Prediction of Potato Leafroll Virus Disease in Maine from Thermal Unit Accumulation and an Estimate of Primary Inoculum

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ABSTRACT

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Prediction of the incidence of potato leafroll (PLR) virus disease for three areas of potato production was based on PLR incidence obtained from Maine's potato certification program and temperatures recorded by the National Oceanic and Atmospheric Administration. For 1954–1976, area and year differences in PLR incidence were associated with the linear combination of the transformed percentage of primary inoculum and thermal unit accumulation above 21 C from 1–10 August. These two variables accounted for 62 and 80% of the variation in PLR incidence for cultivars Russet Burbank and Katahdin, respectively. Accurate PLR incidence was predicted for 1977 and 1978 but not for 1979. Possible explanations for this discrepancy are the absence of an aphid variable in the equations and an inaccurate estimate of the amount of primary inoculum present.

Additional key words: covariance analysis, multiple-regression analysis, PLRV

Potato leafroll virus (PLRV) is a circulatively transmitted plant virus that is vectored by more than 10 species of aphids (6). The green peach aphid, *Myzus persicae* (Sulzer), is considered the most efficient vector (8). The disease caused by PLRV, potato leafroll (PLR), is an important disease of potato and was a leading cause of seed rejection in Maine's potato certification program during the 1970s.

Ambient temperature is an important factor in PLR incidence. Gabriel (4) obtained high correlations of PLR incidence with accumulated daily mean temperatures above 0 C from 1 January to 30 April in Poland. Howell (5) associated seed potato rejection rates for PLR in Scotland's potato certification program with low monthly mean temperatures preceding the growing season. Both studies used regression analysis and presumably related temperature effects on PLR to aphid biology. Byrne and Bishop (3) developed a regression model that predicted levels of PLR in table-stock potatoes as a function of numbers of apterous aphids on plants two consecutive weeks before 1 August. Primary inoculum (PLRV-infected seed) was not correlated with PLR incidence because certified seed stocks were used.

In this paper, we report on a preliminary research model for the annual prediction of PLR occurrence in Aroostook County, ME. This model is based on the multiple regression of PLR incidence on thermal unit accumulation and an estimate of primary inoculum.

MATERIALS AND METHODS

Results of Maine's potato certification program were used to evaluate PLR incidence and estimate primary inoculum. The complete Maine-Florida winter test results for all seed lots submitted for testing were obtained from the Maine Department of Agriculture. The potato (*Solanum tuberosum* L.) cultivars Russet Burbank (1954–1976) and Katahdin (1939–1976) were studied. Three areas of Aroostook County were delimited as north, central, and south. Percentage of incidence was grouped by these areas and averaged to produce one annual observation of PLR incidence per area per cultivar. Arc sine transformation was applied to normalize variance (9). The complete Maine-Florida test results were not available for 1959, 1960, and 1969; therefore, those years were treated as missing data in all analyses.

An estimate of current-season primary inoculum (X_1) was defined as the disease incidence from the previous year. This was based on the assumption that the incidence in the Maine-Florida test approximated the amount of PLRV-infected seed planted the following year because growers predominately used local seed. Furthermore, each X_1 was converted to a $\log_{10}(X_1 + 1)$ value to normalize variance.

Temperatures were obtained from single National Oceanic and Atmospheric Administration (NOAA) weather stations in Fort Kent (north), Presque Isle (central), and Houlton (south), Aroostook County, ME. Thermal unit accumulation was calculated for 15 consecutive periods from 1 April to 31 August. Each month was divided into three accumulation periods (10 or 11 days). Periods were then summed for every combination of beginning date and every combination of ending date to produce 115 additional periods. Daily thermal units were calculated by subtracting a threshold temperature value from the daily mean temperature: daily thermal units = ([daily maximum temperature + daily minimum temperature]/2) − t, where t = temperature threshold and daily thermal units = 0 when the daily mean is less than or equal to t. Daily thermal units were summed for a period to produce a corresponding thermal unit accumulation. Ten thresholds were examined: 0, 4, 7, 10, 13, 16, 18, 21, 24, and 27 C.

