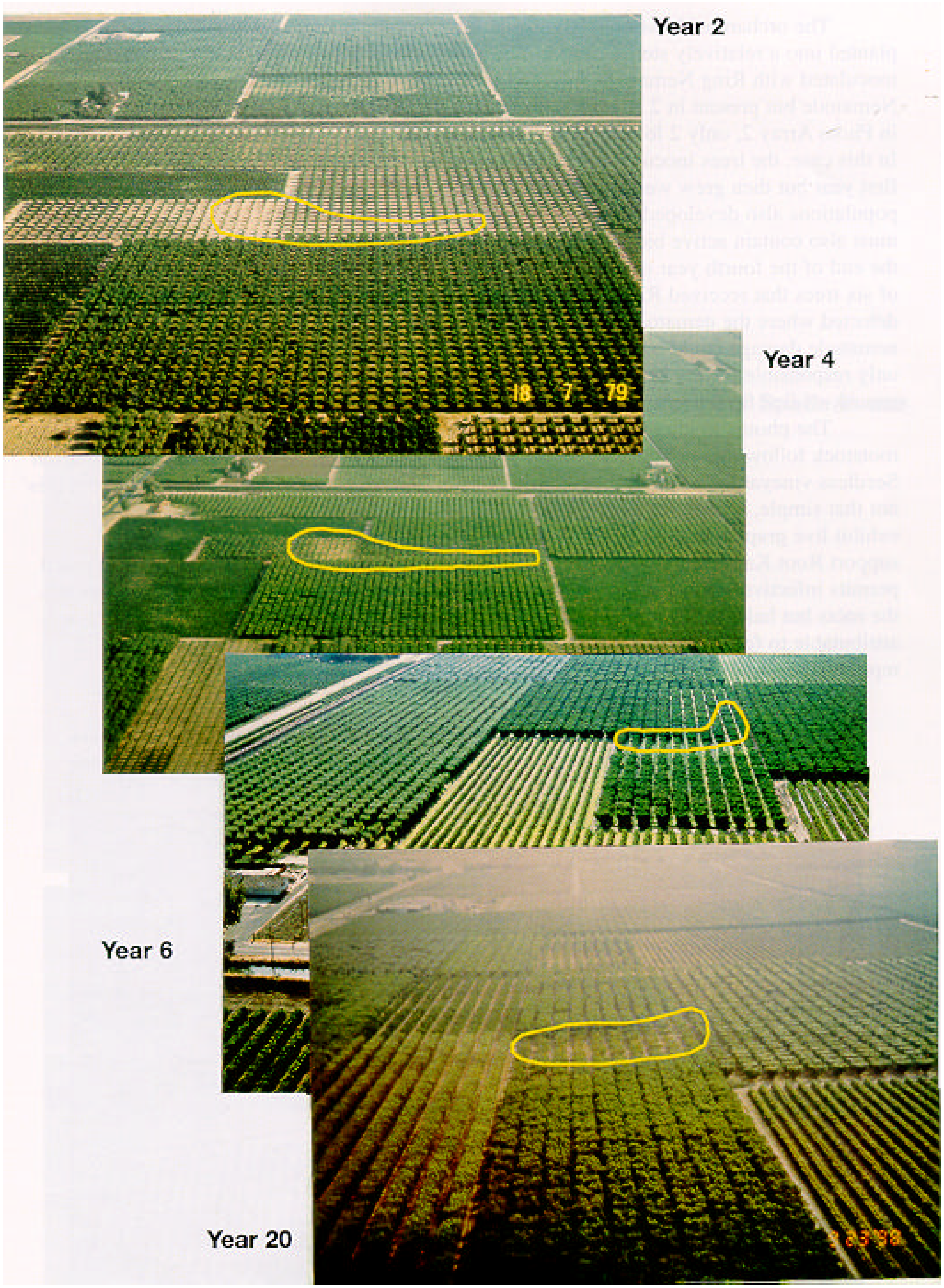
Fourth Year
Limb death

Overview Year 1



Roots from Ring Nematode Only

Photo Array 8 Components of RP can persist in the presence of excellent resistance



