Evaluating Economic Losses Caused by Pathogens of Fruit and Nut Crops

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ABSTRACT

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Optimal decisions on crop management, fungicide regulations, and research priorities cannot be made without reliable estimates of economic losses caused by plant pathogens. The major obstacle preventing a more accurate assessment of these losses is lack of information about the biological effects of the pathogens on crops. Several approaches can be used to calculate the economic losses of an individual producer of fruit and nut crops. In many cases, the best estimate of economic losses caused by pathogens of fruit and nut crops is a measure of the reduction in the grower's net profits discounted over the remaining life of the orchard. This approach is used to calculate approximate losses from Prunus ringspot virus in a newly planted peach orchard.

Reliable estimates of economic losses caused by plant pathogens are not only a prerequisite for optimal crop management at the farm level but also are basic to decisions on broader issues such as research priorities and pesticide regulations. Some may think that such calculations are better left to agricultural economists and need not concern plant pathologists, but the utility of economic estimates depends on the accuracy and appropriateness of the data supplied by plant pathologists. Currently, the major obstacle preventing more accurate assessment of monetary losses attributable to plant pathogens is insufficient information about the biological effects of the pathogen on the host. Data inadequacies are particularly acute in the case of perennial crops, where intertemporal effects operate (ie, because a perennial plant lives for more than 1 yr, its condition in any given season is likely to influence its future condition).

We discuss several conceptual approaches to evaluating economic losses caused by pathogens of fruit or other perennial crops. We hope to clarify the many factors that must be considered and the type of data that must be gathered if existing estimates are to be improved. We emphasize the assessment of an individual grower's losses to provide a basis for generalizations. However, methods for aggregating economic losses (eg, on a local, regional, or industry basis) and for evaluating losses at higher positions in the marketing chain (eg, wholesale or retail) may differ from the procedures outlined here. This issue is addressed briefly.

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Models for evaluating economic losses of individual producers. An individual producer's economic loss attributable to a pathogen is the decrease in net profits caused by the pathogen. This measure applies to any pathogen (fungus, bacteria, virus, or other). Although the concept is straightforward, problems arise in calculating this quantity.

A simplistic way to approximate the change in net profits caused by a plant pathogen is to measure the change in gross receipts during a single season. Assuming for illustrative purposes that the pathogen primarily affects yield rather than quality, this approach estimates economic loss by

$$\Delta R_1 = P_t(Y_{et} - Y_{at}),$$

where ΔR_1 = change in gross revenue, P_t = unit price of the crop in season t, Y_{et} = expected maximum yield in season t in the absence of the pathogen, and Y_{at} = actual yield in season t.

In general, ΔR_1 is an unsatisfactory measure of economic loss because it ignores cost adjustments. Whenever harvest costs are reduced because of lower yields, ΔR_1 overestimates economic losses. Conversely, whenever measures are taken to prevent the introduction of a pathogen or to control a pathogen-induced disease, ΔR_1 underestimates economic losses, because it omits the extra expenses associated with such adjustments in normal cultural practices.

A more suitable estimate incorporating cost factors is

$$\Delta R_2 = P_t(Y_{et} - Y_{at}) - (C_{et} - C_{at}),$$

where C_{et} = expected cost of producing the crop in season t in the absence of the pathogen, and C_{at} = actual cost of producing the crop in season t. Note that because ΔR_2 includes the cost of disease prevention measures, a pathogen can cause economic loss in a season even if yields are not reduced.

When the pathogen affects crop quality instead of or in addition to yield, economic losses will be underestimated unless price reductions applying to lower-grade produce are included. To accommodate quality changes, ΔR_2 could be modified as follows:

$$\Delta R_2' = (P_{et} - P_{at})(Y_{et} - Y_{at}) - (C_{et} - C_{at}),$$

where P_{et} = expected mean unit price of the crop in period t in the absence of the pathogen, and P_{at} = actual mean unit price of the crop in period t.

Although applicable to most annual crops, $\Delta R_2'$ will frequently underestimate losses caused by pathogens of perennials such as fruit and nut crops, because it fails to account for yield reductions and cost adjustments in years after the initial infection. This intertemporal dependence arises from two characteristics of perennial plants that distinguish them from annuals: perennial crop species continue to bear over an extended period of time, and there is a substantial lag between the planting date and the period when the plant attains full production. Because perennials bear for more than 1 yr, a pathogen that debilitates a tree or vine in season t can reduce yields in subsequent seasons and may necessitate expenditures on protective or therapeutic measures until injured plants are restored to normal. Similarly, because of the lag between planting and maturity, a pathogen that kills a tree or vine in season t will lower yields per acre until replants attain full production. Depending on the age of the replants relative to other trees or vines in the orchard or vineyard, special cultural practices (such as increased irrigation) may also be required and will increase costs in future years.

