A Problem Case Study: Influence of Climatic Trends on Late Blight Epidemiology in Potatoes

K.M. Baker
Department of Geography
Michigan State University
East Lansing, MI
USA

W.W. Kirk
Department of Plant Pathology
Michigan State University
East Lansing, MI
USA

J. Andresen
Michigan State University
East Lansing, MI
USA

J.M. Stein
Michigan State University
East Lansing, MI
USA

Keywords: *Phytophthora infestans, Solanum tuberosum,* varieties, fungicides, sustainability

Abstract

Late blight is temporally sporadic in potato crops in the Midwest US, occurring only when microclimate conditions within canopies are favorable and inoculum is present. Increasing concern over climate change projections has prompted numerous crop-based studies on the possible agricultural implications. It is not possible to evaluate sustainability without understanding the interactions between the influence of climatic trends, host resistance, cultural interventions and fungicide efficacy in relation to late blight risk. The objectives of this case study were to report the potential impact of climate change on late blight epidemiology in potatoes.

Analysis of historical data from 1948 - 1999 indicated that late blight risk over a standardized growing season from 1 May - 30 Sep increased in the Upper Great Lakes region of the US. Predominant genotypes of *P. infestans* (e.g. US8) in the US appear more tolerant of temperatures close to 0^{o}C and their survival in warming conditions may explain their supremacy. As conditions become increasingly favorable for late blight development it is essential to reduce sources of initial inoculum through integrated approaches that include prediction of conditions conducive to late blight development and appropriate application of controls.

INTRODUCTION

Late blight of potato (*Solanum tuberosum*, L.) caused by *Phytophthora infestans* (Mont de Bary), is a major worldwide threat to the production of high quality potatoes (Fry and Goodwin 1997). Potato late blight control strategies changed following the migration of mefenoxam/metalaxyl-resistant populations of *P. infestans* from Mexico to North America (Fry, Goodwin et al. 1993) and necessitate cultural control methods and crop protection strategies that rely primarily on protectant foliar fungicide applications (Kirk, Felcher et al. 2001). Although fungicides have been used to manage late blight, both the efficacy and availability of commonly used fungicides have been threatened. This problem is compounded by the demand to reduce chemical input in agricultural systems (Gray and Whalon 1996; Guenthner, Michael et al. 2001) and the potential loss of commonly used protectant fungicides such as chlorothalonil and mefenoxam (Gray and Whalon 1996). In addition, the cost of protecting potato crops in the United States against late blight is estimated at $77.1million annually (Guenthner, Michael et al. 2001) and losses and control costs are estimated at $3 billion worldwide (Forbes, Goodwin et al. 1998). The influence of climate change is therefore critical to assess changes in risk of late blight development for the future.

Leaf wetness duration and in-canopy relative humidity are critical variables in determining the relative risk of late blight development. As a result, changes in meteorological variables throughout the growing season that influence the amount of in-

Proc. XXVI IHC – Sustainability of Horticultural Systems
Eds. L. Bertschinger and J.D. Anderson
Acta Hort. 638, ISHS 2004
Publication supported by Can. Int. Dev. Agency (CIDA)

canopy moisture and vapor pressure could significantly impact subsequent disease pressure. This study addresses recent climate trends (Karl and Knight 1998) and their potential impact on potato late blight disease risk in the Upper Great Lakes region of the U.S. This historical perspective for potato late blight risk characterizes temporal trends in the greater Michigan region from 1948-1999.

In North America, the probability that infected potato stems or foliage will emerge from an infected tuber is difficult to estimate as several factors can influence the fate of the infected tuber (Lambert, Currier et al. 1998; Powelson and Inglis 1999), temperature being one of the most important (Kirk, Niemira et al. 2001). The survival of viable host tissue from infection through dormancy to re-emergence the following spring is vital for survival of *P. infestans* (Zwankhuizen, Govers et al. 1998).