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 Ring Nematode only, *Criconemella xenoplax*, 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 an older, 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 infective-stage 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 **A poor pre-plant treatment can necessitate long-term need for post-plant nematicides.**

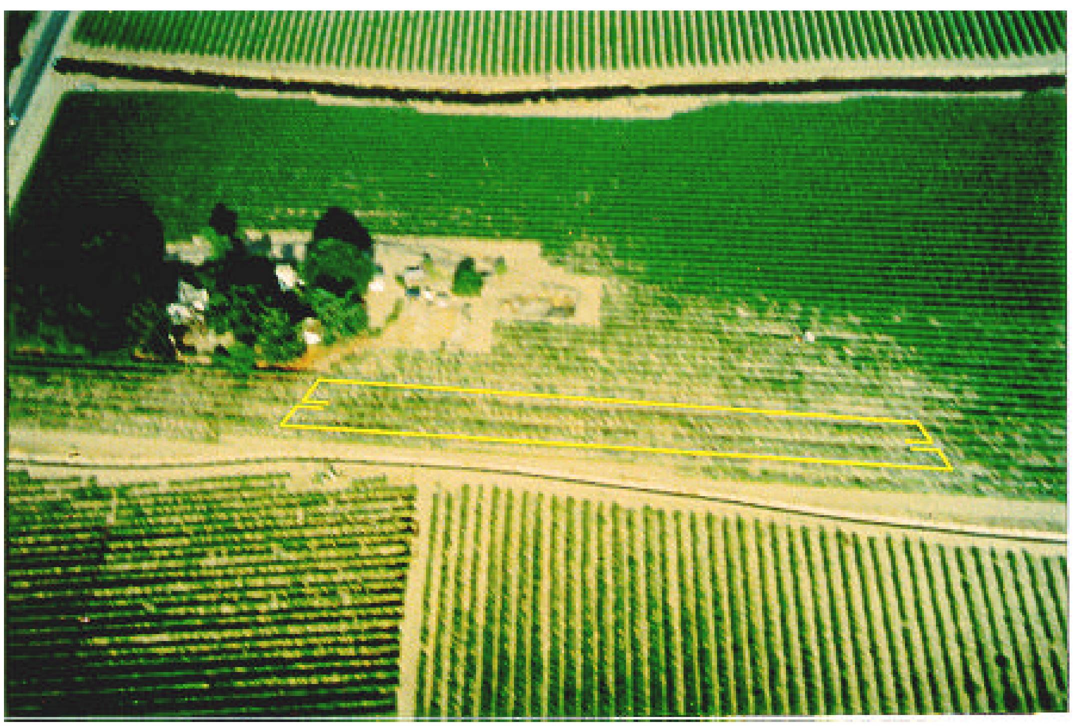
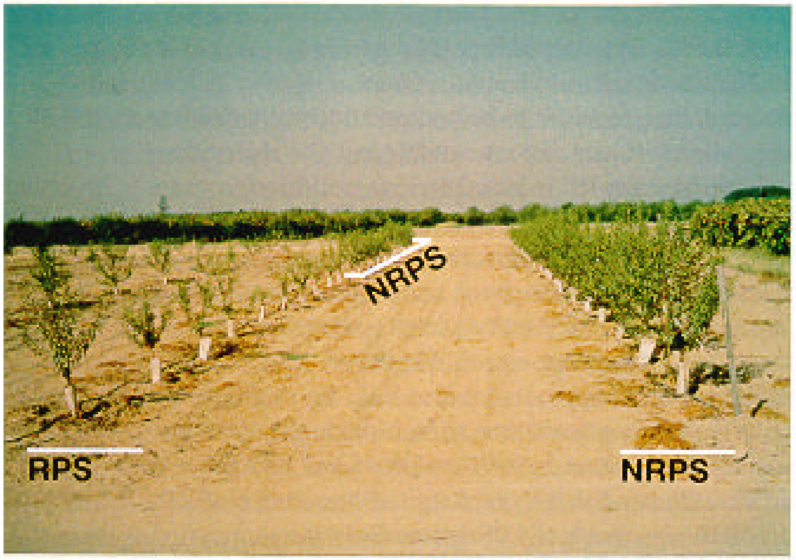
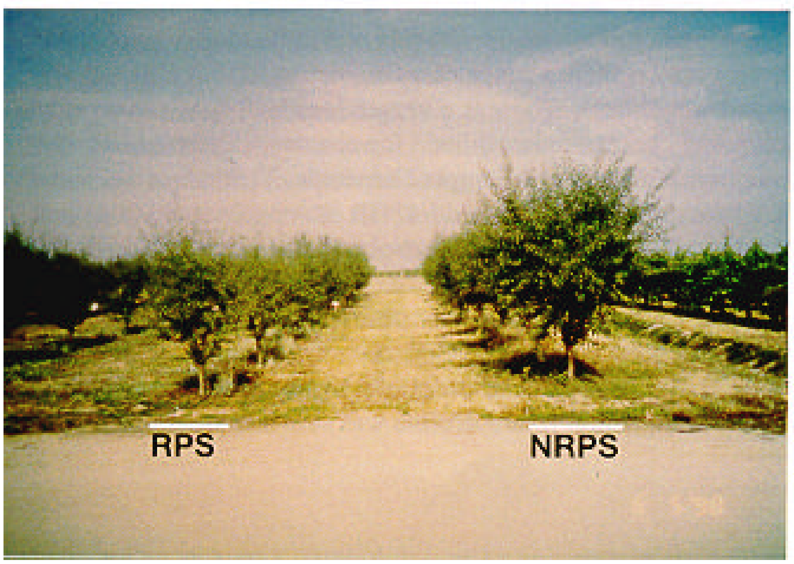