We contend that, whenever possible, estimates of economic losses from pathogens of fruit and nut crops should include such intertemporal effects. A general formula that could be used is

$$\Delta R_3 = \sum_{t=n}^{T} \beta_t[(P_{et} - P_{at})(Y_{et} - Y_{at}) - (C_{et} - C_{at})],$$

where β_t = a discount factor to adjust for interest rate effects in period t, n = year in which the pathogen attacks, and T = year in which the orchard or vineyard is removed from production.

The time dependence reflected in this expression stems from the perennial nature of the crop rather than any interperiod correlation between pathogen levels and/or disease incidence and severity. Hence, the basic formulation is useful for both soilborne and airborne pathogens. Such interperiod correlations must be explicitly considered, however, when optimal control strategies for diseases of fruit and nut crops are devised.

To calculate ΔR_3, one must either know or be able to predict 1) the amount and timing (eg, season) of any yield or quality reductions directly or indirectly attributable to the disease during the productive life of an orchard or vineyard; 2) the nature and timing of any adjustments in standard cultural practices during the productive life of an orchard or vineyard that are made to prevent the introduction of a pathogen, control the progression of a pathogen-induced disease, or compensate for pathogen-induced death of trees or vines; 3) the per-unit value of each grade of fruit or nut produced; and 4) the cost of all standard cultural and harvest practices during each year of the productive life of the orchard.

Clearly, most current estimates of economic losses caused by pathogens of fruit and nut crops must be viewed with caution. The data required to calculate more accurate values such as ΔR_3 are unavailable for most pathogen-crop combinations. The challenge facing plant pathologists and other researchers interested in estimating crop losses is to devise reliable measurement and sampling techniques for obtaining these data (or suitable proxies) with reasonable expenditures of time and money. Concepts such as "expected maximum yield" and "standard cost" need to be explicitly defined and reliably estimated. The intertemporal relationship between inoculum levels and disease incidence and severity should be quantified and correlated with yield reductions. The effects of cultural practices on pathogen and disease levels must be studied. Environmental influences must also be explored.

Such information for one or more representative fruit or nut pathogen-crop combinations could be used to develop a model for assessing economic losses, designing optimal disease management strategies, and evaluating the effects of fungicide restrictions. A general example of such a model is presented in Figure 1 and diagramed in Figure 2. The intertemporal links between pathogen levels in a given period and yield or quality in the following period are more evident in this representation.

To demonstrate the importance of intertemporal influences on costs associated with diseases of fruit and nut crops, the economic losses caused by a mild strain of Prunus ringspot virus in a newly planted peach orchard were estimated. Information on disease spread and yield differentials was obtained from a study by Schmitt et al (2) in which eight diseased trees were uniformly distributed among a block of 200 trees. During this study, which spanned a 14-yr period (1961–1974), annual increases in the number of diseased trees were recorded along with yield data from both healthy and infected specimens. Using these data, we calculated the yield reduction (in metric tons per hectare) from infection for each year (Table 1). These estimates of physical yield loss were then multiplied by the difference between price and harvest plus sorting costs (all expressed in dollars per metric ton) to arrive at the net revenue lost (in dollars per hectare) each year (Table 1). The estimates of annual net revenue loss were summed to obtain an estimate of total net revenue loss per hectare during the study. Over the 14-yr period, the initial infection rate of 4% reduced yield by nearly 16 t/ha and net profits by nearly \$2,200 per hectare (Table 1 and Fig. 3).

Although these estimates are based on certain restrictive assumptions, such large sums suggest that substantial benefits could be realized from planting peach stock that is totally free of Prunus ringspot virus. The case for using virus-free stock is even stronger if losses resulting from the role of Prunus ringspot virus in the peach stunt complex are included. Where infected stock in adjacent orchards might serve as a source of inoculum, gains from using virus-free stock would be reduced but could still be significant.

