The Connecticut Agricultural Experiment Station, New Haven

New Integrated Approach for Controlling X-disease of Stone Fruits

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Despite its presence as a pest in the United States for more than 50 years, X-disease of stone fruits continues to be destructive and uncontrolled in fruit-growing areas, including many regions of Connecticut. This disease causes substantial economic losses in peach and other stone fruits, including nectarine, Japanese plum, sweet cherry, and sour cherry. Disease incidences as high as 60% and yield reductions ranging from 30% for mildly symptomatic to 80% for severely symptomatic trees have been observed in some commercial peach plantings in Connecticut.

X-disease was first observed in the eastern United States in 1933 when Stoddard found it in a Connecticut peach orchard (20). In his pioneering work, Stoddard described and named this new disease of peach, and his investigations completed a framework for understanding many of the factors associated with this disease (Figure 1) (21). Concurrent with Stoddard's work in Connecticut, workers in California described diseases of cherry and peach which had characteristics similar to X-disease (15,22). These eastern and western forms of X-disease were initially considered distinct diseases, but when strains from several regions of North America were compared experimentally, it was concluded that all were strains of the same disease (6). X-disease, in a variety of forms, has been reported in at least 26 states and three Canadian provinces (4).

At the time of its description, the causal agent of X-disease was thought to be a virus which could only be successfully transmitted by budding and grafting, not by mechanical inoculation (20,21). Mycoplasmalike organisms (XMLO) were first associated with the disease in

FIGURE 1—Photograph taken August 31, 1933 by Ernest Stoddard who described this as an "unusual peach disease...cause of trouble not yet determined". Note tattered, shot-holed peach leaves characteristic of X-disease.

FIGURE 2—Electron micrograph showing phloem cells of an X-diseased peach petiole packed with many mycoplasmalike organisms (arrows) which are 0.5 um or 1/100,000 of an inch in diameter.

1970 when they were observed in infected tissue using electron microscopy (14). These organisms comprise a relatively new class of disease agents which are similar to bacteria but which lack a cell wall and are limited to growing in the phloem of plant hosts (Figure 2). In fact, XMLO cannot survive outside of their plant hosts or insect vectors. Although attempts to culture XMLO *in vitro* have been unsuccessful, additional evidence has subsequently supported their role in X-disease including further electron microscopy (7), symptom remission after tetracycline chemotherapy (19), and eradication of XMLO in budwood by heat treatment (21).

Leaves of X-diseased peach trees are usually normal in appearance at the start of the growing season, but there is a sudden onset of symptoms by mid-summer. Leaves develop yellow or red irregular blotches and roll upward longitudinally. Discolored areas become dry and brittle and dead tissue drops out giving affected foliage a tattered appearance. Symptomatic leaves usually abscise, leaving a rosetted tuft of leaves at the terminals (Figure 1). X-disease also reduces the growth and vigor of fruiting wood from both symptomatic and non-symptomatic portions of infected trees, even in the early stages (3). Diseased trees eventually become unproductive with insipid, bitter tasting or aborted fruit; trees of any size or age can be affected. Besides direct economic losses, orchardists have the costs of removing and replacing dead or severely affected trees and the 3-4 year wait for replacements to reach commercial bearing.

Initial observations of orchard trees in Connecticut indicated that the first trees to exhibit X-disease symptoms were located at or near the edge of the orchard (20). This led to the conclusion that infection might originate from a wild host plant in the adjacent wood lot or fence row. Stoddard (20) identified chokecherry, *Prunus virginiana*, as a reservoir host of the X-disease agent on the basis of changes in foliage color similar to those exhibited by foliage of X-diseased peach. Soon thereafter, researchers speculated that the X-disease agent was transmitted from this infected wild host to peach by insects.

Over ten species of leafhoppers, small piercing and sucking insects (Figure 3), were demonstrated to transmit the X-disease agent throughout the United States (4,5,16,18). These leafhoppers are phloem feeders and they acquire

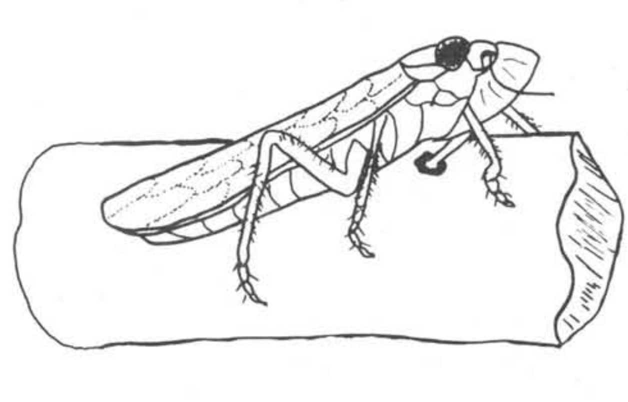

FIGURE 3—Leafhopper stylet penetrating a petiole. Note the dark ring at the site.

