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Controlling Replant Diseases of Pome and Stone Fruits in Northeastern United States by Preplant Fumigation

Many orchard sites in the northeastern United States that previously produced profitable yields of pome and stone fruits will not support satisfactory growth of replanted trees, even though recommended cultural practices have been followed (11). Accordingly, the terms "replant problem" and "replant disease" are considered synonyms and refer to poor growth of fruits obtained on old orchard sites. The incidence and severity of replant diseases, evidenced by stunting and/or tree mortality, vary considerably within and between orchards. The level of severity depends on such factors as age of the orchard, previous fruit crop, soil type, and extent of damage on old tree roots.

The etiology of replant diseases of fruit trees appears to be complex and remains to be fully elucidated. Accumulated research results strongly indicate that the causal agents are soilborne organisms, including plant-parasitic nematodes, parasitic fungi, and nonparasitic microorganisms (3,4,7,9,13). Other causal factors, however, such as toxic chemicals from old roots, unbalanced soil nutrition, and impaired soil structure, have been suggested. These are undoubtedly involved in some orchard sites, but usually as secondary contributing factors rather than as primary causal factors.

Preplant treatment of old orchard soil with fumigants, either primarily nematicides or broad-spectrum biocides, has lowered tree mortality and increased growth and uniformity, yield, and tolerance to cold and drought stresses (1,6,16). Most important, however, research results and observations indicate that the economic benefits gained from soil fumigation have far exceeded the cost.

Not a New Problem

Difficulties in replanting old orchard sites have been encountered for more than 200 years, particularly in Europe. At present, replant diseases are reported from essentially all the major fruit-growing areas of the world. Early orchardists in Canada recognized that these problems were soil related and solved them at great expense by replacing the old orchard soil in planting sites with fresh soil. Although a number of chemical soil treatments have been tested and in limited use for about a century, the discovery of 1,3-dichloropropene (1,3-D) in 1943 and ethylene dibromide (EDB) in 1945 resulted in the first economically effective nematode control and growth and yield increases under field conditions. Additional effective nematicides and broad-spectrum biocides, such as chloropicrin (trichloronitromethane) and methyl bromide, for use under field conditions have since been developed.

In Europe, two general types of replant diseases have been recognized. On apples, these include specific and nonspecific replant diseases (3,13). Nonspecific replant disease affects several fruit tree crops, has a patchy distribution in the orchard, and is correlated with high numbers of plant-parasitic nematodes. In contrast, specific replant disease does not correlate with plant-parasitic nematodes, has an even distribution throughout the orchard, and is limited in activity to one crop or to closely related fruit tree crops. For example, only apple and related fruit trees are affected when replanted in soils from old apple orchards; thus the term "specific apple replant disease." A specific cherry replant disease has been referred to but has not been as widely studied as specific apple replant disease.

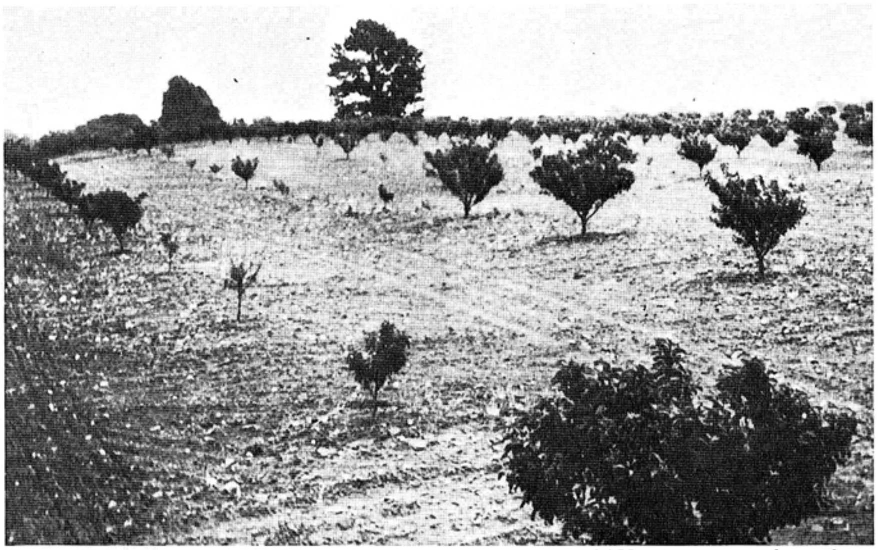

Fig. 1. Widely varying effects of replant disease on 5-year-old Montmorency cherry trees on Mahaleb rootstock.