Many investigators have used in vitro and soil assays to study the optimal and lethal upper temperatures for growth of *Phytophthora* spp. (Zentmyer 1981; Bollen 1985; Juarez-Palacios, Felix-Gastelum et al. 1991; Coelho, Mitchell et al. 2000). No studies have been found that examine the ability for *P. infestans* mycelium to survive at temperatures below zero. *P. infestans* can survive within infected tubers at 3^{o}C as stored seed (Kirk, Niemira et al. 2001), however the fate of mycelium of *P. infestans* within potato tubers exposed to temperatures below 0^{o}C has not been monitored. The objectives of this case study were to report the potential impact of climate change on late blight epidemiology in potatoes.

METHODS AND MATERIALS

Climate Trends

Historical hourly air and dew point temperatures were extracted from the National Climatic Data Center's (NCDC) Surface Airways data-set (NCDC, 1948-1999) for seven first order National Weather Service (NWS) stations in the greater Michigan region. The influence of climate on disease risk is quantified with a modified Wallin disease severity index (Wallin 1962). The index is simple and completely dependent on meteorological variables, without considering irrigation, other cultural practices or pathogen biotype changes could impact late blight risk. Potato late blight disease severity values (DSV) were calculated for each day from May 1 through Sept 30 at each location every year. DSV were based on a modified Wallin method used by Michigan State University Late Blight Lab (Baker, Andresen 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. Trends in the timing and accumulation of disease severity values were quantified using a non-parametric slope estimator (Sen 1968).

The probability of detecting a statistically significant difference between risk indicators, derived as secondary variables from weather data, was estimated at the p=0.05 significance level using Kendall's tau b non-parametric correlation coefficient (SAS statistical software package). Kruskall-Wallis one-way analysis of variance on ranks was also used at the p=0.05 level to test for statistically significant differences between potato late blight risk indicator estimates at various locations.

Thermal Tolerance

Briefly, 50 plates of each of four isolates of *Phytophthora infestans* [US1, 8, 11, 14 (Goodwin, Schneider et al. 1995)] were prepared 48 h prior to introduction to the temperature treatment. Plates were labeled with culture ID numbers and exposure times and transferred to a PTC-1 Peltier-effect temperature cabinet controlled by a PELT-3 Peltier-effect temperature controller (Sable Systems International). The PTC-1 chambers were positioned in temperature-controlled environment chambers, 1.8 m^3 volume at 5^{o}C. Plates were removed after exposures of 1, 4, 8, 12 and 24 h and in a second experiment after exposures of 1, 2, 3, 4, and 5 days. Temperature treatments were 0, -3, -5, -10 and -20^{o}C (experiment 1) and 0, -3, -5 ^{o}C (experiment 2). After plates were removed from the PTC-1 Peltier-effect temperature cabinet they were stored in the light at 12^{o}C. Plates (n =

5) were incubated at 12 °C for 28 days prior to evaluation.

An image analysis technique was adapted used to determine recovery of the treated cultures (Niemira, Kirk et al. 1999). The image was formed from light reflected from the agar surfaces. The brightness value of the image controlled the light intensity of every pixel in the image. The contrast value controlled the differences between light and dark regions of the image.

The image files created with the scanner software were loaded into the image analysis software (SigmaScan Pro ver. 5.0.0 build number 3981, SPSS Science). The black background has 0 light intensity units (LIU), while pure white has 255 LIU. The clarified rye was pale gray (LIU = 90). The average reflective intensity (ARI) of all the pixels within the image gave a measurement of any growth of the sample. Mycelium of *P. infestans* is white and a mature culture measures about 110 – 170 LIU. The threshold at which no growth occurred (on non-inoculated controls) was used as an indication to determine if cultures were alive (LIU 90 – 100).

