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Nematode Management Strategies in Stone Fruits in the United States[1]

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Stone fruits (*Prunus* spp.) include almond (*P. amygdalus* Batsch), apricot (*P. armeniaca* L.), cherry (*P. avium* L. and *P. cerasus* L.), peach (*P. persica* (L.) Batsch), nectarine and plum (*P. domestica* L. and *P. salicina* Lindl.). Almond, however is usually classified with nuts and is not discussed here. Leading stone fruit producing states in the continental United States are listed in Table 1. The total bearing acreage and value of utilized production of stone fruits in the United States in 1989 were estimated at 1.8×10^5 ha and $\$9.25 \times 10^8$ (Table 1) (1). Peach occupies the largest area and yields the greatest economic return. As with any other crop grown in the United States, damage to the tree and (or) fruit by pests and diseases, including nematodes, reduces the grower's profit.

The major nematode pests of stone fruits in the United States include root-knot nematodes, *Meloidogyne* spp.; dagger nematodes, *Xiphinema* spp.; lesion nematodes, *Pratylenchus* spp.; and ring nematodes, *Criconemella* spp. The current taxonomic status for the genus *Criconemella* is unclear and controversial (17); in this discussion, the genus *Criconemella* will be used.

Management options: Effective nematode management begins with site selection. A preferred site is suitable for stone fruit culture and does not have a history of stone fruit or nematode problems. If nematode-free sites are not available nematode problems need to be identified and management practices implemented. Recommended control practices include preplant and postplant nematicide application, resistant rootstocks, and crop rotation, when available. In addition, proper sanitation should be used to prevent reinfestation of treated sites. Certified virus-free rootstock, free of nematode infestation, should be planted to circumvent future problems.

Preplant nematicides available today include 1,3-dichloropropene (1,3-D), methyl bromide, methyl isothiocyanate, and DD-MENCS. Postplant nematicides include phenamiphos and oxamyl. Because state recommendations for nematicide use are not the same and change frequently, current local sources of information need to be consulted for updated recommendations.

Rootstock resistance or tolerance should be considered strongly by a grower when it is available for a nematode problem in that site. Resistance and (or) immunity to *Meloidogyne* can be found in 'Nemaguard' and 'Nemared' peach, 'Marianna 2624' apricot (*P. cerasifera* Ehrh. × *P. munsoniana* W. F. Wight & Hedrick), and 'Myrobalan 29C' plum (*P. cerasifera* Ehrh.) (7, 23,25,32,35,40). Nemaguard and Nemared are resistant to *M. incognita* and *M. javanica* (35). In Florida, both rootstocks also exhibited resistance to *M. arenaria* (38) but not to *M. incognita* Race 3 (37). Some promising peach selections (e.g., Flordaguard) that combine root-knot nematode resistance of 'Okinawa' and Nemaguard toward *M. incognita* Race 3 have been identified (37; W. B. Sherman, pers. comm.).

Tolerance to *Pratylenchus vulnus* has been found in the plum rootstocks Marianna 2624 and Myrobalan 29C, 'Royal' apricot, and sand cherry (*P. besseyi* Bailey) (9). Tolerance to *P. penetrans* also was identified in a peach cross (Okinawa and Nemaguard) that exhibited resistance to *Meloidogyne* (16).

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TABLE 1. Leading states in stone fruit (*Prunus* spp.) production by crop in the United States, 1989.

	Bearing hectares (1,000)	Total production (T)	Total production (%)	Value of total production ($1,000)
		Apricots		
California	7.0	115,000	98.3	35,948
Utah	NA†	400	0.3	165
Washington	NA	1,600	1.4	2,236
		Nectarines		
California	9.6	200,000	100.0	79,290
		Plums and prunes		
California	47.6	967,800	95.7	269,946
Oregon	3.9‡	11,000	1.1	1,609
Washington		13,500	1.3	2,187
Michigan		13,000	1.2	2,281
Idaho		6,500	0.7	2,677
		Cherries (sweet)		
Washington	5.4	84,000	43.2	67,390
Oregon	4.9	53,000	27.3	28,002
Michigan	3.9	25,000	12.9	11,705
California	4.1	26,000	13.4	24,418
Montana	NA	3,300§	1.7	1,042§
Other	NA	3,150	1.5	4,040
		Cherries (tart)		
Michigan	13.5	95,000	69.2	21,878
New York	2.0	15,500	11.3	3,396
Utah	NA	12,000	8.7	2,716
Pennsylvania	0.7	3,000	2.2	1,027
Wisconsin	1.2	4,100	3.0	835
Other	NA	7,750	5.6	2,302
		Peaches		
California‖	10.9	262,000	22.5	79,904
California¶	11.2	496,000	42.4	98,262
South Carolina	12.3	135,000	11.6	46,974
Georgia	8.1	62,500	5.4	23,260
New Jersey	4.5	35,000	3.0	22,512
Pennsylvania	3.1	32,500	2.8	16,799
Other	24.3	143,650	12.3	72,666