It has been suggested that nonspecific replant disease is generally more severe on coarse-textured soils (11). Both types of replant disease are controlled by preplant treatment with soil fumigants. A broad-spectrum biocide such as chloropicrin or methyl bromide, however, is required for specific replant disease control, whereas nematicides such as 1,3-D control nonspecific replant disease. Thus, planting fruit seedlings in soil treated with a nematicide and a broad-spectrum biocide may aid in determining the severity and type (specific or nonspecific) of replant diseases in orchard soils. Such tests have been used in Europe to determine the need for soil fumigation (3,13).

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Research results in New York have suggested that replant diseases of fruit crops appear to resemble both the specific and the nonspecific type (4,7). For example, the apple replant disease in New York resembles the nonspecific type because it equally affects other crops (pear, peach, and cherry) and is associated with a high population of the root-lesion nematode (*Pratylenchus penetrans*). However, it also resembles specific replant disease because growth response of apple and other fruits is greater to broad-spectrum biocides than to nematicides such as 1,3-D. Observations and research reports from other fruit-growing areas in the Northeast and from other regions in the United States suggest the occurrence of a similiar replant disease. In addition, a recent report from Europe (14) questioned the specific nature of replant disease on apples and other crops.

Diagnosis of Replant Diseases in the Northeast

Severe replant disease in newly established orchards causes characteristic uneven growth as well as relatively high tree mortality (Fig. 1). It should be pointed out that poor and uneven growth can also result from wet soil, poor nutrition, hardpans, cold injury, drought, and other stress factors. Uniform but unthrifty tree growth in orchards with less severe replant disease is difficult and at times impossible to recognize unless trees growing on untreated sites are compared to more vigorous trees growing on sites treated with a preplant fumigant (Fig. 2). Severely damaged root systems may lack feeder rootlets and be entirely or partially dead. Infected feeder roots are discolored and stunted and may show witches' broom symptoms (Fig. 3). Similar root symptoms occur on older trees in mature orchards, but aboveground symptoms usually are less obvious.

Fig. 2. Four-year-old McIntosh apple trees growing (left) in soil that received preplant treatment with 234 L/ha (25 gal/A) of Vorlex and (right) in untreated soil.

Nematodes as Pathogens

Although recent research indicates that several soilborne microorganisms are involved (3,4,7,13,14), there is considerable evidence that nematodes, especially *P. penetrans*, play an important role in root destruction associated with replant diseases in the Northeast (4,7). Root-lesion nematodes have been closely associated with replant failure, unthrifty growth, and poor yield of cherries, apples, and peaches and, to a lesser extent, of other stone and pome fruits. However, several other species of plant-parasitic nematodes have also been found associated with soils and roots of fruit trees. The dagger nematodes (*Xiphinema* spp.) and ring nematodes (*Macroposthonia* spp.) are considered to be potentially the most important economically. Large numbers of pin nematodes (*Paratylenchus* spp.) are frequently associated with roots of fruit trees in the Northeast, but their pathogenicity and damage have not been determined. Although the root-knot nematodes (*Meloidogyne* spp.) are important pathogens of peaches in warmer areas, they do not appear to damage peaches or other crops in the Northeast.

High populations of several nematode species can cause direct root destruction and eventual growth and yield reduction. Additional damage to fruit trees is undoubtedly caused by interactions among nematodes and other soilborne microorganisms and among nematodes and such unfavorable environmental

Fig. 3. Mahaleb cherry rootstock: (Left) Normal roots; (center) moderately damaged roots with witches' broom symptoms; (right) severely damaged roots, with almost no feeder rootlets.