Photo Array 10 **Rejection component in the absence of other RP components**

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 (this Non Replant Problem Soil was 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, Appendix Items 14 and 15). 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 Pin Nematodes, *Paratylenchus hamatus*, 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, Appendix Item 11).

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 Dagger Nematode, *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, 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 (1,3-D soil fumigants). 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 inoculating 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, *Tylenchulus semipenetrans*, 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, *Phytophthora* spp. 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 is 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/ **Persistance –** 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 preplant 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, 1996).

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., 1979)
- 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 for orchards (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 more specific 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 (note treatment 73 of Table 1, McKenry et. al. 1995 and Appendix Item 3). 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 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 against ectoparasitic nematodes including Pin Nematode (McKenry, M. V., et. al., 1995 and Appendix Item 4), *Xiphinema index* and Ring Nematode (see Photo Array 7).

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 (Appendix Item 8). 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 MS treatments, the increased growth response may result from the cascade of microbial populations that re-inhabit soil after fumigation, some of which are more compatible with plant growth. For Prunus orchards, re-adjustment of soil pH back up to 6.5 is beneficial, and nutrient availability is a major benefit of liming soil.

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 (Nemaguard) 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 (Appendix Item 2). Equally important, 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 aggressive to less-aggressive 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 above-ground 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 (Appendix Item 3). 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, *T. 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.

E-3. More on the Rejection Component of RP

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, Appendix Item 4). 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, Appendix Item 15). 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 MS (unpublished).

(4) Soil treated at 500 ppm MS is less compatible to new root system development than soil treated with 250 ppm MS (McKenry, M. V., et. al., 1995, Appendix Item 3).

(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 (Appendix Items 14 and 15).

(6) Trees replanted into the old drive row (10 ft away) grow moderately well the first year but can be noticeably slowed in growth in the second year as their roots reach into RPS (Appendix Item 3).

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 of California.

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 treatments are viable , for example, if the only soil pest is Root Knot Nematode and Nemaguard Peach is to be planted.