XMLO during feeding. The relative importance of each species is influenced by their biology, especially feeding and egg laying preferences. McClure documented the occurrence and seasonal distribution throughout Connecticut of six vector species using yellow sticky traps (10). These included *Colladonus clitellarius*, *Fieberiella florii*, *Gyponana lamina*, *Norvellina seminuda*, *Paraphlepsius irroratus*, and *Scaphytopius acutus*. These leafhoppers were most abundant in peach orchards which had wild host plants in the ground cover and at the orchard edge (11). Researchers have found that orchard blocks with the most leafhoppers generally had the most X-disease (17).

Additional experiments at the Station demonstrated the influence of ground cover type on the number of leafhoppers which visited peach trees. *S. acutus* was reported to be the most abundant and widespread vector in commercial Connecticut orchards and it was most highly attracted to red clover for both feeding and egg laying (10,11,12). McClure and co-workers (13) found that invasion of peach trees by vectors could be reduced by manipulating the type of ground cover around each tree. The greatest numbers of adults were trapped in plots with pure red clover as ground cover; significantly fewer leafhoppers, in order of decreasing number, were trapped in plots with ground covers consisting of mixed weeds of mainly roseaceous species (i.e., raspberry, strawberry), pure orchard grass, or bare ground. They speculated that reduced numbers of vectors might reduce incidence of disease, but did not test this hypothesis.

The cycle of X-disease is complex (Figure 4). Eggs of leafhoppers hatch in spring and nymphs develop on weeds at the edge of the orchard or in wood lots. These leafhoppers are thought to feed on nearby X-diseased chokecherry, the key reservoir host, where the leafhoppers acquire the XMLO. Seasonal changes in vector preferences for feeding and egg laying subsequently encourage dispersal of the adults into the orchard and stimulate movement among various ground cover species and peach trees. In addition to influencing leafhopper movement into an orchard, ground cover species (e.g., wild strawberry, wild carrot) have been implicated as reservoirs of

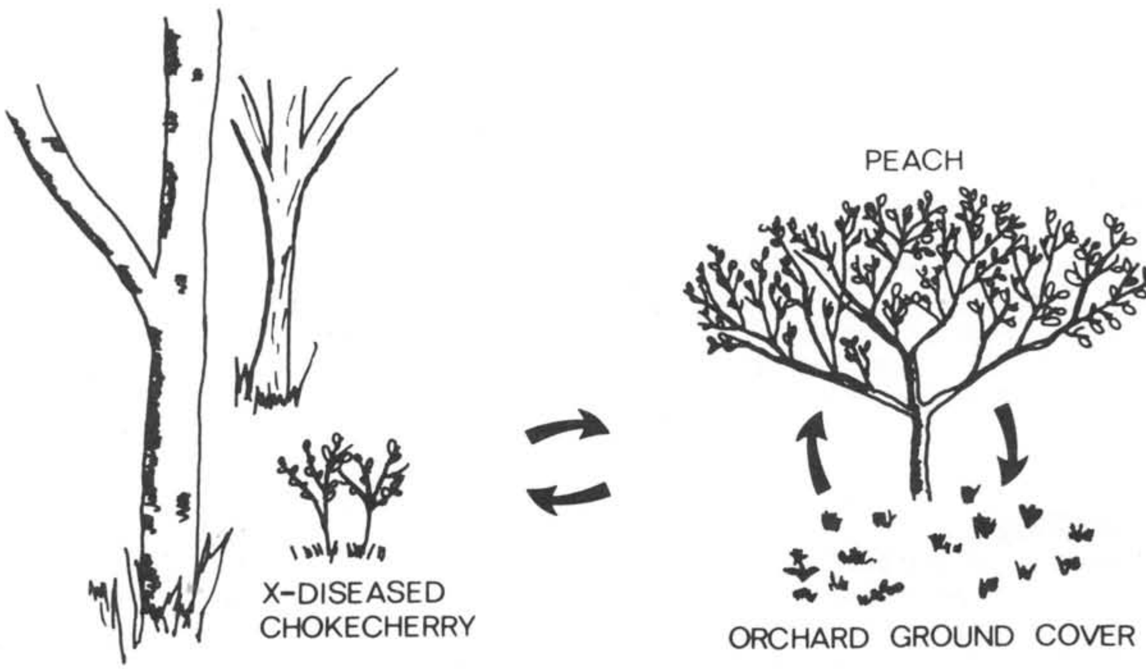

FIGURE 4—The X-disease cycle. Arrows represent the movement of leafhopper vectors from the orchard edge (X-diseased chokecherry) into the orchard and between ground cover species and peach trees.

