Effect of Black Knot Incidence on Yield of Stanley Prune Trees and Economic Benefits of Fungicide Protection

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ABSTRACT

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Captan, benomyl plus captan, zineb plus captan, thiophanate-methyl, ferbam plus sulfur, and dichlone, applied to 3-yr-old Stanley prune trees in seasonal spray programs for black knot control, resulted in black knot infection of 14, 20, 5, 36, 14, and 7% of total limb length, respectively, compared with 52% in untreated controls. Yield was measured the season following infection, and a regression equation was developed to relate yield to tree size and severity of black knot infection. Economic benefits of fungicides were calculated after fungicide and application costs were deducted. Zineb plus captan sprays applied during a single epidemic season could save $8,533/ha in subsequent losses attributable to black knot, but economic benefits of fungicides applied on an annual basis would be diminished by the infrequent occurrence of conditions favoring severe black knot epidemics.

Additional key words: *Dibotryon morbosum*

Black knot, caused by *Dibotryon morbosum* (Sch.) Th. & Syd., is a disease affecting numerous *Prunus* spp., including peaches, prunes, cultivated cherries, and numerous species of wild cherries (4,8). The disease was investigated extensively by Koch (5–8), who described the symptoms and control measures and reported on the life history and naturally occurring mycoparasites of the pathogen. Removal of black knots during pruning is commonly recommended to reduce inoculum, but fungicides are also needed because some inoculum escapes detection and additional inoculum may reach the orchard from outside sources. Koch (5) showed that removing knots during pruning provided more than 80% reduction in infection, and adding three sprays of lime sulfur improved control to 95%. Lewis et al (9) and Rosenberger and Meyer (11) reported that zineb effectively reduced infection by *D. morbosum*, but Ritchie et al (10) reported that benomyl and thiophanate-methyl were more effective than zineb. None of the published reports indicate the effects of black knot infection on yield.

The fungicides benomyl, captan, and zineb have proven highly effective when used on plums and prunes in the eastern United States to control black knot and brown rot blossom blight caused by *Monilina fructicola* (Wint.) Honey. (Although zineb has been widely recommended for controlling black knot, there is currently no federal registration for use of zineb on plums and prunes.) The U.S. registrations for these fungicides were recently reevaluated by the Environmental Protection Agency. The reevaluation of registrations involved Rebuttable Presumptions Against Registration (RPAR), which required an analysis of potential risks and benefits inherent in continued use of the pesticides in question. This study was conducted to determine the effect of black knot infection on yield, determine the economic benefits of using fungicides for black knot control, and evaluate registered alternatives for the fungicides subject to RPAR.

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MATERIALS AND METHODS

During 1981, seasonal fungicide programs were compared in a block of Stanley prunes on Myrobalan rootstocks planted in 1978. Treatments were applied to single-tree plots in a randomized block design with four replicates. Sprays were applied to runoff using a handgun at prebloom, white bud, bloom, and petal fall on 16, 22, and 28 April and 5 May, respectively. Cover sprays were applied on 14 and 27 May and 5 and 16 June. The first spray and the last three sprays were applied primarily for black knot control, whereas sprays applied on 22 April through 14 May were needed for both brown rot and black knot (1).

Fungicides tested were captan (Captan 50W), benomyl (Benlate 50W), thiophanate-methyl (Topsin-M 4F), zineb (Zineb 75W), dichlone (Dichlone 50WP), ferbam (Carbamate 76W), and sulfur (Kolospray 81W). Captan was tested alone and in combination with benomyl. Benomyl is more effective than captan for controlling black knot and brown rot where no benomyl-resistant pathogens are present. Use of a contact fungicide with benomyl is commonly recommended, however, to prevent or delay development of benomyl-resistant pathogens. A captan-zineb combination spray was tested because captan controls brown rot and zineb controls black knot. Neither fungicide is considered adequately effective for both pathogens. Thiophanate-methyl, ferbam plus sulfur, and dichlone were tested because they were the registered fungicides that would most likely be used if registrations for benomyl and captan were withdrawn as a result of the RPAR process. Dichlone is registered for use only through petal fall. In this test, it was applied in four sprays after petal fall to allow evaluation of its effectiveness in controlling black knot.