USDA National Agricultural Statistics Service, July 1990.
† Not available for individual state(s).
‡ Four-state total in bearing hectares for OR, WA, MI, and ID.
§ Total production and value of total production figures for 1988 were used for MT, since there was no significant commercial production in 1989 because of frost.
‖ Freestone.
¶ Clingstone.

'Mahaleb' cherry (*P. mahaleb* L.) has been reported to tolerate attack by *P. penetrans* because the root system penetrates deeply into light, well-drained soils (10). However, if root growth is restricted in heavy, poorly drained soils, this advantage of Mahaleb might be negated.

Resistance to tomato ringspot virus (TmRSV), which causes prune brownline disease (PBL) and is vectored by *Xiphinema californicum* (Lamberti & Bleve-Zacheo), syn. of *X. americanum* (Cobb) Griesbach & Maggenti, has been identified in Marianna 2624 plum rootstock (12). A different strain of TmRSV causes *Prunus* stem pitting (PSP) disease in other *Prunus* species (e.g., peach and cherry). This nematode-vectored strain of TmRSV causes grooves and pits in the woody cylinder of the lower tree trunk. Mahaleb rootstock exhibited typical PSP symptoms, whereas Mazzard remained symptomless after inoculation (24).

Resistance to the ring nematode, *Criconemella xenoplax* (Raski) Luc & Raski, has not been identified. However, partial tolerance to the nematode has been identified in 'Lovell' rootstock, and it is preferred over Nemaguard because it survives longer on peach-tree-short-life (PTSL) sites in the southeastern United States (6,36,43).

Even though resistant or tolerant stocks have been identified, not every cultivar may be available on every rootstock because scion and rootstock may be incompatible. For instance, Marianna 2624 and Myrobalan 29C plum rootstocks are resistant to *M. incognita* and *M. javanica* and grow well in wet areas in orchards, but they are unsatisfactory rootstocks for peach scions (20). Reliable nurseries can provide information on cultivars and rootstocks best suited for the local area and the nematode pests to be managed. Rootstock selection is based on factors in addition to nematode resistance. Whereas some rootstocks have demonstrated resistance or tolerance to different nematodes, they vary greatly in susceptibility to other soil-borne diseases and in horticultural usefulness (25,26). Sometimes, the overriding reason for selecting or rejecting a rootstock is a problem other than nematodes (e.g., wet feet).

Crop rotation is not widely recommended for nematode control in stone fruit. Disadvantages include 1) lack of data for recommending a rotation, 2) delayed planting of orchards for several years, 3) no or low economic return from current rotational crops recommended, and 4) potential creation of a new nematode problem while attempting to control the first one. The advantages of rotation include 1) reduction in use of chemical nematicides, 2) improved soil structure, pH, and fertility, 3) control of perennial weed problems, 4) reduction in virus reservoirs, 5) eradication of certain soil-borne pathogens and insect pests, and 6) economic return from the rotation crop. In Georgia, rotation with coastal bermudagrass, which can harvested for hay, is recommended to control root-knot nematodes (3). Coastal bermudagrass is a nonhost for *Meloidogyne* spp. (2); however, data for its use in a peach rotation are lacking.

Nematode problems and management for specific regions: Major apricot production occurs in California, Washington, and Utah, and major nematode problems are recognized in California only. The primary nematode problems in California apricot production include *Meloidogyne* spp., *Criconemella xenoplax, Pratylenchus vulnus,* and, more recently, *Criconema mutabile* (Taylor) (21). *Criconema mutabile* was associated with the bacterial canker complex in an 8-year-old apricot orchard established on Nemaguard rootstock, the resistant stock recommended in orchards infested with *Meloidogyne* spp. For nematode problems, other than root-knot nematode on apricot, preplant fumigation with methyl bromide is recommended. Where *Meloidogyne* spp. are the only problem, resistant rootstocks are recommended.