All statistical analyses were performed using the statistical package for the Social Sciences system of computer programs (7). Covariance analysis was conducted to assist in data interpretation (9).

RESULTS

The average annual numbers of Russet Burbank samples Florida-tested between 1954 and 1976 were 8, 68, and 11 from northern, central, and southern Aroostook County, respectively. Similarly, the average annual numbers of Katahdin samples tested between 1939 and 1976 were 63, 518, and 130.

Russet Burbank. The correlation of PLR incidence with primary inoculum produced a simple correlation coefficient of $r = 0.61$. PLR incidence was optimally correlated with thermal unit accumulation during 1–10 August at temperature thresholds of 21, 24, and 27 C ($r = 0.66$ for each threshold). We concluded from multiple covariance analysis that PLR incidence varied because of primary inoculum and temperature threshold (21 C) and that only as these factors varied in

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areas and years was PLR incidence affected.

Regression of PLR incidence on primary inoculum [$\log_{10}(X_1 + 1)$] and temperature threshold (X_2) produced the following equation: $Y = 5.874 \log_{10}(X_1 + 1) + 0.395 X_2 - 1.088$. The multiple correlation coefficient (R) equaled 0.790 ($R^2 = 0.62$). Annual graphs of observed and predicted PLR incidence for 1954–1979, fitted for 1954–1976, in northern, central, and southern Aroostook County, ME, are shown in Figure 1. Percentage of disease was determined by reconverting arc sine transformed values to percentages.

Katahdin. Results for Katahdin for 1939–1976 were similar to those found for Russet Burbank, except year differences confounded the effects of primary inoculum and temperature threshold on PLR incidence when multiple covariance was performed. Therefore, results for Katahdin were analyzed only for the years of Russet Burbank production (1954–1976). This approach is based on biological grounds and follows the recommendation of Butt and Royle (2) to use only recent-years' data to develop regression equations of disease because changes in climate and grower management techniques may occur with time.

Results of this multiple covariance analysis were similar to those obtained for Russet Burbank. The simple correlation coefficients for primary inoculum and temperature (1–10 August at 21 C) with PLR incidence were $r = 0.78$ and $r = 0.67$, respectively. Regression of PLR incidence on primary inoculum [$\log_{10}(X_1 + 1)$] and temperature threshold (X_2) produced the following equation: $Y = 5.993 \log_{10}(X_1 + 1) + 0.216 X_2 - 0.933$. The multiple correlation coefficient (R) equaled 0.895 ($R^2 = 0.80$). Figure 2 shows the reconverted annual graphs of observed and predicted PLR incidence for 1954–1979, fitted for 1954–1976, in northern, central, and southern Aroostook County, ME, respectively.