Fig. 4. Northern Spy apple seedlings (right) inoculated with *Pratylenchus penetrans* and (left) uninoculated.

factors as cold temperatures and low soil moisture. The nature and importance of these interactions are little understood. The importance of plant-pathogenic nematodes that occur at populations below the recognized damaging level is unknown.

Root-lesion nematodes. Root-lesion nematodes (*Pratylenchus* spp.) are the most damaging nematode pathogens of pome and stone fruits (Figs. 4 and 5) in the Northeast and probably in the world (11). These nematodes have been associated with replant diseases in fruit-growing areas throughout the world, particularly in coarse-textured soil. Root-lesion nematodes live inside feeder root tissues, migrating through the root tissue and through the soil from root to root. This nematode and others parasitic to fruit trees are moved longer distances by cultivation equipment and occasionally by floodwater, dust storms, and other agents. Although *P. penetrans* is the economically most important species in the Northeast, others, especially *P. vulnus*, *P. brachyurus*, and *P. coffeae*, have been shown to cause damage to pome and stone fruits in other fruit areas.

Feeding by root-lesion nematodes results in necrotic lesions on feeder roots. When the lesions coalesce, rootlets and sometimes entire root systems of recently planted trees are destroyed. Although root-lesion nematodes attack roots of trees of every size and age, young trees appear to be more damaged than older trees. Severe damage to young trees may result in tree mortality, whereas less serious damage results in uneven growth and lower yields. The pathogenicity and damage of *P. penetrans* to fruit seedlings have been documented in numerous greenhouse and growth chamber studies (5,9,11). Indirect evidence obtained from field tests in New York (10) has indicated that apple rootstocks vary considerably in tolerance to *P. penetrans*.

In New York, young Montmorency cherry trees growing in soils with a high population of *P. penetrans* were less winter-hardy than similar trees established in sites treated with 1,3-D before planting (Fig. 6). Also, twigs taken from trees growing in nematicide-treated soil showed greater frost resistance in laboratory tests than twigs taken from trees growing in untreated soil.

Dagger nematodes. Large populations of dagger nematodes (*Xiphinema* spp.) have been associated with unthrifty pome and stone fruits in a number of fruit-growing areas, including New York, Pennsylvania, West Virginia, and Wisconsin. The dagger nematodes are ectoparasites and feed from the root surface. In inoculation experiments with *X. americanum*, reduced growth and necrosis of feeder roots of apple seedlings were observed (15). The tips of feeder rootlets of inoculated plants frequently were devitalized and swollen. Brown lesions were on the short feeder roots, and the entire root systems were darkened. The entire root cortex had often sloughed in severely damaged seedlings. More tests should be conducted to determine whether dagger nematodes reduce growth and yield of pome and stone fruits.

Fig. 5. Bartlett pear seedlings inoculated with (left to right) 0, 500, 1,000, and 2,000 root-lesion nematodes (*Pratylenchus penetrans*).

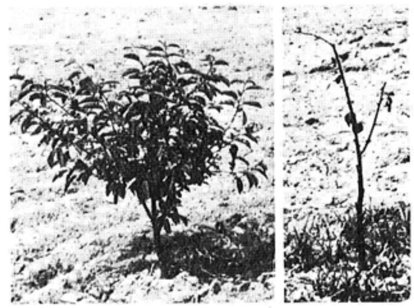

Fig. 6. Montmorency cherry trees on Mahaleb rootstock in second growing season: (Left) Soil fumigated with 420 L/ha (45 gal/A) of D-D (1,3-dichloropropene, 1,2-dichloropropane, and related C_3 hydrocarbons) before planting. (Right) Untreated soil.

X. americanum transmits peach yellow bud mosaic virus, which causes a debilitating disease of peaches, and also tomato ringspot virus, which causes an economically important disease of peaches, cherries, apples, grapes, and brambles. The disease is referred to as Prunus stem pitting in cherries and peaches and as union necrosis in apples. Both viruses are involved in decline of fruit trees but are not considered part of the replant disease described in this article.