To increase inoculum in the test orchard, black knots were placed in wire-mesh baskets 2 m above the ground in the center of each tree on 7, 13, and 20 April and 8 and 27 May. Knots placed in baskets in April were collected from local prune orchards and for unknown reasons produced relatively few ascospores. Knots used in May were collected in Virginia and produced abundant ascospores.

Trees were pruned according to commercial standards in March 1982. Total yield for each tree was determined by harvesting and weighing all fruit on 1 September 1982. Trunk diameters 30 cm above the soil line and the length of all branches and limbs were measured after pruning in spring of 1982. The latter measurement represented the total limb length available both for infection during the 1981 season and observation of symptom development during 1982. In this and all subsequent measurements of limb length, spurs shorter than 4 cm were not included.

Trees were evaluated for black knot infection in spring of 1983 by removing all knots during pruning (as commonly recommended for commercial growers). The following measurements were taken after pruning: 1) total length of 1981 (or older) wood removed in the process of removing the black knots; 2) total limb length actually infected with knots; and 3) number and length of distinct, individual knots that resulted from single infections. The 1982 growth was not included in evaluations because it was not available for black knot infection in 1981, when the infections being evaluated were initiated.

Many sections of limbs were so severely infected that numerous knots merged to produce lengthy sections of infected limb and the number of individual infections could not be determined. The number of original infections was estimated for such areas by determining the average length of distinct individual infections in each tree (using data from 3 in the previous paragraph) and dividing the total length of infected limb by the mean knot length for that tree. The individual knots and the calculated number of infections from limbs with merged infections were totaled and reported as the number of infections per tree.

RESULTS

Field research. Fifteen wetting periods exceeding 8 hr and with temperatures higher than 8 C occurred between prune bud burst and cessation of terminal growth in late June 1981. A few swellings and developing black knots were evident on unsprayed check trees by October 1981, and occasional knots were visible on some treated trees. The true extent of infections in the inoculated trees did not become evident, however, until blossom time in 1982, when trees showed distinct swellings where black knot stromata were developing beneath the epidermis. Severely affected trees produced few blossoms. At full bloom, differences in blossom density caused by differing levels of black knot infection were clearly evident.

Because of variation in tree size in the test orchard, evaluations based on numbers of knots per tree and total lengths of limbs infected and lost by pruning were less meaningful than other comparisons that compensated for tree size (Table 1). In comparisons of the percentage of limb length infected and percentage lost in removing knots, the zineb plus captan combination proved most effective; however, results with captan, zineb plus captan, and ferbam plus sulfur were not significantly different in number of infections per meter of limb. Zineb plus captan was comparable to captan alone on a yield-per-tree basis but was significantly better than any other treatment when yield was compared on the basis of trunk cross-sectional area or meters of bearing surface per tree (Table 2).

Relationships between 1982 yield and black knot infection values were determined by regression analysis of the results from individual trees. Very low or zero yield values for the heavily infected trees in untreated and thiophanate-methyl plots did not fit the straight-line relationship obtained for the other, less severely affected trees. With severely affected trees removed, all regression analyses produced coefficients significantly different from zero. Regression analysis of yield per meter of tree limb, as affected by percentage of limb length infected, resulted in an R^2 of 0.55. However, yield per tree was influenced more by total limb length alone ($R^2 = 0.44$) than by degree of black knot infection alone ($R^2 = 0.26$). Multiple regression using limb length and percentage of limb infected as independent variables resulted in an R^2 of 0.72. The R^2 increased to 0.79 when trunk cross-sectional area was also included as a further measurement of tree size. However, in the equation resulting from the latter analysis, increases in cross-