XMLO and are thought to have important roles in the epidemiology of X-disease (1).

Past approaches to the control of X-disease have targeted the plant hosts and have not considered the insect vectors. These traditional control strategies included removing chokecherry in the vicinity of orchards (9,20,21), removing or pruning diseased orchard trees (6), and treating diseased trees with an antibiotic (19). Although these approaches have helped retard the spread of X-disease, they have not given orchardists satisfactory control. In addition to these measures, researchers have suggested management of leafhopper populations by use of insecticides (18) or by ground cover type (13), but the effectiveness of such measures in controlling disease is not known. In light of the growing need for more effective control of X-disease in Connecticut, we conducted experiments from 1981-1984 to determine the impact of manipulating ground cover type on populations of leafhopper vectors during the growing season and over a period of several years, to determine if ground cover affects vector feeding on peach leaves, and to determine if these factors influence the spread of disease.

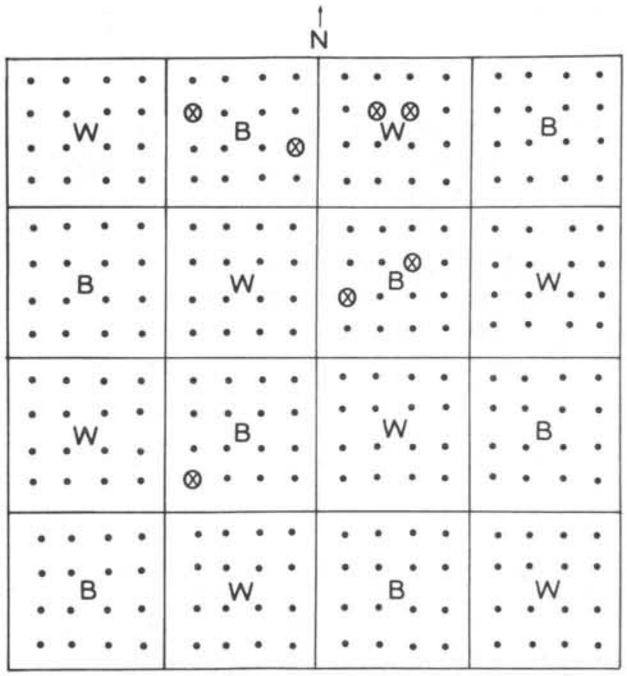

FIGURE 5—Diagram illustrating the arrangement of the experimental plot. B=bare ground, W=weedy cover; solid dots=healthy trees, and X= X-diseased trees.

MATERIALS AND METHODS

In April 1981, 256 one-year-old peach trees (cv. Blake) were planted at the Station's Lockwood Farm in Hamden, Connecticut. The experiment was set up with two treatments, bare ground and weedy cover, which were each replicated eight times so there were eight plots with weeds and eight plots with bare ground in the grid (Figure 5). Each plot measured 335 m sq. and contained 16 trees which were equally spaced 3.6 m apart. Bare ground was maintained throughout the experiment by herbicide treatments and hand weeding. Weedy cover consisted of naturally occurring plant species which were occasionally mowed during the experiment to maintain height at $\leq$ 0.5 m.

Bright yellow, sticky paper traps (Zoecon Pherocon AM Traps) measuring 23 X 28 cm (644 cm sq.), which are attractive to adult leafhoppers, were placed on stakes 1 m above the ground in the center of each of the 16 plots. Traps were replaced at 14-day intervals from June through October for a total of ten intervals each growing season. The number of each vector species was counted.

In late June and late September 1983, sweep samples were taken in each plot using a 0.5 m diameter sweep net. Each of four trees along a NW to SE transect (Figure 5) were swept five times per tree. In weedy plots, the ground cover beneath each of these four trees was also swept five times. The numbers of leafhopper vectors captured were recorded for comparison with sticky trap catches.