Ring nematodes. Ring nematodes (*Macroposthonia* spp.) occur frequently around the roots of fruit trees in the Northeast. Occasionally, high populations of these nematodes are associated with roots of unthrifty trees in recently planted and mature orchards. Research is needed, however, before the economic importance of these nematodes to fruit trees growing in this area can be determined. *M. xenoplax* causes considerable damage to peaches in other areas, including several southeastern states (16), and to peaches and plums in California (6). These nematodes are ectoparasitic and usually do not enter feeder rootlets, feeding from the root surface instead. The feeding destroys cortical tissues of roots, darkens roots, and reduces growth and yield. This nematode also predisposes peaches and plums to bacterial canker caused by *Pseudomonas syringae*.

Pin nematodes. Large numbers of pin nematodes (*Paratylenchus* spp.), which do not enter roots but feed on cortical cells from the root surface, are frequently found around the roots of unthrifty pome and stone fruits in the Northeast. In several field tests, growth and yield of apples and peaches with high populations of pin and other plant-parasitic nematodes were increased by soil treatment with nematicides. No histological or pathological signs or symptoms were observed, however, on roots of apple trees artificially inoculated with pin nematodes. More research is needed to determine the influence, if any, of pin nematodes on growth and yield of pome and stone fruits in the Northeast.

Root-knot nematodes. Root-knot nematodes (*Meloidogyne* spp.) are rarely associated with pome and stone fruits in the Northeast. Although *M. mali* is known to parasitize apples in Russia, root-knot nematodes are more important as pathogens of peaches than of any other pome or stone fruit, particularly in the warmer regions of the world. In fact, before root-knot-resistant rootstocks were developed, particularly Nemaguard (immune or resistant to the common root-knot species), these nematodes were considered the most important ones attacking peaches in California. Root-knot nematodes are still regarded as important pathogens of peaches in a number of regions. Several species, including *M. incognita*, *M. javanica*, and, to a lesser extent, *M. arenaria*, are known pathogens of peaches. Nemaguard, however, is susceptible to ring nematodes.

Other Soilborne Organisms

Although the etiology of replant diseases of fruit trees is incompletely understood, most investigators have concluded that replant diseases are caused by the combined effect of nematodes and several other soilborne organisms. Published reports of the presence of several organisms in damaged roots of trees in the Northeast have substantiated this viewpoint. The enhanced response obtained when such broad-spectrum biocides as chloropicrin and methyl bromide are combined with 1,3-D treatment strongly suggests the involvement of parasitic and/or nonparasitic soil microorganisms. Furthermore, increases in growth and yield of fruit trees because of soil treatment with fumigants have also been observed, even in the absence of any plant-parasitic nematodes at or above a damaging threshold level.

A number of fungi and other soilborne microorganisms known to be pathogenic to fruit trees are found in the soil of orchards with replant diseases in the Northeast and undoubtedly are important in causing the death of feeder roots (4). Plant-pathogenic fungi shown to cause damage to fruit tree roots include *Rhizoctonia solani* on apple and cherry; *Thielaviopsis basicola* on cherry; *Pythium* spp. and *Phytophthora* spp. on peach, cherry, and apple; and *Cylindrocarpon lucidum* on apple. Several *Fusarium* spp. and many other soilborne organisms have been shown to be associated with roots and soils of poorly growing apples. Their effect on pome and stone fruits or their involvement in the response of fruit trees to soil fumigation is largely unknown, however. Recent data from England suggest that additional research should be conducted on the role of *Pythium* spp. in replant problems of apple (14).