Economic losses at higher levels of aggregation. Calculating regional or

$$Y_{it} = f(B_{it}, CP_{it}, E_{it}, PA_{it}, A_{it})$$

$$B_{it} = g(FW_{it-1}, CP_{it}, E_{it}, PA_{it})$$

$$FW_{it} = h(CP_{it}, E_{it}, PA_{it}, A_{it})$$

$$PA_{it} = j(PA_{it-1}, E_{it}, CP_{it})$$

A_{it} = age of the ith unit in period t

B_{it} = number of blossoms in period t

CP_{it} = cultural practices performed on the ith unit in period t

E_{it} = environment influencing the ith unit in period t

FW_{it} = fruiting wood produced by the ith unit in period t

PA_{it} = level of the pathogen (inoculum) in or near the ith unit in period t

Y_{it} = yield of acceptable fruit produced by the ith unit in period t

Fig. 1. A general biological model of host-pathogen interactions in a fruit or nut crop. A unit may be either an individual plant or an area such as a hectare.

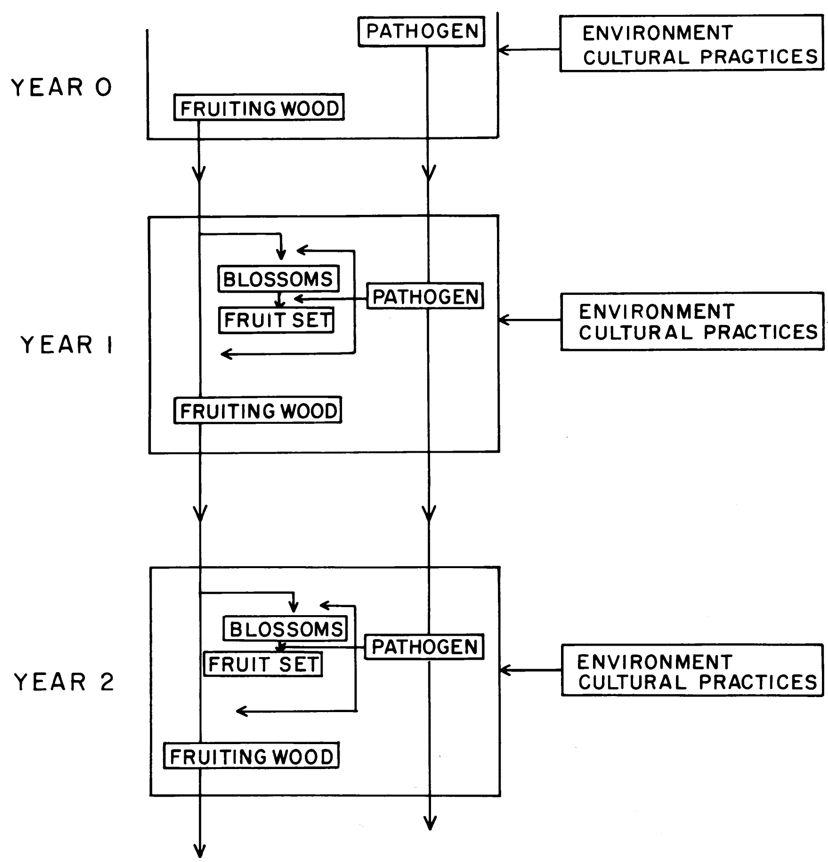

Fig. 2. A simplified diagram of the intertemporal interactions in host-pathogen relationships of fruit and nut crops.

Table 1. Losses in yield, gross revenue, and net revenue per hectare in a 200-tree peach orchard planted with 4% Prunus ringspot virus-infected stock[a]

Year	Diseased trees (no.)	Diseased trees (%)	Yield (t/ha) Diseased trees	Yield (t/ha) Healthy trees	Yield (t/ha) Combined[b]	Yield loss (t/ha)	Harvest cost reduction[c] ($/ha)	Gross revenue loss[d] ($/ha)	Net revenue loss ($/ha)
1961	8	4.0	...[e]	...	...	...	...	...	...
1962	8	4.0	...	...	...	...	...	...	...
1963	8	4.0	...	...	...	...	...	...	...
1964	8	4.0	8.7	11.6	11.5	0.1	2.42	16.50	14.08
1965	9	4.5	16.3	18.1	18.1	...	...	...	...
1966	14	7.0	23.4	24.8[f]	24.7	0.1	2.42	16.50	14.08
1967	23	11.5	NA[g]	NA[g]	NA[g]	NA[g]	NA[g]	NA[g]	NA[g]
1968	40	20.0	28.3	44.4[f]	41.4	3.3	79.86	544.50	464.64
1969	55	27.5	28.2	28.0[f]	28.0	...	...	...	...
1970	62	31.0	27.3[h]	31.7[h]	30.3	1.4	33.88	231.00	197.12
1971	97	48.5	27.3[h]	31.7[h]	29.6	2.1	50.82	346.50	295.68
1972	120	60.0	27.3[h]	31.7[h]	29.0	2.7	65.34	445.50	380.16
1973	142	71.0	27.3[h]	31.7[h]	28.6	3.1	75.02	511.50	436.48
1974	164	82.0	27.3[h]	31.7[h]	28.1	2.6	62.92	429.00	366.08
Total						15.4	372.68	2,541.00	2,168.32