Table 1. Effectiveness of various black knot fungicide programs applied to Stanley prunes as determined by infection counts and by measures and proportions of limb length infected and removed

	Mean number of infections[w]		Length (m) of limbs[x]		Percentage of 1981 limb length[y]	
Material and rate per 100 L (100 gal)	**Per tree**	**Per meter of limb**	**Infected, with knots**	**Lost by removing knots**	**Infected, with knots**	**Lost by removing knots**
No fungicide	1,416 c	24.0 d	30.6 c	59.8 b	52.3 e	100.0 d
Captan 50W, 240 g (2 lb)	228 a	3.1 ab	10.6 ab	52.5 b	14.2 bc	71.3 b
Benomyl 50W, 30 g (4 oz) + captan 50W, 120 g (1 lb)	465 ab	7.1 b	13.4 ab	57.3 b	20.1 c	91.1 c
Zineb 75W, 240 g (2 lb) prebloom Zineb 75W, 120 g (1 lb) + captan 50W, 120 g (1 lb)	80 a	1.3 a	3.0 a	24.2 a	4.5 a	38.4 a
Thiophanate-methyl 4F, 87.5 ml (11.2 fl. oz)	772 b	15.2 c	18.4 b	47.2 ab	36.0 d	99.6 d
Ferbam 76W, 240 g (2 lb) prebloom Ferbam 76W, 120 g (1 lb) + sulfur 81W, 360 g (3 lb)	239 a	4.1 ab	8.0 ab	37.1 ab	13.5 b	64.9 b
Dichlone 50W, 30 g (4 oz)	282[z]	3.4	6.0	35.8	7.2	42.8

[w] See text for method used to determine the number of infections. Means within columns followed by the same letter are not significantly different ($P = 0.05$).

[x] Determined by measuring lengths of infected limb and lengths of 1981 or older wood removed when knots were removed from trees after the 1982 season.

[y] Determined by dividing lengths of infected limb and lengths of limbs removed during pruning after the 1982 season by the total limb length evaluated for knot development.

[z] Dichlone treatments were not included in analyses because two replicates were missing.

sectional areas have a small negative effect on yield. This unexpected result may have occurred because some of the trees with large trunks were heavily infected with black knot and therefore had small yields. The regression equation used for further calculations of economic losses attributable to black knot is

$$Y = 14.08 + 0.35\ TLL - 0.99\ PLLI, \quad (1)$$

where Y is yield (kg/tree), TLL is total limb length, and $PLLI$ is percentage of limb length infected.

Economic analysis. For economic analyses of the value of various fungicides for plums and prunes, disease incidence from our field trials were combined with the average production and returns to growers to calculate potential savings attributable to use of the fungicides in a mature orchard. Average production for bearing prune acreage (trees at least 4 yr old) in New York State is about 14.44 t/ha (230 bu/acre). This figure was derived using statistics from the 1980 New York Orchard and Vineyard Survey (12): 102,110 total prune trees on 1,276 acres produced 154,000 bu in 1980. However, 18.7% of the trees included in the survey were less than 4 yr old and could therefore be considered nonbearing because they would contribute little to the state's total production. If the 83,015 bearing trees produced 154,000 bu, the average production per tree was 1.86 bu or 47.24 kg (1 bu = 56 lb = 25.4 kg). For convenience and because state statistics include some old and virtually abandoned orchards, we used 2 bu or 50.8 kg/tree as an average yield. About 125 trees are usually planted per acre and we used 250 bu/acre or 15.691 t/ha as the average yield for mature prune orchards. The average 1982–1983 wholesale price for prunes in New York State was about $314.92/t ($8.00/bu). With the average production of 15.691 t/ha, the average gross income per hectare of prunes would be $4,942 ($2,000/acre). Thus, subsequent calculations of disease loss and savings with fungicides are based on maximum potential income of $4,942/ha/yr.