Results of recent research in New York suggest that nonparasitic rhizosphere organisms (possibly bacteria or actinomycetes), in addition to *P. penetrans*, are important causal agents of an apple replant disease (4). A rhizosphere wash obtained from apple seedlings growing in apple replant soil was shown to serve as an effective source of inoculum. The causal agent(s) in the rhizosphere wash could be eliminated by filtration (0.2 μm) or heat treatment at 60 C for 10 minutes. In addition, soil treatment with gamma radiation, chloropicrin, methyl bromide, or a very high rate of 1,3-D effectively controlled the disease, but 1,3-D at a nematicidal rate was generally ineffective. The possible involvement of nonparasitic microorganisms in the replant disease of apples has been reported from Europe (3,13). Parasitic and nonparasitic rhizosphere organisms and root-lesion nematodes may act singly and independently from each other in reducing growth of fruit trees. On the other hand, these rhizosphere organisms may well interact with each other and with plant-parasitic nematodes.

Soil Treatment with Nematicides

Soil fumigants have been used increasingly to control replant diseases in the Northeast as well as many other fruit-growing areas. The effectiveness of soil fumigants has been recognized since approximately 1950. An important reason for this effectiveness is that the toxic factor is volatile and moves throughout the soil interspaces, killing nematodes and other organisms in these spaces. As a result of the concentrated research efforts on the use of fumigants, specific recommendations and application practices have been developed and adopted by growers. The most common method of applying soil fumigants is by injection on a broadcast, row, or single replant site basis. The need to seal the surface with a plastic cover or water layer or by simply firming the soil depends on the fumigant formulation used and its volatility. Also, the effectiveness of soil fumigation is greatly affected by soil and environmental conditions at application time. Some of the latter factors include ambient and soil temperatures, soil moisture, and soil tilth.

The most commonly used fumigant nematicides in the past were 1,3-D, EDB, and DBCP (1,2-dibromo-3-chloropropane). DBCP is not available now; its registration was recently suspended by the Environmental Protection Agency, and cancellation appears probable. Some of the leading biocides are chloropicrin, methyl bromide, and Vorlex, a mixture of methyl isothiocyanate and chlorinated C_3 hydrocarbons. Mixtures of nematicides and broad-spectrum biocides are available and frequently used. Treatment with highly volatile broad-spectrum biocides such as methyl bromide and chloropicrin usually results in a greater growth response than when nematicides are used alone. These treatments are expensive, however, because a plastic surface seal is needed to prevent the immediate escape of the fumigant from the soil. DBCP had been widely used in the warmer fruit-growing areas of the United States as a postplant treatment to control root-knot and ring nematodes but had not been used commercially in the Northeast to control root-lesion nematodes.

Most nonfumigant nematicides (organocarbamates and organophosphates) have low phytotoxicity at nematicidal rates and thus can be applied at planting time or after planting. The equipment required is less expensive than that needed to apply fumigants. Nonfumigant nematicides have been shown to kill nematodes and improve growth of fruit trees under orchard conditions, and their use by fruit growers is increasing. More research is needed, however, to compare the effectiveness of fumigant and nonfumigant nematicides in stimulating growth and yield of fruit trees. A nonfumigant broad-spectrum biocide is not available for use in orchards at the present time. The combined effect of fumigant and nonfumigant nematicides applied as a preplant and a postplant treatment, respectively, on growth and yield of fruit trees warrants investigation.

Growth and Yield Response to Soil Fumigation

In New York, pome and stone fruit trees grown on fumigated replant sites have always shown increased growth and yield. Numerous investigators in the Northeast and other fruit-growing areas have reported similar responses to soil fumigation. During the first growing season after fumigation, trees in fumigated soil are more vigorous and have greener leaves, larger shoots, and greater trunk circumferences than trees in untreated sites (Fig. 6). Preplant fumigation of soils with severe replant disease manifests itself best by decreased tree mortality and uniform growth of trees throughout the orchard. In most locations, growth stimulation of all pome and stone fruits by soil fumigation has varied considerably, from as low as 10% to as high as 100%.

Thrifty growth of trees on fumigated sites continues up to full growth unless such limiting factors as unfavorable soil pH or hardpans exist in the replanted orchard and/or poor cultural practices are applied (6,8). Trees growing in fumigated sites also have a deeper and more extensively branched frame root system with healthier feeder roots. Such root systems take up water and minerals from the soil more effectively and thus stimulate growth and yield.