Cherry production can be divided among those states that produce either sweet or tart cherries (Table 1). Leading states for sweet cherry production include Michigan, California, Washington, Montana, and Oregon; and for tart cherry, Michigan, New York, Pennsylvania, Utah, and Wisconsin. Nematode problems on sweet and tart cherries in Michigan include *X. americanum, P. penetrans,* and *C. xenoplax,* all of which can be controlled with preplant and postplant nematicides (G. W. Bird, pers. comm.). Preplant nematicides include phenamiphos, 1,3-D, and DD-MENCS. Phenamiphos and oxamyl are the only postplant nematicides recommended; oxamyl can be applied to nonbearing trees only. Nematode-resistant cherry stocks are not commercially available in Michigan.

In Oregon, *P. crenatus* and *P. penetrans* have been associated with poor tree stands and off-colored foliage. Preplant soil fumigation with methyl bromide or 1,3-D is recommended. *Xiphinema* spp. vector cherry raspleaf virus (CRLV). This virus can be controlled with use of virus-free nursery stock, removal of infected trees as soon as symptoms appear, and deep soil fumigation with methyl bromide or 1,3-D (15). In New York, *P. penetrans* is an occasional problem of tart cherries; it can be controlled with preplant nematicides. Significant nematode problems have not been recognized in the other sweet or tart cherry-producing states.

Plums and prunes are grown primarily in California, Michigan, Oregon, Washington, and Idaho. Nematodes are recognized as pests, however, only in the first three states. Four nematodes are considered potential problems to plums in California, but only *P. vulnus* and *C. xenoplax* are considered major nematode pests (20). *Meloidogyne* spp. and TmRSV, vectored by *X. californicum,* can be managed with Nemaguard and Marianna 2624 rootstocks, respectively (12,35). Tolerant plum rootstocks have also been identified for *P. vulnus* (e.g., Marianna 2624); however, growers prefer to use the more susceptible peach rootstocks (Nemaguard or Lovell) because they produce better plums in sandy loam soils (19). Therefore, if nematode pests are present before orchard establishment, preplant fumigation with methyl bromide is recommended.

In Oregon, a strain of TmRSV causes girdling and stem pitting at the graft union of infected plum trees, resulting in weakened trees that may die prematurely. The disease is PBL and the vectors are *X. americanum* and *X. rivesi.* This disease has been controlled by preplant fumigation with

1,3-D or methyl bromide, use of certified virus-free nursery stock, and planting trees propagated on the virus-immune Marianna 2624 rootstock. This rootstock, however, has a shallow root system and profuse suckers (15). In Michigan, *X. americanum* vectors TmRSV and is the major nematode pest. Control practices differ from California and Oregon in the use of specific nematicides. Recommendations include preplant treatment with DD-MENCS and 1,3-D and postplant treatment with phenamiphos or oxamyl. Oxamyl, however, is recommended for nonbearing trees only.

Leading peach-producing states in 1989 were California, South Carolina, Georgia, New Jersey, and Pennsylvania, all of which have certain nematodes as pests on peach. In Pennsylvania, nematode-related problems with peach production usually appear by the 10th year, and these have been divided into two disease complexes. One complex involves predisposition of trees to winter injury and Cytospora canker. Factors that predispose trees include poor tree nutrition, orchard floor management, soil conditions, and nematodes (11). *Xiphinema* spp., *C. xenoplax*, *C. curvata*, and *Pratylenchus* spp. can be found in many orchards with winter injury and canker (11,13). The second complex involves Prunus stem pitting (PSP), which is caused by TmRSV. This virus is vectored by *Xiphinema rivesi* and *X. americanum*. In addition, many broad leaf weeds serve as hosts to both the virus and nematode vectors. Thus, broadleaf weed control is important in the mid-Atlantic region to prevent reinfestation of orchards with TmRSV and to reduce natural reservoirs of the virus. Controlling nematodes is not the sole recommendation for preventing peach tree decline in Pennsylvania, but it appears to be an effective tool. Preplant fumigation with 1,3-D is recommended but controls nematodes for only 4 years. Postplant nematicides recommended include oxamyl (nonbearing trees only) and phenamiphos (bearing and nonbearing trees).