Leafhopper feeding damage to peach leaves was assessed once or twice each year after vector population peaks. Twenty leaves (five leaves each from four sides of a tree) were removed from each of four trees along a SW to NE transect (Figure 5) through each plot. Leaves were examined for the presence of stipling, which is evidence of leafhopper feeding. The numbers and kinds of leafhoppers observed feeding on peach leaves at the time of sampling were also recorded for comparison with sticky trap and sweep net samples.

Each August, all trees were visually assessed for symptoms of X-disease.

RESULTS

All six leafhopper vectors of X-disease previously reported in Connecticut (10) were captured during the four years of this study. Of the total 4,731 adult vector leafhoppers trapped on yellow sticky traps, 81-94% were captured in plots with weeds as compared with 6-19% in plots with bare ground (Table 1). The difference in the number of leafhoppers trapped in plots with these two types of ground cover was highly significant (R^2= 0.98) for each year. Numbers of individual leafhopper species trapped in weedy and bare ground plots followed the same pattern for total leafhoppers. *P. irroratus* was by far the most abundant species (79% of total), and *S. acutus* was a distant second (10%); each of the other vector species comprised less than 8% of the total leafhoppers trapped (Table 1).

TABLE 1—LEAFHOPPERS[1] CAPTURED ON YELLOW STICKY TRAPS IN PLOTS WITH BARE GROUND OR WEEDY COVER.

Year	Bare Ground Number	%	Weedy Cover Number	%
1981	278	19	1169	81
1982	230	15	1305	85
1983	38	6	639	94
1984	133	12	939	88

[1] Six X-disease vectors and relative abundance (%): *Paraphelpsius irroratus* (79), *Scaphytopius acutus* (10), *Gyponana lamina* (7), *Colladonus clitellarius* (2), *Norvellina seminuda* (1), and *Fieberiella florii* (1).

Data from leafhopper sticky trap catches for all four years revealed two distinct peaks of abundance (Figure 6). The magnitude of the second population peak (late September) was as much as six times greater than that of the first peak (late June). Lowest numbers of adult leafhoppers occurred during mid-August. Patterns for peaks of abundance were the same, albeit different in magnitude, whether leafhoppers were trapped in plots with bare ground or with weeds.

Numbers of vector leafhoppers collected with sweep nets from peach trees and weeds in weed-cover plots and from peach trees in bare ground plots during the two sampling periods were small (n=76). However, more leafhoppers were collected in weedy than in bare plots and more were caught in September (2nd peak) than in June (1st peak), as with sticky trap catches. Four of the six X-disease vector species were represented in these sweep samples, and patterns were similar to sticky trap catches; *P. irroratus* was the most prevalent species (75% of total). Absent from sweep samples were *F. florii* and *N. seminuda*.

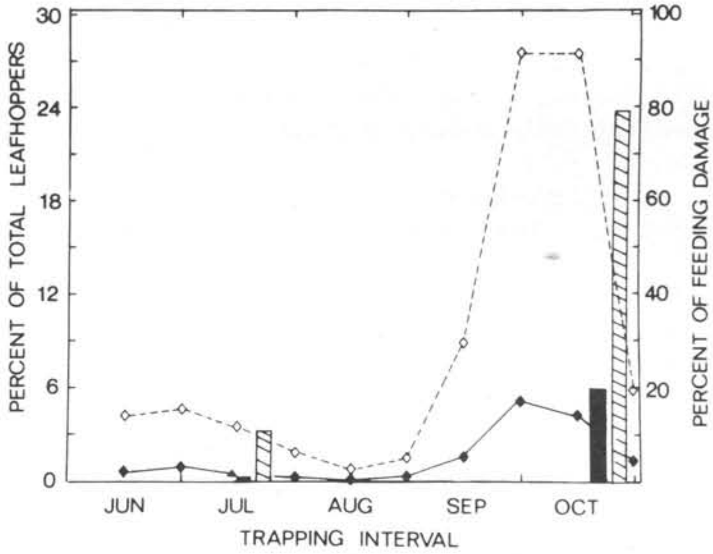

FIGURE 6—Mean seasonal abundance (1981-1984) of leafhopper vectors trapped in plots with bare ground (solid line) or weedy cover (dashed line). Bars represent amount of feeding damage to peach leaves in bare (solid bar) and weedy (slashed bar) plots.