The influence of preplant soil fumigation on yield of pome and stone fruits for a number of bearing years has been determined in only a few long-term orchard experiments. In an experiment continued for 9 bearing years in New York State, preplant soil fumigation (1965) with 234 L/ha (25 gal/A) of Vorlex (a broad-spectrum biocide) and 327 L/ha (35 gal/A) of Telone (a nematicide, 1,3-D and related C_3 hydrocarbons) increased apple yields by 96 and 46%, respectively, over those of trees growing in untreated sites (1) (Fig. 7). The total costs for the Vorlex and Telone treatments per acre (0.41 ha) were \$78 and \$34, whereas the additional yields for the 9 years were valued at \$2,262 and \$1,405, respectively. In another experiment conducted for 7 bearing years in New York State, the application of Telone at 299 L/ha (32 gal/A) increased sour cherry yields by 55%. The expenditure of \$32 for the nematicide per acre resulted in an additional fruit yield valued at \$860 (8). The latter experiment was conducted on a replanted orchard block with a Colonie soil series of loamy very fine sand at a pH range of 5.0–6.0. In a separate treatment, the application of potassium, magnesium, calcium, and phosphorus fertilizers (8) at each planting site (400 ft^2 or 37.2 m^2) at a cost of \$30/A increased yield by 54% and resulted in an additional return of \$845/A. The combined application of the nematicide and the fertilizer resulted in a 109% yield increase. In Michigan, preplant soil fumigation of cherry nurseries with EDB (W-85 at 12 gal/A or 112 L/ha) at a cost of \$80/A resulted in an increased return of \$2,409/A (2).

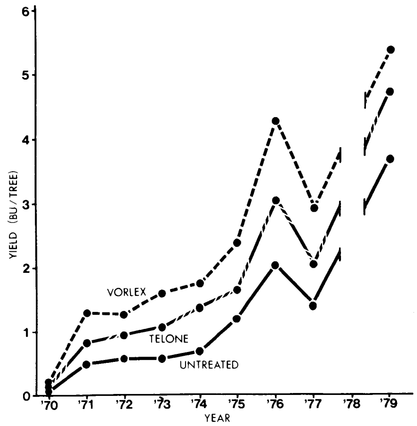

Fig. 7. Yield responses of McIntosh apple trees on M.7 rootstock to preplant soil fumigation.

Control of replant diseases of pome and stone fruits with soil fumigation is to a large extent due to the biocidal activities of the fumigants used. The effectiveness of these nematicides in controlling plant-parasitic nematodes is well documented. Although there is some evidence that nematicides vary in relative effectiveness against specific nematodes, the same nematicides have been recommended and used to control all the nematodes attacking pome and stone fruits. Several plant-parasitic nematodes are generally present in most orchard soils, but one species frequently predominates and is considered to be responsible for most of the observed damage. The application of a nematicide to orchard soil reduces the populations of all nematode species but usually does not eradicate a nematode population. Changes in population dynamics of a particular nematode species after a nematicide treatment therefore depend on such factors as residual population, fecundity of the nematode, soil type, and other environmental conditions. The number of root-lesion nematodes frequently equals or exceeds the prefumigation level within 2 years after fumigation.

The effect of broad-spectrum fumigants such as chloropicrin, methyl bromide, and Vorlex on soilborne flora and fauna is well recognized and documented. Other fumigant nematicides, such as 1,3-D, have also been reported to have a nontarget effect on other soilborne microorganisms (12). Accordingly, it is likely and reasonable to assume that soil treatment with fumigants also controls parasitic and nonparasitic microorganisms that are partly responsible for growth and yield stimulation of pome and stone fruits.