[a] Unless otherwise noted, data on disease spread and yield losses were taken from Schmitt et al (2). Information on harvest costs and median state yields was obtained from Chaney et al (1).

[b] Combined yields were obtained from the formula $Y_C = P_H Y_H + P_D Y_D$, where Y_C = combined yield, P_H = percentage of healthy trees, P_D = percentage of diseased trees, Y_H = yield of healthy trees, and Y_D = yield of diseased trees.

[c] Calculations were based on costs of $22 per metric ton for picking and hauling and $2.20 per metric ton for sorting.

[d] Calculations were based on a price of $165 per metric ton.

[e] ... = Neither diseased nor healthy trees produced any fruit until the fourth year.

[f] Figures obtained from Schmitt et al (2) were adjusted to include the effect of natural infection.

[g] NA = no data available because of frost.

[h] Figure is based on the statewide median yield in 1976, assuming a 14% reduction in yield for diseased trees (the average for years when data were available).

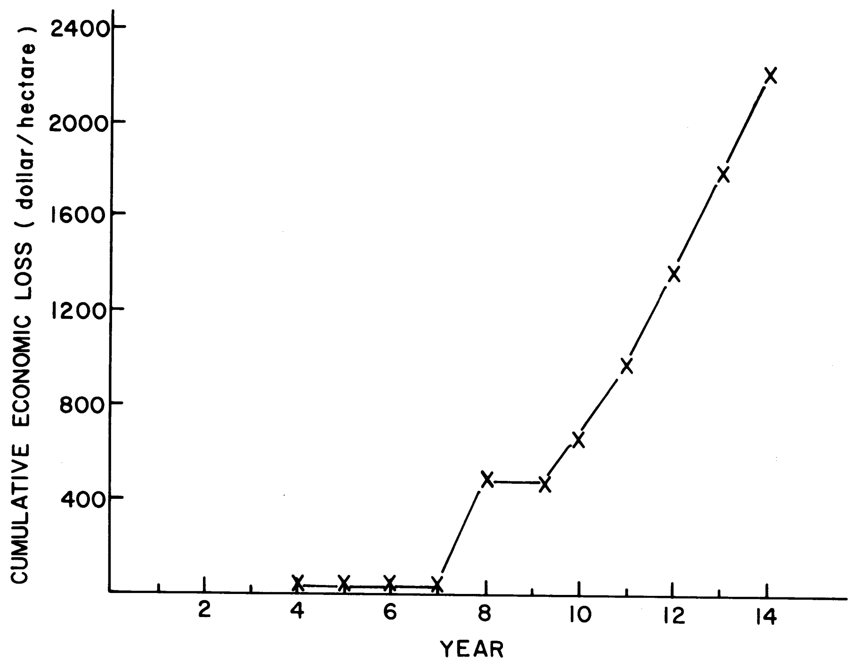

Fig. 3. Cumulative economic losses ($/ha) attributable to Prunus ringspot virus in a peach orchard with an initial infection level of 4%.

industrywide economic losses caused by plant pathogens is substantially more complex than estimating losses incurred by an individual grower. At higher levels of aggregation, interaction between supply and demand factors produces price variations. Consequently, economic losses from reductions in quantity or quality may be partially or wholly offset by price increases. Hence, estimates of losses at higher levels of aggregation cannot be derived by summing the losses of individual producers.

Economic losses at higher levels in the marketing chain. Economic losses at higher levels in the marketing chain would normally be figured on the basis of reduction in net profit. However, except for losses caused by postharvest pathogens, such estimates are difficult to calculate for an individual wholesaler or retailer who receives produce from many sources.

The task ahead. We wish to stress that the validity and usefulness of economic loss estimates depend on the accuracy and appropriateness of the biological data available. We have outlined the type of information on intertemporal host-pathogen interactions that is needed to calculate such estimates for fruit and nut crops. The task ahead is to devise efficient ways to gather these data.

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