In the fine-textured soils of northern and central New Jersey, *P. penetrans*, *P. crenatus*, and *X. americanum* can cause problems on peach. *Criconemella xenoplax* is the major nematode pest in southern New Jersey where 95% of the peaches are grown. This nematode predisposes trees to the PTSL disease complex. *Xiphinema americanum* is occasionally troublesome in southern New Jersey. *Meloidogyne* spp. generally are not a problem on peach in New Jersey. Chemical control recommendations for all nematodes include preplant fumigation with 1,3-D + chloropicrin or DD-MENCS. Methyl bromide is recommended for preplant spot treatment on replant sites only. Postplant nematicide recommendations include phenamiphos (8). Lovell rootstock is recommended in southern New Jersey. Nemaguard rootstock is not planted in New Jersey because of its inability to withstand the fluctuating temperatures that result in cold injury. Rotation is not economically feasible in New Jersey because land taxes and labor costs prevent growers from having land lay idle (J. K. Springer, pers. comm.).

Meloidogyne spp., *P. vulnus*, and *C. xenoplax* are the three major nematode pests on peach in California, Georgia, and South Carolina. Preplant fumigation with 1,3-D (excluding California) or methyl bromide are recommended. These nematicides encourage rapid tree growth but are effective for only 2–5 years, depending on the quality of the fumigation and the nematode involved. *Meloidogyne* spp. (primarily *M. incognita* and *M. javanica*) are not currently considered to be as important as *C. xenoplax* and *P. vulnus*, because damage is significant only during tree establishment and can be circumvented with the use of preplant nematicides. In addition, nematode resistance in rootstocks is available for control of *Meloidogyne* spp. but not *C. xenoplax* and *P. vulnus*. In California, *C. xenoplax* is associated with the bacterial canker complex (18), whereas *P. vulnus* reduces growth and yield (20). Both nematodes occur in the Southeast, but *C. xenoplax* is considered far more important because it is associated with PTSL (27,29). In Georgia and South Carolina, preplant fumigation with 1,3-D or methyl bromide is recommended when *P. vulnus* or *C. xenoplax* are present (4,22). Postplant, split applications of phenamiphos are recommended in Georgia and South Carolina to suppress *C. xenoplax* and reduce the incidence of PTSL (33).

A preplant and postplant nematicide treatment threshold of 50 *C. xenoplax*/100 cm^3 soil is recommended in South Carolina for prolonging tree life and maintaining productivity in orchards. Three disadvantages of using phenamiphos postplant are cost, long-term commitment by the grower, and the need for annual, multiple applications to achieve nematode control. If pest species in addition to *C. xenoplax* are present (e.g., *Meloidogyne* spp.), *C. xenoplax* is considered the more economically important nematode pest. Therefore, preplant fumigation, planting Lovell rootstock, and postplant nematicide treatments are recommended. Lovell is superior to Nemaguard rootstock in this situation because preplant fumigation controls the short-term *Meloidogyne* problem and Lovell is more tolerant of the long-term problems with *C. xenoplax*.

Alternative cultural control systems: Current research efforts in the Southeast and California have shifted toward nonchemical control. Research areas presently under investigation include the search for better rootstock resistance, cover crops, and rotation crops. Researchers in California, Georgia, and South Carolina are cooperating in the search for a peach rootstock resistant to one or all major nematode pests. Researchers in California (USDA ARS and UC–Riverside) are evaluating *Prunus* spp. and related genotypes for tolerance and (or) resistance to *Pratylenchus vulnus* and *Meloidogyne* spp. Their primary concern is *P. vulnus*, however, because peach rootstocks resistant to root-knot nematode are available. Field and greenhouse procedures have been developed for screening such germplasm to *P. vulnus*, which is one of the critical first steps in evaluating material reliably (9). Resistance to *P. vulnus* has been identified, based on nematodes per gram of dry root, trunk diameter, and reductions in calcium and magnesium in new rootlets. *Prunus* rootstocks tolerant to *Pratylenchus vulnus* included *Prunus besseyi*, *P. cerasifera*, and *P. armeniaca*.