RESULTS

Climate Trends

From 1948 to 1999, all total disease severity values accumulated per growing season increased with respect to time for each of the seven locations (Table 1). The increases at all sites except Toledo and Traverse City were significantly greater than zero. DSV accumulated 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. Increases in median number of DSV accumulated at Sault Ste Marie, Green Bay, Muskegon and Toledo were of similar magnitude, between 0.54 and 0.61 DSV per year from 1948-1999. The magnitude of the increases in accumulated DSV at Alpena and Grand Rapids, 1.00 and 1.10 respectively, was nearly double those at the other locations.

Thermal Tolerance

All genotypes of *P. infestans* survived in vitro exposure up to 1 day at 0 and -3°C. Exposure of A2 genotypes to -5°C up to 24 h at was not always lethal but A1 genotypes were not able to survive exposure of 24 h. A1 and A2 genotypes survived 1 h exposure to –10 and -20°C and A2 genotypes sometimes survived exposure to 24 h at –10 but not –20°C. So far, exposure of mycelium to 0°C for up to 5 days has not proved to be lethal to any genotype. Both A1 genotypes survived exposure of up to 2 days at –3°C and A2 genotypes consistently survived exposure to 4 days and some recovery was also measured after 5 days exposure. A1 genotypes did not survive exposure of 1 day at –5°C but A2 genotypes showed some potential for recovery (Table 2).

DISCUSSION

Environmental conditions between 1948 and 1999 became more conducive for development of potato late blight throughout the Upper Great Lakes region, within the parameters of what is currently known about the influence of temperature and relative humidity on late blight development. Indicators not discussed in this case study showed that accepted fungicide spray thresholds are occurring earlier after planting i.e. when accumulation of DSV = 18 and 30; that Wallin day-type 2 is increasing in frequency i.e. when relative humidity is > 90% for 19 – 21 h at 7 – 12°C or 16 – 18 h at 12 – 15°C or 13 – 15 h at 15 – 27°C; risk of late blight conducive conditions are increasing before highest risk peak in August; and average temperature and dew point temperature are increasing (Baker 2002). These agree with other published data that indicate increasing precipitation and an increasing number of wet following wet days in the Midwest US (Karl and Knight 1998; Andresen, Alagarswamy et al. 2001). The measured increase in average temperature is of concern both from the perspective of increasing the favorability of ambient

conditions conducive to late blight and because canopy development is directly related to temperature. Canopy closure occurring earlier in the season prolongs the duration of late blight risk.

CONCLUSIONS

The apparent increased tolerance of A2 genotypes of *P. infestans* that are also mefenoxam-resistant, to lower temperatures is cause for concern. As the environment in which the mycelium of *P. infestans* survives (potato tubers) is less frequently exposed to temperatures which normally cause substrate breakdown (about $-3^{o}C$) the risk of survival of blighted tubers surviving winter also increases. Risk of infection has also been increasing with the advent of mefenoxam-insensitive strains of *P. infestans* and tightening fungicide regulations. Although host resistance may become an option, in the immediate future this is not a viable solution to late blight risk until new varieties have market acceptance. Taken together, these trends indicate that potato production is becoming relatively more difficult through time in the Upper Great Lakes region.

Literature Cited

Andresen, J., Alagarswamy, G., Rotz, C.A., Ritchie, J.T. and LeBaron, A.W. 2001. Weather impacts on maize, soybean, and alfalfa production in the Great Lakes region, 1895-1996. Agronomy Journal 93: 1059-70.

Baker, K.M. 2002. Spatial and temporal modeling of microclimate for risk assessment and management of late blight (*Phytophthora infestans*) in Michigan potatoes. Ph.D Thesis, Department of Geography, Michigan State University.

Baker, K.M., Andresen, J.A., Kirk, W.W. and Stein, J.M. 2000. Crop disease mitigation: daily risk modeling for Michigan potato growers. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospect and Research Needs, Banff, Alberta, Canada.