Pesticide costs used in the economic analysis are retail prices quoted by agrichemical distributors for 1983. Chemical costs per hectare per application were calculated using the cost of materials required to mix 2,806 L of spray because that is the standard volume recommended per hectare (equivalent to 300 gal/acre) for dilute stone fruit sprays. Application costs (fuel, labor, and equipment) of $21.25/ha ($8.60/acre) per application were also included in the cost of disease control (3). Where fungicide applications served for both black knot and brown rot control (white bud, bloom, petal fall, and shuck-split sprays), the fungicide prices and application costs were divided evenly between the two diseases (Table 3).

Potential yield losses attributed to black knot in an average mature orchard were calculated using equation 1. The intercept coefficent of equation 1 (14.08) along with the TLL term and coefficient (0.35) represent yield without the influence of disease. Because we know the average yield (Y) in New York is 50.8 kg/tree, equation 1 can be rewritten as

$$Y = 50.8 - 0.99\ PLLI. \quad (2)$$

This equation was used to determine the average yield to be expected from mature trees with the same severity of black knot infection observed in our field trial (Table 4). First-year losses attributable to black knot were determined by subtracting the value of the calculated crop for each treatment from the maximum potential value of $4,942/ha.

Black knots must be removed from trees during pruning to prevent further disease spread in subsequent years.

Table 2. Effectiveness of various black knot fungicide programs applied to Stanley prunes as determined by subsequent effects on tree yield

Material and rate per 100 L (100 gal)	Mean 1982 yield[w] kg/Tree	g/cm² Of trunk cross section[x]	g/m Of limb[y]
No fungicide	0.2 d	4 d	3 d
Captan 50W, 240 g (2 lb)	29.5 ab	584 ab	386 b
Benomyl 50W, 30 g (4 oz) + captan 50W, 120 g (1 lb)	14.1 c	339 c	246 c
Zineb 75W, 240 g (2 lb) prebloom Zineb 75W, 120 g (1 lb) + captan 50W, 120 g (1 lb)	33.6 a	802 a	531 a
Thiophanate-methyl 4F, 87.5 ml (11.2 fl oz)	0.9 d	28 d	30 d
Ferbam 76W, 240 g (2 lb) prebloom Ferbam 76W, 120 g (1 lb) + sulfur 81W, 360 g (3 lb)	20.1 bc	438 bc	347 bc
Dichlone 50W, 30 g (4 oz)[z]	23.7	377	365

[w] Fresh weight of fruit at harvest, 1 September 1982. Means within columns followed by the same letter are not significantly different ($P = 0.05$).
[x] Determined from autumn 1982 trunk diameters measured 30 cm above the ground.
[y] Limb length as determined at the start of the 1982 season.
[z] Dichlone treatments were not included in analyses because two replicates were missing.

Table 3. Costs of the seasonal black knot fungicide programs as determined from fungicide prices and application costs

Material and rate per 100 L (100 gal)	Pesticide cost per application[x] $/ha	$/acre	Number of sprays applied	Cost partitioning of applications[y] Black knot	Brown rot	Total cost of season-long control program[z] $/ha	$/acre
Check	0	0	...	...	...	0	0
Captan 50W, 240 g (2 lb)	22.54	9.12	8	6	2	262.72	106.32
Benomyl 50W, 30 g (4 oz)	22.98	9.30					
+ captan 50W, 120 g (1 lb)	11.27	4.56	8	6	2	332.99	134.76
Zineb 75W, 240 g (2 lb)	31.13	12.60	1	1	0		
Zineb 75W, 120 g (1 lb)	15.57	6.30					
+ captan 50W, 120 g (1 lb)	11.27	4.56	7	5	2	292.81	118.50
Thiophanate-methyl 4F, 87.5 ml (11.2 fl oz)	32.74	13.25	8	6	2	323.95	131.10
Ferbam 76W, 240 g (2 lb)	30.39	12.30	1	1	0		
Ferbam 76W, 120 g (1 lb)	15.20	6.15					
+ sulfur 81W, 360 g (3 lb)	6.67	2.70	7	5	2	267.24	108.15
Dichlone 50WP, 30 g (4 oz)	11.93	4.83	8	6	2	199.11	80.58