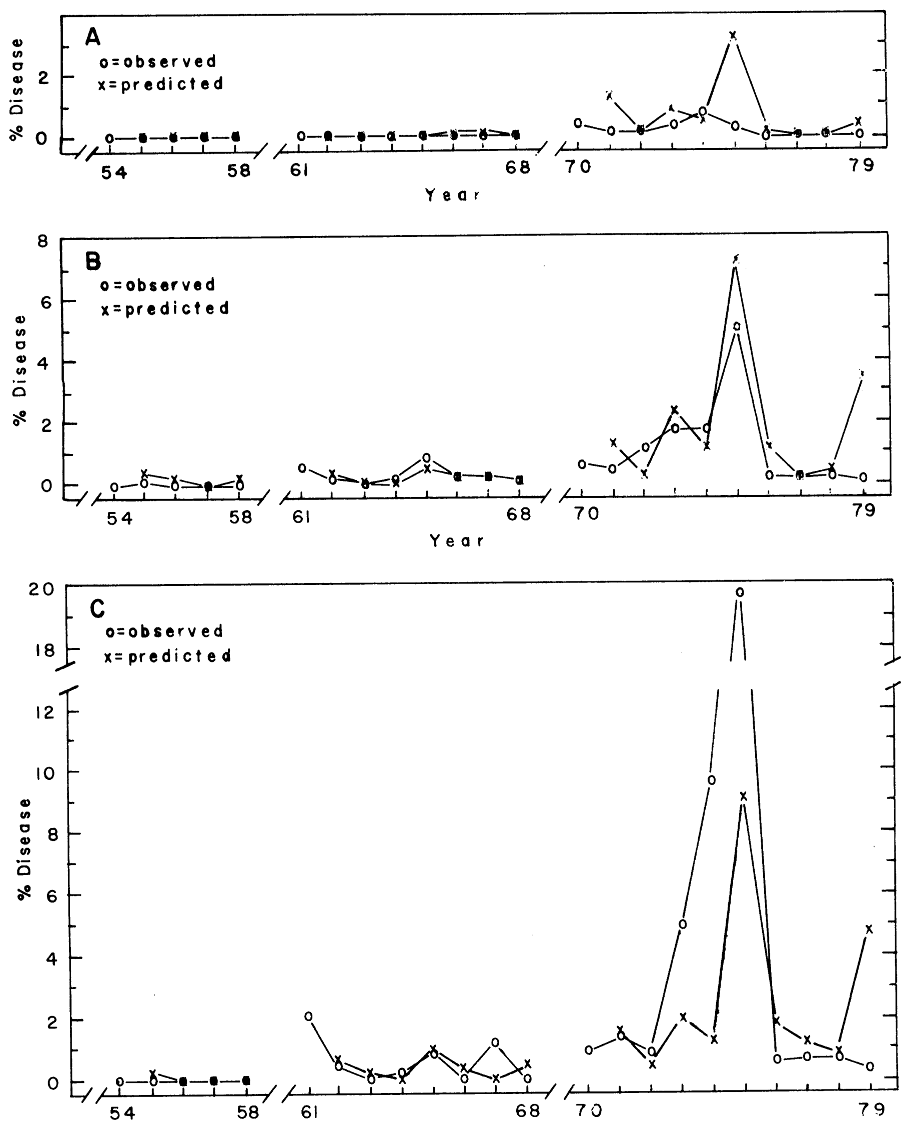

Fig. 1. Reconverted percentage of observed and predicted potato leafroll incidence for Russet Burbank for 1954–1979, fitted for 1954–1976, for three areas of Aroostook County, ME. **(A)** Northern, **(B)** central, and **(C)** southern.

DISCUSSION

A high incidence of PLR occurred in the mid-1970s (Figs. 1 and 2). The disease was most severe in southern Aroostook County and least severe in northern Aroostook County (Figs. 1 and 2). For 1954–1976, differences in PLR incidence were associated with the linear combination of thermal unit accumulation and primary inoculum. These two variables accounted for 62 and 80% of the variation in PLR incidence for cultivars Russet Burbank and Katahdin, respectively.

The high correlation of PLR incidence with thermal unit accumulation above 21 C for the period 1–10 August led us to conclude that the process is mediated by a high temperature threshold. This process could involve mechanisms within the vector, the host, or both (1). The nature of this process was not, however, within the scope of this study. The finding of a correlation between PLR incidence and primary inoculum in this study contrasts with the results of Byrne and Bishop (3), who used only certified seed lots (seed with less than 5% primary inoculum) in their study. Our findings are attributed to the probable inclusion of noncertified seed lots in our study. We assumed that the Florida tests provided a realistic estimate of the levels of PLRV in the seed planted in Maine during the study. We believe the assumption is supported by the correlation coefficients obtained between PLR incidence and primary inoculum.

A pattern of underprediction in southern Aroostook County and overprediction in northern Aroostook County was seen for the period 1954–1976 (Figs. 1 and 2). We set up the equations on the assumption that except for thermal unit accumulation and primary inoculum, all other factors are equal between areas. Two factors that may not be comparable between areas and may account for the patterns seen are production practices and aphid density. Potato production in southern Aroostook County consists of seed, table, and processing potatoes. Potatoes produced for fresh market and processing are not necessarily entered for certification but may be used for seed. Estimates of primary inoculum in that area are likely to be conservative. In contrast, production in northern Aroostook County consists primarily of seed stock; therefore, roguing diseased plants may result in a liberal estimate of primary inoculum in that area. Differences in aphid density in the three areas could produce results paralleling those suggested for primary inoculum estimates. High aphid densities in the south could result in underprediction and low aphid densities in the north could result in overprediction. These two factors, potato production practices and