Bollen, G.J. 1985. Lethal temperatures of soil fungi. Ecology and Management of Soil-borne Plant Pathogens. A.D.R.C.A. Parker, K.J. Moore, P.T.W. Wong, and J.F. Kollmorgen. St. Paul, MN, The American Phytopathological Society: 191-193.

Coelho, L., Mitchell, D.J. and Chellemi, D.O. 2000. Thermal inactivation of *Phytophthora nicotianae*. Phytopathology 90: 1089-1097.

Forbes, G.A., Goodwin, S.B., Drenth, A., Oyarzun, P., Ordonez, M.E. and Fry, W.E. 1998. A global marker database for *Phytophthora infestans*. Plant Disease 82(7): 811-818.

Fry, W.E. and Goodwin, S.B. 1997. Re-emergence of potato and tomato late blight in the United States. Plant Disease 81(12): 1349-1357.

Fry, W.E., Goodwin, S.B., Dyer, A.T., Matuszak, J.M., Drenth, A., Tooley, P.W., Sujkowski, L.S., Koh, Y.J., Cohen, B.A., Spielman, L.J., Deahl, K.L., Inglis, D.A. and Sandlan, K.P. 1993. Historical and Recent Migrations of *Phytophthora infestans* - Chronology, Pathways, and Implications. Plant Disease 77(7): 653-661.

Goodwin, S.B., Schneider, R.E. and Fry, W.E. 1995. Use of cellulose-acetate electro-phoresis for rapid identification of allozyme genotypes of *Phytophthora infestans*. Plant Disease 79(11): 1181-1185.

Gray, J.I. and Whalon, M.E. 1996. The assessment of pesticides at risk in the future of Michigan food and feed plant agriculture: A process. East Lansing, Michigan Agricultural Experiment Station: 15.

Guenthner, J.F., Michael, K.C. and Nolte, P.E. 2001. The economic impact of potato late blight on US growers. Potato Research 44: 121-125.

Juarez-Palacios, C., Felix-Gastelum, R., Wakeman, R.J., Paplomatas, E.J. and DeVay, J.E. 1991. Thermal sensitivity of three species of Phytophthora and the effect of soil solarization on their survival. Plant Disease 75: 1160-1164.

Karl, T. and Knight, R. 1998. Secular trends of precipitation amount, frequency, and intensity in the United States. Bulletin of the American Meteorological Society 79(2): 231-241.

Kirk, W.W., Felcher, K.J., Douches, D.S., Coombs, J., Stein, J.M., Baker, K.M. and

Hammerschmidt, R. 2001. Effect of host plant resistance and reduced rates and frequencies of fungicide application to control potato late blight. Plant Disease 85(10): 1113-1118.
Kirk, W.W., Niemira, B.A. and Stein, J.M. 2001. Influence of storage temperature on rate of potato tuber tissue infection caused by different biotypes of *Phytophthora infestans* (Mont.) de Bary estimated by digital image analysis. Potato Research 44:86–96.
Lambert, D.H., Currier, A.I. and Olanya, M.O. (1998). Transmission of *Phytophthora infestans* in cut potato seed. American Journal of Potato Research 75(6): 257-263.
Niemira, B.A., Kirk, W.W. and Stein, J.M. 1999. Screening for late blight susceptibility in potato tubers by digital analysis of cut tuber surfaces. Plant Disease 83(5): 469-473.
Powelson, M.L. and Inglis, D.A. 1999. Foliar fungicides as protective seed piece treatments for management of late blight of potatoes. Plant Disease 83(3): 265-268.
Sen, P. 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 63: 1379-1389.
Wallin, J.R. 1962. Summary of recent progress in predicting late blight epidemics in United States and Canada. American Potato Journal 39: 306-312.
Zentmyer, G.A. 1981. The effect of temperature on growth and pathogenesis of *Phytophthora cinnamomi* and on growth of its avocado host. Phytopathology 71: 925-928.
Zwankhuizen, M.J., Govers, F. and Zadoks, J.C. 1998. Development of potato late blight epidemics: Disease foci, disease gradients, and infection sources. Phytopathology 88(8): 754-763.