[x] Based on 1983 retail pesticide cost and application of 2,806 L of spray per hectare (300 gal/acre).
[y] Sprays at white bud, bloom, petal fall, and shuck-split were partitioned evenly between black knot and brown rot; the single prebloom and three additional cover sprays were solely for black knot control.
[z] Total pesticide cost (number of applications for black knot control multiplied by pesticide cost per application) plus total application costs of $127.50/ha ($51.60/acre) for the six black knot sprays.

Considerable bearing surface may be lost when knots are removed from heavily infected trees. Because prune and plum trees bear fruit mostly on wood 2 yr old or older and because more than one growing season is required to grow replacement limbs, we estimate that an average of 1.5 growing seasons would be required to regenerate the bearing surface removed with the black knots. Thus, removal of black knot infections precipitates yield losses that extend into the second and third growing season after infections occur. These losses were estimated by multiplying the percentage of total limb length removed with knots by 1.5 (subsequent growing seasons required for regeneration) by the maximum potential yield ($4,942/ha). The total potential loss from a single year's infection (Table 4) includes both the first year's losses caused by reduced vigor in the infected tree and second and third years' losses caused by removal of bearing surface during black knot removal.

Savings attributable to black knot fungicides are calculated by subtracting a single-year's fungicide and application costs from the potential savings (loss in the check plots minus loss in the treatment) that accrue over 3 yr. These figures may be unrealistic, however, because black knot infection varies from year to year and only infrequently is as severe as in our trial. Ideal infection conditions such as those we had in this trial may occur only once every 5–8 yr. Realistic estimates of the economic benefits of fungicides must be adjusted to account for the estimated frequency of black knot epidemics. Because growers cannot know in advance which years fungicides are needed, they apply fungicides every year and the costs of these annual sprays must be subtracted from savings accrued in years when sprays are really beneficial. Frequency-adjusted annual savings were therefore calculated by dividing savings from epidemic years by the number of years in the interval and subtracting the cost of black knot sprays for the entire interval (Fig. 1). In calculating frequency-adjusted benefits of black knot control, the four sprays applied for both black knot and brown rot were not included as black knot costs, because these sprays would be applied for brown rot even if growers knew black knot was not a threat. The partitioned spray costs (Table 3) were still used for the single year in which black knot occurred.

Of the three fungicides subject to RPAR, only zineb proved important for black knot control. Substituting dichlone for zineb would result in greater frequency-adjusted annual savings (Fig. 1) because of lower fungicide cost. However, dichlone is labeled for application only until petal fall because of potential phytotoxicity when applied later in the season. The next-best alternative, ferbam plus sulfur, was less cost-effective than zineb.

DISCUSSION

Field experiments. Black knot infection in our trials was evaluated in several ways because we were uncertain which method of measuring infection would prove most useful. The number of infections per tree used in some reports (9,10) proved less useful in our trial because our trees were relatively small and size variations among the trees contributed to large variations in the number of knots within treatments. Comparisons of healthy and infected limb lengths proved most useful because it compensated for variations in tree size.

