12.2 RECENT CLIMATIC TRENDS AND CHANGES IN POTATO LATE BLIGHT DISEASE RISK IN THE UPPER GREAT LAKES REGION

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1. INTRODUCTION

Potato late blight is a temporally sporadic plant disease that occurs when microclimate conditions within the canopy are favorable and inoculum is present (Lacy and Hammerschmidt, 1995). Measurements of leaf wetness duration and its common proxy, in-canopy relative humidity, are considered to be critical in monitoring development and spread of the disease (Wallin, 1962). As a result, temporal changes in meteorological variables that influence the amount of in-canopy moisture could significantly impact the relative risk of the disease as well as its control.

Previous studies in the climatological literature have suggested changes in precipitation frequency and amounts. For the United States as a whole, Karl and Knight (1998) found a 10 percent increase in the annual precipitation totals during the last 80 years. In addition, the authors also found a greater portion of the total precipitation in both single and multiple day precipitation events to be associated with heavy and extreme precipitation events. The annual number of days with precipitation also increased in the contiguous United States. In the Great Lakes region, precipitation amounts were found to have increased approximately 0.4 mm yr^{-1} since 1895, with an overall greater number of wet days and wet days following wet days (Andresen et al., 2001). These increases in annual precipitation, number of days with precipitation, and the number of wet days following wet days may have been associated with an increased risk of potato late blight infection and subsequent yield and economic losses.

This study addresses recent climate trends and their potential impact on potato late blight disease risk in the Upper Great Lakes region of the U.S. The influence of climate on disease risk is quantified with the modified Wallin disease severity index (Wallin, 1962). The index is simple and totally dependent on meteorological variables, but does not consider irrigation, other cultural practices or pathogen biotype changes that may also impact late blight risk. In this study, temporal trends of potato late blight risk in Michigan and surrounding areas were characterized for the period 1948-1999.

2. MATERIALS AND METHODS

Historical hourly air and dew point temperature values were extracted from the National Climatic Data Center's Surface Airways data-set (NCDC, 1948-1999) for seven stations in the region: Alpena (APN), Grand Rapids (GRR), Green Bay (GRB), Muskegon (MKG), Toledo (TOL), Traverse City (TVC), and Sault Ste. Marie (Y62). For each location (Figure 1), years with more than seven days of missing values during the growing season, defined as 1 May through 30 September, were not used. Following this check, station record lengths ranged from 35 to 49 years for the period1948-1999. Throughout this paper, the station locations are listed in tables and figures in order of latitude, from northernmost to southernmost, i.e. Y62, APN, TVC, GRB, MKG, GRR, TOL.

During the time frame of the study, instrument updates, site modifications, location changes, and instrument changes occurred at each of the sites independently, which may have led to non-climatological trends in the series. Robinson (2000) found less than 1°C change in these temperature series associated with record discontinuities for the pre-1990 period. While the overall impact of the gradual shift of the data network to the Automated Surface Observing System (ASOS) system beginning in the 1990's remains unclear (Robinson 2000), any impact of series discontinuity relative to the Wallin disease severity index is expected to be small, and the data series were used as recorded.

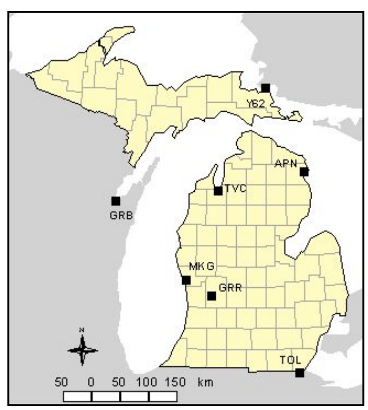

Figure 1. Stations used in the study.

Potato late blight disease severity values (DSV) were calculated each day from 1 May through 30 Sept at each location, each year. The

DSV were based on a modified Wallin method used by Michigan State University Late Blight Lab (Baker et al, 2000). A relative humidity threshold of 80 percent was used to classify hourly values as conducive for late blight if the associated air temperature ranged from 7.2 to 27°C. Hours that were both above the 80% relative humidity threshold and within temperature ranges from 7.2 -11.7, 11.7-15.0, and 15.0-27.0 for a requisite number of hours were assigned the corresponding DSV. 24-Hour daily periods were considered to begin at noon local standard time to better characterize leaf wetness of a single diurnal cycle. Because a 24-hour loop was used in data processing, missing hourly data values often altered start time between years. Slight discrepancies in start time between years and locations, therefore, became a source of error. Archived weather data also alternated between hourly and three-hour values. When hourly values were not available, three-hour values were used to estimate hourly data with linear interpolation techniques.