The amount of feeding damage on leaves from trees in weedy plots was significantly greater than on leaves from trees in bare ground plots for all years of this study, regardless of when damage was assessed (Table 2). Our data defined a relationship between numbers of leafhopper vectors and amounts of feeding damage: higher numbers of leafhoppers were associated with greater levels of damage (R^2= 0.90) (Figure 7). Levels of damage were also consistent with our previous observation of two peaks of leafhopper abundance. In 1983 and 1984, the mid-summer peak accounted for only 14-22% of the cumulative damage as compared with the fall peak which accounted for 56-78% of

TABLE 2—CUMULATIVE LEAFHOPPER FEEDING DAMAGE ON PEACH LEAVES IN PLOTS WITH BARE GROUND AND WEEDY COVER. NUMBERS ARE MEANS (± S.E.).

	% LEAVES WITH FEEDING DAMAGE	
Date	Bare Ground	Weedy Cover
11/82	22.7 (±1.1)	93.3 (±1.3)
8/83	0.7 (±0.3)	9.9 (±0.4)
10/83	14.1 (±1.6)	56.9 (±2.1)
8/84	1.4 (±0.9)	9.5 (±0.5)
10/84	22.0 (±1.6)	78.3 (±1.6)

overall feeding damage (Figure 6). The mean total damage was greater in weedy than in bare plots, reflecting similar trends in numbers of leafhoppers trapped in those plots. Representatives from most of the six vector species were observed feeding on peach leaves during our study. Our observations were once again consistent with data from sticky trap and sweep net catches. *P. irroratus* was most commonly observed (82% of total), followed by *S. acutus* (9%). Other leafhoppers not known to vector X-disease were also observed on peach foliage and captured on sticky traps, but their numbers were few compared to vector leafhoppers.

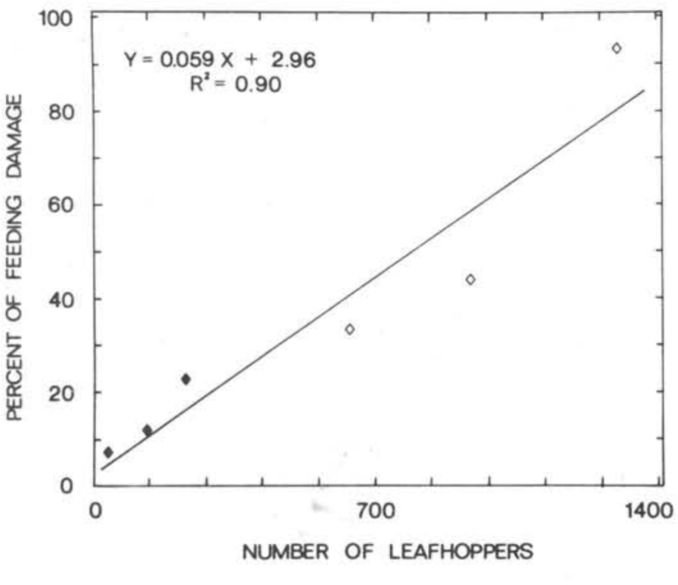

FIGURE 7—Relationship between number of leafhoppers trapped in plots with bare ground (solid diamond) and weedy cover (open diamond) and amount of feeding damage on peach leaves.

The number of trees with symptoms of X-disease by August 1985 was too small in both weedy (2 trees) and bare ground (5 trees) plots to determine significant differences. However, four out of five of the trees with X-disease symptoms in bare ground plots were border trees, located next to weedy plots (Figure 5).

DISCUSSION

Our study reaffirmed the importance of ground cover type to the size of leafhopper vector populations. But, more importantly, it established a relationship between leafhopper numbers and amount of feeding damage to peach leaves: higher numbers of vectors were associated with greater amounts of feeding damage. These findings emphasize the need to adopt a more integrated approach for controlling X-disease than has traditionally been undertaken. Such an approach includes both cultural and chemical measures and takes into account not only the disease agent and its numerous plant hosts but, for the first time, also includes the leafhoppers which carry and vector XMLO.

The low incidence of X-disease (3%) in the four years of our experiment is not unusual. For example, our results are consistent with observations from several commercial orchards of similar age and over a similar period of time which revealed 4% of the trees had X-disease in 4 years (Douglas, unpublished). When evaluating the importance of a disease such as X-disease that has an apparently low infection rate, it is necessary to consider that peach treees are perennial and once infected, will remain infected until death. Consequently, small numbers of new infections each year can effectively reduce productivity by shortening the normal lifespan of a peach block. In this light, all efforts aimed at interrupting the X-disease cycle are important for disease control.