Black knot infections in our trial were extremely severe because of the inoculum

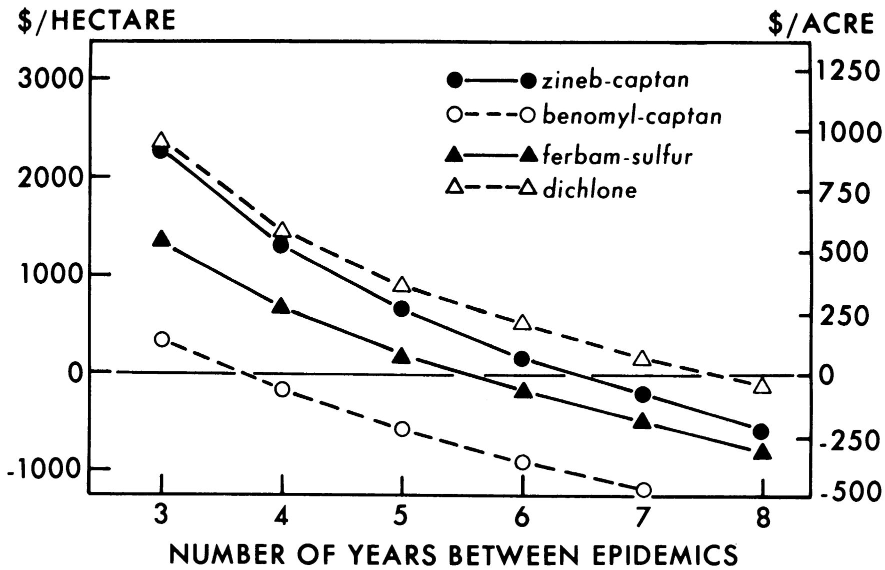

Fig. 1. Annual savings attributable to four black knot fungicide programs as affected by the occurrence frequency for black knot epidemics.

Table 4. Calculations of the value of yield losses attributable to black knot and economic benefits of fungicides in a mature prune orchard based on observed disease incidence in experimental trees sprayed with various fungicides

Material and rate	Observed limb length infected	Calculated yield for similarly diseased mature trees[v]		Crop value[w]		Crop loss				Total potential loss from single-year's infection[y]		Economic benefit from fungicide programs[z]	
						First year		Subsequent years[x]					
per 100 L (100 gal)	(%)	t/ha	bu/acre	$/ha	$/acre	$/ha	$/acre	$/ha	$/acre	$/ha	$/acre	$/ha	$/acre
No fungicide	52.3	−0.302	−5	99	401	4,843	1,960	7,413	2,940	12,256	4,900	···	···
Captan 50W, 240 g (2 lb)	14.2	11.349	191	3,578	1,448	1,364	552	5,285	2,139	6,649	2,691	5,197	2,103
Benomyl 50W, 30 g (4 oz) + captan 50W, 120 g (1 lb)	20.1	9.545	152	3,005	1,216	1,938	784	6,753	2,733	8,691	3,517	3,084	1,248
Zineb 75W, 240 g (2 lb) prebloom Zineb 75W, 120 g (1 lb) + captan 50W, 120 g (1 lb)	4.5	14.315	228	4,507	1,824	435	176	2,847	1,552	3,282	1,328	8,535	3,545
Thiophanate-methyl 4F, 87.5 ml (11.2 fl oz)	36.0	4.683	75	1,483	600	3,480	1,480	7,383	2,988	10,863	4,396	922	383
Ferbam 76W, 240 g (2 lb) prebloom Ferbam 76W, 120 g (1 lb) + sulfur 81W, 360 g (3 lb)	13.5	11.563	184	3,637	1,472	1,305	528	4,811	1,947	6,115	2,475	5,725	2,317
Dichlone 50W, 30 g (3 oz)	7.2	13.489	215	4,250	1,720	692	280	3,173	1,284	3,865	1,564	8,043	3,244
Theoretical perfect control	0	15.692	250	4,942	2,000	0	0	0	0	0	0	···	···

[v] Calculated from the observed limb length infected and Eq. 2: $Y = 50.8 - 0.99\ PLLI$.
[w] Calculated from $314.94/t ($8.00/bu).
[x] Potential crop value of $4,942/ha multiplied by percentage of limb length removed in pruning out knots and by 1.5 yr, estimated time required to regenerate bearing wood.
[y] Sum of losses from first and subsequent year.
[z] Determined by subtracting cost of the fungicide program (Table 3) from difference in losses between treatments and the untreated control.