Trend analysis was performed for the time series of the summed DSV accumulations each growing season (∑DSV), as well as the time in days to reach defined fungicide spray thresholds. Time series trend analysis included the entire data set, as well as two temporal subsets. The first subset excluded years after 1990, to limit the study to pre-ASOS data to conform with Robinson's (2000) earlier findings regarding discontinuities associated with changes in instrumentation. Because the period of record at some sites were shorter than others, the study included a comparison of data subsets limited to pre-1990 years and years from 1965, the latest station start date, through 1990, as well as the entire data set.

The time (t) in days to reach a fungicide spray thresholds was calculated for values of both 18 and 30 accumulated DSV. The 18 DSV ($t_{0\text{-}18}$) accumulation corresponds to the traditional Wallin model threshold (MacKenzie, 1981; Wallin, 1962; Wallin and Schuster, 1960), while 30 ($t_{0\text{-}30}$) is currently used in the MSU modified system. The number of days where 10 DSV were accumulated in a prior five-day period ($t_{(i=10)} \geq 5$) were also analyzed, as these situations have important implications for spray recommendations.

The five possible disease severity values (0,1,2,3,4) each indicate different types of day relative to disease risk (the greater the number, the greater the risk). The number of days with a value greater than zero ($\sum DSV_{n>0}$) and the number of days with each specific DSV value ($\sum DSV_n$) were compared to determine if the trends were related. The distribution of $\sum DSV_{n>0}$ and the change in $\sum DSV_n$ distribution were also compared by site. Trends in monthly accumulated values ($\sum DSV_{t=i..i+30}$)were assessed at two week intervals to determine which periods in the growing season were most influenced by changing climatic patterns. Similarly, to determine relationships between trends and the variables from which they were derived, monthly dew point and temperature trends were also investigated. In order to determine the nature of changes in the variables studied, estimates of both trend magnitude and significance were calculated. Trend magnitude was obtained with the method of Sen (1968). A nonparametric statistic was selected due to the lack of normality for some of the variables analyzed. The trend magnitude statistic, a nonparametric analogue of the least squares derived slope parameter estimate, is defined as:

$$B = med \{D_{ij}\}$$

where $D_{ij} = (x_j - x_i)/(j-i)$ for all possible pairs (x_i, x_j), $1 \leq i < j \leq n$, and n the number of observations in the series. The nonparametric Mann-Kendall or Kendall's tau statistic (Kendall, 1975) was used to determine the significance of the trends. The null hypothesis, H_o, was that the data in the series of interest (x_1, x_2, ... x_n) were a sample of n independent and identically distributed variables. The alternative hypothesis, H_1, of the two-sided test was that the distribution of x_i and x_j were not identical for all pairs of $i, j \leq n$, and $i \neq j$. The series were analyzed with a two-sided test for trend, with H_o accepted if the standard normal variate of S was less than or equal to the standard normal cumulative distribution function for a given level of significance α, $|Z| \leq z_{\alpha/2}$. The power of this test for sample sizes larger than10 has been shown to be nearly as great as that of the more traditional t-statistic which assumes normality (Kendall, 1975; Hirsch et al., 1982).

3. RESULTS

3.1 *Seasonal DSV Accumulation*

Time series of annual DSV accumulations, with median value line and smoothed trend line (9-year moving average) overlaid, are shown in Figure 2. Across the region, DSV accumulations (∑DSV) tended to be greater in 1960-62, 1978-79 and

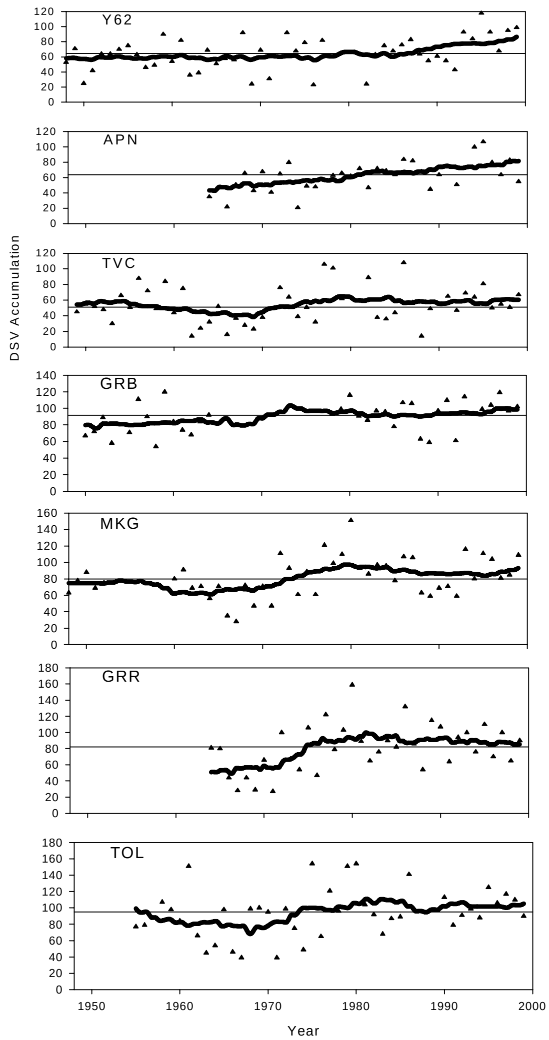

Figure 2. DSV accumulation by year for each station location, 1948-1999. Values are overlain with location-specific median value line and smoothed trend line.