Some of the cultural control measures that have been used for years are important components of our integrated approach. Removal of X-diseased chokecherry within 152 m of a peach planting (9,20,21) and removal of diseased peach trees or pruning of affected parts (6) continue to be prudent practices for reducing the X-disease inoculum in and about the orchard.

Results of this and previous studies (11,12,13) reveal that management of ground cover in the orchard is also an effective cultural measure for reducing leafhopper vector populations and feeding damage to peach. In general, vector leafhoppers thrive in ground covers that are comprised mostly of red clover or roseaceous species (e.g. raspberry, strawberry). All vector leafhoppers are discouraged from invading the orchard if unfavorable conditions for leafhoppers are maintained in the orchard floor by regular mowing, by planting unsuitable host species, or by keeping the ground bare through use of herbicides and by weeding. All species except *P. irroratus* also find a cover of pure orchard grass highly unsuitable for their needs (12). Studies have shown that the condition of the orchard floor directly beneath each peach tree is important because leafhopper movements between peach trees and ground cover species in response to feeding and breeding preferences are localized (13). These cultural measures will provide the additional benefit of eliminating potential reservoirs of XMLO which are apt to be common in the herbaceous weedy ground cover of a peach orchard. Our results have also shown that maintaining bare ground beneath peach trees gives the added advantage of enhancing growth and yield by eliminating competition for moisture and nutrients from ground cover. In fact, mean trunk diameter measurements (1985) for trees in plots with bare ground were 6.6 cm as compared with 3.6 cm for their weedy counterparts.

Earlier studies have shown that vector leafhoppers overwinter in the leaf litter and mature on the weedy and woody vegetation (primarily roseaceous plants) at the edges of the orchard in the spring (10,11,12). This coincides with the time during which detectable levels of XMLO are present in diseased chokecherry (2). In June, adult leafhoppers, some of which are probably carrying XMLO, invade the orchard and colonize both peach trees and ground cover species. Removal of the leafhoppers' spring hosts (especially roseaceous species) from the orchard edge is another important cultural control practice aimed at reducing vector populations before they enter the orchard.

Several chemical control measures targeting either the disease agent or the vector leafhoppers complement these cultural practices in our integrated control scheme for X-disease. Antibiotics, in particular oxytetracycline-HCl used annually as a tree injection (19), prolong the productive life of diseased trees. Other chemical procedures for reducing the spread of X-disease involve insecticides which target vector leafhoppers (8). Most routine insecticide treatments of peach trees are applied between petal fall (May) and harvest (August). These treatments probably have minimal effects on leafhoppers present in the ground cover or at the orchard edge and essentially leave no residual on peach trees after harvest. Since results of this and previous studies (10-13) have shown that weedy species in and around the orchard harbor high numbers of leafhoppers, periodic insecticide treatments of weedy ground cover and of weedy vegetation at the orchard edge should reduce numbers of vector leafhoppers.

Our study also showed leafhopper densities and feeding damage on peach were much higher in September and October following harvest than at any other time of the year. Even if only a small percentage of these leafhoppers are actually carrying XMLO, this period should be important for the spread of X-disease because of the intensity of feeding. Therefore, insecticide applications in and about the orchard during peak leafhopper activity in early autumn could be another effective means of reducing leafhopper numbers and presumably, the spread of X-disease. These autumn treatments would also reduce the number of overwintering eggs and in so doing, reduce the number of nymphs developing at the orchard edge the following spring.

Briefly, the seven measures available for the orchardist include: 1) removal of chokecherry; 2) removal and pruning of X-diseased peach; 3) removal of spring hosts of leafhoppers (especially roseaceous species) at the orchard edge; 4) management of orchard ground cover during the growing season by planting unsuitable species for leafhoppers, by mowing, and by herbicide treatments; 5) periodic insecticide sprays applied to ground cover during the growing season; 6) antibiotic injections of peach; and 7) additional insecticide sprays to peach trees after harvest (during September and October).

Because of the complexity of the X-disease cycle, we cannot expect to effectively control the disease with a simple solution. We are continuing to unravel the mysteries of the complex system involving the X-disease mycoplasmalike organism, its vector leafhoppers and the numerous plant species including peach, which they share. Until then, the multifaceted approach for controlling X-disease that integrates both cultural and chemical measures may help us to continue to grow peaches in the midst of this destructive disease.

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