Tables

Table 1. Analysis of accumulated late blight Disease Severity Values (DSV) per growing season, May 1 through September 30, at seven locations in the greater Michigan region from 1948-1999 including a) the median DSV accumulated per growing season and b) the rate of change in DSV accumulated per growing season.

Site of weather station	a) Median number DSV[1] accumulated per growing season[2]		b) Non-parametric trend *B* (rate of change in DSV per year) for DSV accumulated per growing season	
	Median		*B*	
Sault Ste Marie, MI[3]	64.0	b[4]	0.55	**[5]
Alpena, MI	64.0	b	1.00	***
Traverse City, MI	51.0	b	0.25	
Green Bay, WI	92.5	a	0.56	**
Muskegon, MI	80.0	a	0.54	*
Grand Rapids, MI	82.0	a	1.10	*
Toledo, OH	95.0	a	0.61	

[1] Disease severity value index (Wallin 1962) dependent on meteorological variables calculated for each day from May 1 through Sept 30 at each location every year. DSV were based on a modified Wallin method used by Michigan State University Late Blight Lab (Baker, Andresen et al. 2000).
[2] Growing season included May 1 through September 30 (153 days).
[3] National Weather Service (NWS) station locations: Y62 - Sault Ste Marie; APN - Alpena; TVC - Traverse City; GRB - Green Bay, WI; MKG - Muskegon, MI; GRR - Grand Rapids, MI; TOL - Toledo, OH.
[4] Within a single column, values followed by the same letter are not significantly different at P = 0.05 (Kruskal-Wallis One Way Analysis of Variance on Ranks).
[5] Rate of change is significantly greater than zero at each location at P = 0.05 (*), P = 0.01 (**), or P = 0.001 (***); (Kendall Tau b).

Table 2. Survival of isolates of different genotypes of *P. infestans* exposed to temperatures from 0 to -20°C for different durations up to 24 hours and 0 – 5 °C from 1 to 5 days measured as average reflective intensity of images of cultures incubated for 4 weeks after exposure at 12°C.

Treatment temperature °C	Exposure duration	Genotype of *Phytophthora infestans* isolate (mating type)			
		US1 (A1)	US8 (A2)	US11 (A1)	US14 (A2)
Experiment 1 (up to 24 h)					
0 and -3	1	+[1]	+	+	+
	4	+	+	+	+
	8	+	+	+	+
	12	+	+	+	+
	24	+	+	+	+
-5	1	+	+	+	+
	4	+	+	+	+
	8	+/-	+	+/-	+
	12	+/-	+	+/-	+
	24	-	+/-	-	+/-
-10	1	+	+	+	+
	4	-	+/-	-	+/-
	8	-	-	-	+/-
	12	-	-	-	-
	24	-	-	-	-
-20	1	+	+	+	+
	4	-	-	-	-
	8	-	-	-	-
	12	-	-	-	-
	24	-	-	-	-
Experiment 2 (up to 5 days)					
0	1	+	+	+	+
	2	+	+	+	+
	3	+	+	+	+
	4	+	+	+	+
	5	+	+	+	+
-3	1	+	+	+	+
	2	+	+	+	+
	3	-	+	-	+
	4	-	+	-	+
	5	-	+/-	-	+/-
-5	1	-	+/-	-	+/-
	2	-	-	-	-
	3	-	-	-	-
	4	-	-	-	-
	5	-	-	-	-

[1] '+' = growth significantly greater than ARI on non-inoculated plates, ARI = 90 - 100, '+/-' = growth not significantly different from ARI on non-inoculated plates, ARI = 90 – 100 and nsd from ARI on plates with '+' evaluation, '-' = colonies dead, not significantly different from non-inoculated plates (ARI = 90 - 100).