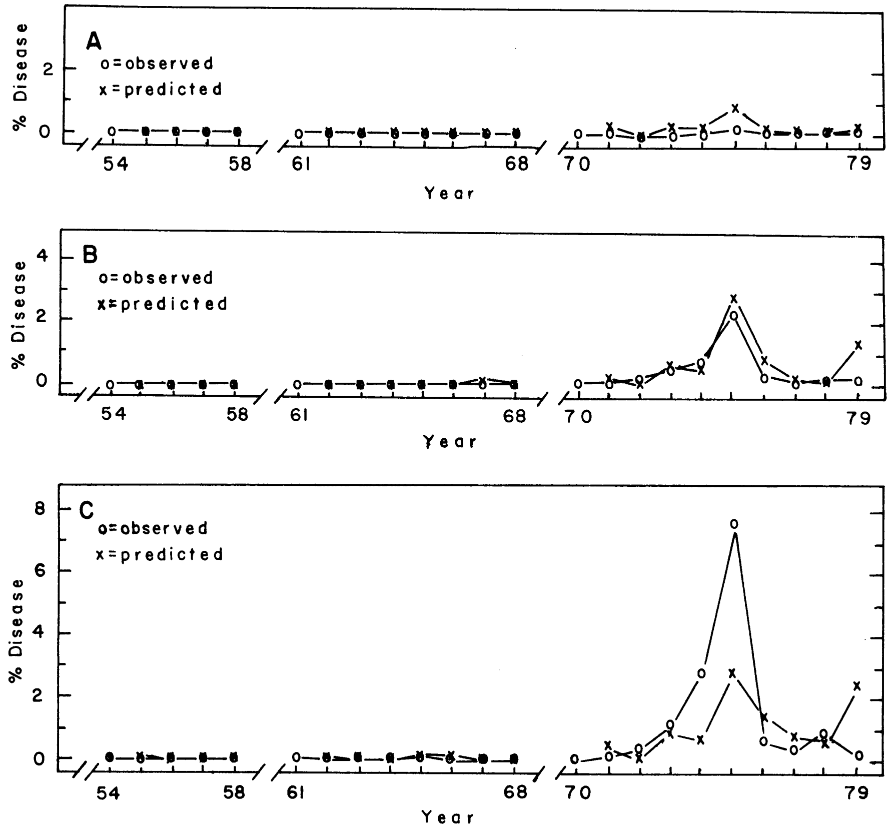

Fig. 2. Reconverted percentage of observed and predicted potato leafroll incidence for Katahdin for 1954–1979, fitted for 1954–1976, for three areas of Aroostook County, ME. **(A)** Northern, **(B)** central, and **(C)** southern.

aphid density, should be studied in the future and incorporated into the equations.

The equations will represent a satisfactory research model only if PLR incidence can be predicted accurately in future years. Accurate predictions were obtained for 1977 and 1978. In 1979, however, predictions of PLR incidence were too high in the central and southern areas. A possible explanation of this overprediction may be the absence of an aphid variable in the equations. Aphid numbers have been used in equations to predict the spread of PLR in table stock (3) and the incidence of yellowing viruses of sugar beets (10). In 1979, overprediction may have resulted from reduced aphid numbers even though the conditions for thermal unit accumulation and primary inoculum favored an increase in PLR incidence. The lack of adequate aphid data for all areas precluded an aphid variable from being evaluated in this study. Another possible explanation of the overprediction of PLR incidence in 1979 may have been lower amounts of PLR in seed stock. The price of certified seed was stable throughout the marketing season in both 1977 and 1978. In 1979, however, there was a decline in price of more than 25% as the growing season approached. Such a situation often encourages growers to buy higher quality seed, ie, seed with lower amounts of primary inoculum.

We suggest that accurate prediction of PLR incidence in potatoes could be made by developing equations that include primary inoculum, thermal unit accumulation, and aphid numbers as independent variables.

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