The search for peach rootstocks resistant or tolerant to *C. xenoplax* is being conducted in Georgia (USDA ARS) and South Carolina (Clemson University). Such rootstocks would improve tree survival and allow growers to reclaim sites previously abandoned because of PTSL. The programs at both locations were initiated when sister plantings (about 144 *Prunus* lines) were established on known PTSL sites in 1983. Seedling longevity was the basis for selecting rootstocks. The advantage to this field approach is that the test seedlings are challenged with realistic disease pressure. Therefore, a resistant or more tolerant rootstock candidate could be identified and eventually replace Lovell. Disadvantages to this approach are the length of time before PTSL resistance is identified (at least 6 years) and the large amount of land required. An alternative to field testing is to evaluate *Prunus* germplasm for nematode resistance in greenhouse trials. Greenhouse techniques were developed in South Carolina and Georgia to increase the number of lines that could be elevated in a reasonable time. Inhibited nematode reproduction is the criterion used in South Carolina to measure host suitability. Results are evaluated by calculating the nematode doubling constant in degree days for a particular line and comparing it to the standard rootstocks. Individuals are retested in a series of sequential plantings to confirm any results indicating low host suitability (S. W. Westcott, pers. comm.).

In Georgia, *Prunus* species seedlings are evaluated for resistance and tolerance to *C. xenoplax* in two phases (31). Phase 1 evaluates host suitability as measured by nematode density 6 months after inoculation with 2,000 *C. xenoplax*/15-cm-d pot. Nematode density is based on number of *C. xenoplax* per gram of dry root. Selections supporting a nematode density lower than Nemaguard and lower than or equivalent to Lovell are then reevaluated in phase 2.

Phase 2 measures the capacity of the selections from phase 1 to tolerate a high initial nematode population density (Pi) (14,000 *C. xenoplax*/15-cm-d pot) in conjunction with pruning stress (28). Nematode density per gram of dry root, seedling survival, and increase in shoot length are the criteria used to make the final evaluation for resistance or tolerance.

Cover crops that can be interplanted in the tree row or tractor row and that suppress *C. xenoplax* populations are of interest. In Georgia (5) and South Carolina, several bahiagrasses (*Paspalum* spp.) have demonstrated some promise in suppressing *C. xenoplax*. Bahiagrass must be planted between rows of trees, because it is a strong competitor for water and nutrients. If bahiagrass lowers the population of *C. xenoplax* between rows during the life of the current planting, a later planting could be established in the bahiagrass centers following herbicide treatment. Former peach rows then would be planted to bahiagrass. In California, 'Cahaba' white vetch (*Vicia sativa* L.) shows promise as a nonhost of *P. vulnus* and *Meloidogyne* spp. (except *M. hapla*) when planted between rows.

Aqueous extracts from California poppy (*Eschscholzia papaver* Chamb.), select marigold species (*Tagetes* spp.), and Cahaba white vetch demonstrated nematicidal activity against *C. xenoplax* in California (39). The feasibility of applying these extracts to orchard soils is being investigated. In South Carolina (44), two perennial groundcover species, nimblewill grass (*Muhlenbergia schreberi* J. F. Gmel) and buckhorn plantain (*Plantago lanceolata* L.) suppressed *C. xenoplax* when interplanted in the tree row (41). Two advantages to this system of nematode control are that both species are perennial and they do not appear to compete excessively with peach for water and nutrients. Nimblewill is, however, susceptible to root-knot nematodes (Nyczepir, unpubl.).

Crop rotation also is being investigated for suppressing *C. xenoplax* on peach in Georgia. Crop rotation is one of the oldest methods for managing nematodes that parasitize annual crops. However, the effectiveness of crop rotation in lowering the population density of a nematode pest on a perennial plant is open to question.

Based upon the experience of a grower in central Georgia, research has begun on suppression of *C. xenoplax* with small grain crops. Host range studies with *C. xenoplax* indicate that this nematode prefers woody perennials and legumes to annuals with some exceptions (34,42,44). Little is known about the host suitability to *C. xenoplax* of small grains and row crops that are commonly planted in the Southeast. Results from a 3-year field trial in conjunction with greenhouse studies indicate that soybean (*Glycine max* (L.) Merrill) and sorghum (*Sorghum vulgare* Pers.) cultivars are good hosts for *C. xenoplax*. However, 'Stacy' wheat (*Triticum aestivum* L. em Thell) was a nonhost to *C. xenoplax* and appeared to be antagonistic via some unknown mechanism (30). The benefits to the peach grower in rotating with wheat are the monetary return while waiting to replant the land with peaches and the potential to avoid or reduce the need for preplant fumigation. However, Stacy wheat is a host for *M. incognita*, *M. arenaria*, and *M. javanica* (14). Evaluation of Stacy wheat, bahiagrass, and nimblewill grass for management of *C. xenoplax* is being initiated in peach orchards.

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