1994-96. From 1948 to 1999, all ∑DSV had positive slopes with respect to time (Table 1), and the slopes at all sites except Toledo and Traverse City were significantly greater than zero. ∑DSV at northern locations, including Sault Ste Marie, Alpena and Traverse City, were significantly different from the southern group of Green Bay, Muskegon, Grand Rapids and Toledo, but locations within each group were not significantly different from each other.

The estimated rate of increase in ∑DSV at both Alpena and Grand Rapids were significant when ∑DSV after 1990 were excluded from the analysis (data not shown). The rate of increase in ∑DSV was statistically equal to zero at the remaining stations, but in comparison to the analysis that continued through 1999, the rate of change in ∑DSV increased at Toledo, remained constant at Muskegon, and decreased elsewhere

Table 1. Magnitude of non-parametric slope estimates for accumulated disease severity values, 1948-1999. Superscripts *, **, and *** denote significance at p=0.10, 0.05, and 0.01 levels, respectively.

Site	N	∑DSV	t_{0-18}	t_{0-30}	$t_{(i=10)} \geq 5$
Y62	47	0.55*	-0.47*	-0.45*	0.00
APN	35	1.00***	-0.83	-1.08**	0.00
TVC	49	0.25	-0.08	-0.18	0.25*
GRB	36	0.56**	-0.14	-0.21	0.05
MKG	45	0.54**	-0.32	-0.33	0.07
GRR	36	1.10*	-0.64*	-1.09***	0.14*
TOL	41	0.61	-0.39	-0.47*	0.13**

3.2 *Threshold Analysis*

The number of days from the start date of the growing season to accumulation of 18 (t_{0-18}) and 30 DSV ($_{t0-30}$) exhibited negative slopes with respect to time at all sites (Table 1). The time in days to both thresholds significantly decreased at Grand Rapids and Sault Ste Marie, while t_{0-30} also decreased significantly at Alpena and Toledo. Similarly, the number of $t_{(i=10)} \geq 5$ intervals increased at all sites, and was significant at Grand Rapids, Toledo and Traverse City.

3.3 *DSV Day Types*

Trends statistics for the number of days during the growing season with specific ∑DSV values are given in Table 2. All locations had decreases in the number of days with a DSV of 0 (∑DSV_0). These decreases were significant at Sault Ste Marie, Alpena, Green Bay and Muskegon.

Temporal trends for every location and every ∑$DSV_{n>0}$ were either positive or near zero. No location showed a significant change in ∑DSV_1 , but all locations except Traverse City had significant increases of ∑DSV_2. Green Bay had a significant increase in ∑DSV_3 and Grand Rapids and Sault Ste Marie had a significant increase in ∑DSV_4 over the 50 year time period.

Table 2. Magnitude of non-parametric slope estimates for number of growing season days with each disease severity value,1948-1999. Superscripts *, **, and *** denote significance at p=0.10, 0.05, and 0.01 levels, respectively.

Site	$\sum DSV_0$	$\sum DSV_1$	$\sum DSV_2$	$\sum DSV_3$	$\sum DSV_4$
Y62	-0.22*	0.03	0.08*	0.02	0.04*
APN	-0.44**	0.14	0.16**	0.11*	0.07
TVC	-0.10	0.00	0.00	0.03	0.00
GRB	-0.19*	0.00	0.09*	0.06*	0.03
MKG	-0.30**	0.09	0.09*	0.04	0.04
GRR	-0.48	0.15	0.22**	0.00	0.13*
TOL	-0.25	0.06	0.13*	0.00	0.08

3.4 *30-Day Disease Risk*

Trends in monthly accumulated values ($\sum DSV_{t=i..i+30}$)were assessed at two week intervals within the growing season to determine which periods were most influenced by changing climatic patterns. Slope estimates and associated significance of 30 day accumulations of disease severity values ($\sum DSV_{t=i..i+30}$) were calculated for each site. All trend estimates were positive with the exception of two locations during September. For the region as a whole, the slope of $\sum DSV_{t=i..i+30}$ was most frequently greater than zero from the end of June to early August. $\sum DSV_{t=i..i+30}$ at Alpena and Grand Rapids were significantly greater than zero during four different time periods, at Muskegon and Sault Ste Marie during two, and at Toledo during one period earlier in the season. Time periods with significant increases are shown in comparison to overall annual risk by site in Figure 3. In most cases, periods with significant increases during the study time frame occurred earlier in the season than the consistent late blight risk peak in August. Increases in $\sum DSV_{t=i..i+30}$ were found to associated with increases in dew point temperature for at least a portion of the growing season at Alpena, Grand Rapids, Green Bay and Toledo (data not shown). Dew point increases were particularly frequent during July and August. Seasonal means in air temperature also were found to be significantly positive at Alpena and during July at Traverse City.