Treatment with soil fumigants may also result in chemical and physical changes in the soil, such as inhibition of nitrification, that may persist for several weeks. It has been suggested that accumulated nitrogenous ammoniated compounds are at least partially responsible for growth stimulation of several crop species, especially of annual crops. The involvement of this factor in growth response of trees to soil nematicide treatments has not been fully investigated, but it probably does not have a major effect. Soil fumigation may also affect the availability of other minerals, such as potassium, magnesium, phosphorus, and calcium. Again, this effect does not appear to play a major role in growth response under natural conditions. Proper fertilization, however, has been shown to be essential to maintaining the beneficial effect obtained from soil treatment with nematicides for a long period of time. The effect of nematicides on availability of nutrients explains the response of plant growth to soil treatments above that attributed to replant disease control (4,13). Land preparation for fumigation, such as deep plowing or backhoeing, and deep injection of fumigants may improve soil drainage and aeration by loosening the soil and breaking hardpan layers.

Occasionally, soil treatment with fumigants has resulted in decreased growth of several crops. This deleterious effect usually has been attributed either to direct toxicity from residues of the fumigant or to the elimination of mycorrhizal fungi. Decreased growth of pome and stone fruit in the orchard caused by preplant fumigants has not been generally observed in the Northeast. However, repeated fumigation of peach nursery blocks in Pennsylvania with broad-spectrum nematicides has resulted in uneven and poor seedling growth. Initial fumigations of the blocks using the same biocides have resulted in greater growth and uniformity of peach seedlings.

Further Research Needed

Replant diseases of pome and stone fruits are important and widespread in nurseries and orchards. For maximum benefits in both nurseries and orchards, replant diseases must be controlled. Preplant soil treatment with a nematicide or broad-spectrum biocide is the most effective and economical measure available.

Results to date indicate that a number of replant diseases are caused by several soilborne organisms. Incidence and severity of replant diseases vary considerably among regions, orchards, and even trees in an orchard. Causal organisms implicated in replant diseases include pathogenic nematodes and fungi and nonparasitic rhizosphere microorganisms. Factors such as rootstock, soil type, previous crop, cultural practices, and environmental conditions undoubtedly have a direct or indirect influence on the causal agents and the extent of root damage to replanted trees. More detailed information is needed on the etiology of replant diseases. Research studies are also needed to determine the damage thresholds of the causal organisms. These data are necessary to improve control practices and to justify expenditures for control.

Limited experimental data indicate that soil treatments with broad-spectrum biocides prevent damage to the first roots developing on newly planted trees. This early protection of roots is believed to be largely responsible for increases in growth and yield. Further research is needed on the dosage and the timing of applications of preplant biocides in order to use them more effectively and economically, with minimum contamination to the environment. More research should be conducted on the use of nonfumigant nematicides as a preplant or postplant treatment. These nematicides have a relatively low level of phytotoxicity and are easier and cheaper to apply, but data are limited on their effectiveness in controlling replant diseases and increasing growth and yield of fruits. There is an acute need for information concerning the effectiveness, costs, and benefits of postplant nematicide treatments to maintain nematode populations at a low level during the life of the tree.

There is also a need to develop alternatives to chemical control measures, using an integrated pest management approach. This will require detailed studies on the biology and ecology of nematodes and other organisms associated with roots of stone and pome fruits. The development of resistant or tolerant rootstocks should be emphasized. A comprehensive research program to develop integrated control measures may well result in a better means for protecting young and old roots of pome and stone fruits, higher yields for lower cost, and minimum risk to the producer and the environment. To accomplish these objectives, a long-term commitment of additional funds for root disease research is required.

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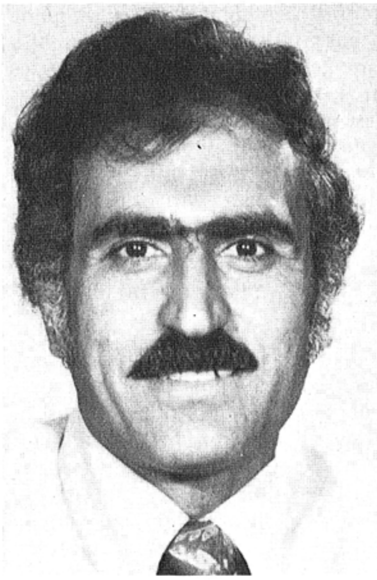

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