placed in each tree. The failure of even the best treatment to provide perfect control in this and in other trials (9,11) emphasizes the need for sanitation in addition to fungicide sprays. Inoculum production as determined by spore trapping (D. A. Rosenberger, *unpublished*) is extremely variable from year to year and from orchard to orchard. This variability is illustrated by the poor spore production in locally collected knots in 1981 compared with profuse spore production in knots from Virginia. In some cases, poor spore production may be attributable to use of benzimidazole fungicides, which inhibit ascospore development (10), but other unidentified factors such as mycoparasites (4,6) may also be involved. The variability in spore production with occasional peak production years may contribute to the sporadic nature of black knot outbreaks observed in commercial orchards.

Our results confirmed those of earlier trials (9,11) in which zineb was the most effective black knot fungicide. We cannot explain why benomyl and thiophanate-methyl proved effective in Michigan (10) but were less effective in this trial and a previous trial in New York (11). We did not test for benomyl resistance in our inoculum, but involvement of resistant isolates was not likely because the heavily sporulating inoculum from Virginia used in this trial came from an unsprayed, backyard tree. The efficacy of ferbam, captan, and dichlone was comparable to that reported in Pennsylvania (9).

The regression equation relating yield to limb length and percentage of infection provides a useful relationship for evaluating yield loss attributable to black knot. The equation, however, was derived from trees in a single size and age group and used results from a single season's infections. Because yield loss in kilograms decreases in an almost 1:1 relationship with percentage increase in infection, we suspect the equation would not hold for all sizes of trees. When infection exceeds 51% of limb length, the equation predicts negative yields (see control treatment, Table 4). Thus, the equation is valid only for trees with less than 51% of limb length infected.

Sporodochia of *Nectria cinnabarina* were observed around knots on several severely infected trees, and one check tree developed silver leaf caused by *Chondrostereum purpureum*. Invasion of weakened trees and pruning cuts by these organisms or by other wood-decay fungi can shorten tree life even after black knots are removed. Long-term losses attributable to secondary invaders that enter trees during black knot epidemics should be considered when evaluating disease losses attributable to black knot but were not included in our economic analysis.

Economic analysis. Numerous assumptions were necessary throughout our economic analyses, and extrapolating from a single experiment is obviously risky. The precise size of losses attributed to black knot varies with the wholesale price of prunes, frequency of epidemics, yield per hectare, and the costs of pesticides and their application. Potential losses are likely to remain high, however, because a single season's black knot infection reduces production for 3 yr. On the basis of our results, the use of zineb as a fungicide for black knot control could save prune and plum growers $2,810/ha ($1,137/acre) in a single epidemic year compared with the use of a ferbam plus sulfur control program. Losses caused by black knot would be somewhat lower if dichlone were used until petal fall. Although plums and prunes are a minor crop in the eastern United States, a savings of $2,810/ha would lead to a savings of $8.4 million for the 3,000 ha of plums and prunes in New York and Michigan (2,12).

The lack of quantitative information on costs and benefits of sanitation in black knot control precludes evaluation of the economic value of sanitation. Undoubtedly, most serious growers would not willingly allow inoculum levels to build to the levels we introduced in our trial. However, black knot is often present in wild *Prunus* in hedgerows, and small numbers of infections may be difficult to locate and remove from mature trees. We have also seen several commercial orchards where inoculum levels exceeded those in our trial, either through carelessness or failure to recognize and remove knots or because growers decided the cost involved in removing knots made it economically unfeasible. The frequency of epidemic conditions may be significantly affected by the effectiveness of sanitation measures. To improve the accuracy of our frequency-of-occurrence estimate, however, more data are needed both on factors affecting ascospore production and on effectiveness of sanitation measures in preventing initial inoculum buildup.

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