4.0 **DISCUSSION**

Spatially, there was an overall tendency for results at the three northern Michigan stations to be similar, and the four southernmost stations to also be similar to one another throughout all aspects of the analysis. Although at nearly the same latitude of Traverse City, but on the opposite shore of Lake Michigan, Green Bay was consistently similar to the southern stations, while Traverse City was frequently different from all other stations.

The overall variability of the total growing season accumulated potato late blight disease severity values was surprising. The northern Michigan stations were more moderate in variability and had consistently lower risk accumulations as would be expected by their higher latitude and influence of the Great Lakes on weather systems crossing the state from the West. Green Bay had lowest variability, perhaps due to its position on the western shore of Lake Michigan, where prevailing winds do not cross the lake. Muskegon, Grand Rapids and Toledo, however, had an overall range of about 120 DSV values, from 30 to 150. This quantification of the immense seasonal variability of conducive conditions for potato late blight definitely supports the use of weather-based monitoring systems for disease management recommendations.

With respect to the number of days with DSV of different values, increases at most stations were likely associated with increasing trends in precipitation noted in earlier studies (e.g. Andresen et al., 2001). However, the fact that no stations had significant increases in the number of days with DSV of 1 was surprising. Equally impressive was that fact that all stations except Traverse City increased markedly in $\sum DSV_2$. A value of 2 can indicate three different environmental conditions, and further studies could perhaps narrow still further the environmental changes impacting this significant trend. Again for these individual $\sum DSV_{n>0}$, the more northern and southern locations remained similar throughout.

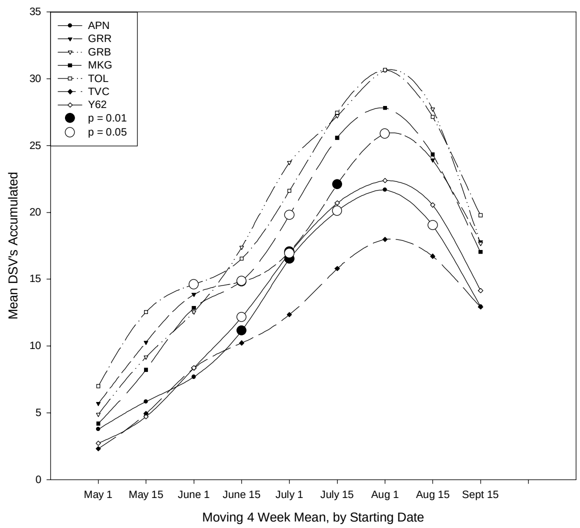

Figure 3. DSV accumulations for 30-day period averaged over the 1948-1999 period at each site. Larger circles indicate positive temporal trends and significance during the period.

Threshold accumulation times decreased most at northernmost and southernmost stations during the time period of the study. Data recorded at Traverse City was only significant in one instance, showing an increasing accumulation of five-day intervals with a DSV accumulation of at least 10. The variability in these periods of extremely conducive conditions was also surprising. In fact, for several years at each station none of these periods exist. At other times, they occurred upwards of 10 times for northern stations and up to 27 times at Toledo. Interestingly, Traverse City, Grand Rapids, and Toledo seem to have a decreasing frequency of zero values over time, and these were the locations with significant trends. These highly conducive periods and their variability are of great importance to potato late blight management, as the duration of high moisture conditions in the canopy indicate that field work would be extremely difficult simultaneous to highly favorable conditions for epidemic initiation.

Changes in parameters of localized disease severity value distributions were interesting from the perspective of late blight disease management strategies. The spatial and temporal aspects of change in the accumulation of disease severity values provided insights as to patterns across the region and across the growing season. Peak disease risk throughout the region occurred in August, while relative increases in accumulations (Figure 3) occurred in June and July, suggesting greater disease pressure earlier in the season. This result is important in terms of foliar fungicide spray applications early in the season, as well as extending the period of greatest risk in some locations. Similar to trends of threshold times, Traverse City and Green Bay did not have accumulation increases during any particular time period.

Dew point increases corresponded closely with the time of increasing ∑DSV. Most noticeable were Alpena and Grand Rapids, which were the two stations that retained their significance in ∑DSV, regardless of temporal subset. Increasing dew point temperatures we also found at Toledo. These three stations, in addition to Sault Ste Marie were also the stations with decreases in the time to threshold of 30 DSV.

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