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Full Length Article

Development of Predictive Model Based on Epidemiological Factors for the Management of Potato Late Blight Disease

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Abstract

Potato late blight (PLB) caused by *Phytophthora infestans* (Mont.) de Bary, is an important and serious threat to successful potato production in the world. It spreads through seed and soil residual material. In Pakistan, PLB disease may cause complete crop failure under severe epidemic conditions. Due to lack of resistance in indigenous potato germplasm, disease is managed through fungicides by the growers of Pakistan. Nonetheless, excessive use of fungicides cause resistance in the pathogen and create fatalistic effect on the environment. Disease predictive model under such situation may be effective tool to predict early onset of disease which is helpful to reduce number of sprays. The data of five susceptible to highly susceptible varieties sown for consecutively ten years were collected from Plant Pathology Section, Ayub Agricultural Research Institute (AARI), Faisalabad. A disease predictive model was developed based on ten years data of PLB severity and epidemiological variables using stepwise regression analysis. The model was validated by regression model based on two years data. The results revealed that the ten years model explained 74%, while two years model explained 80% disease variability. In accordance of variety wise models, SH-5 and Diamont models explained up to 91% and 89% disease variability, respectively during two year. The predictive model was used for the management of PLB disease and only three sprays were applied. Applied sprays reduced the PLB disease severity on all the five varieties (N-22, FD48-4, FD69-1, FSD White and Cardinal) up to 2.46, 6.50, 2.50, 8.46 and 1.67%, respectively. All the treatments significantly reduced the disease severity whereas Phenylamide and Propineb were the most effective as compared to the control. Prediction of disease model would be helpful to apply two or three sprays of fungicides (Phenylamide and Propineb) to control late blight of potato successfully.

Keywords: Environmental variables; Potato late blight; *Phytophthora infestans*

Introduction

Phytophthora infestans is a water mold lower fungus that infects potato crop during cool and wet weather, causing potato late blight. This disease on potato crop is a major concern to potato growers worldwide and considered to be the most economically important disease to potato crop in North America (Guenther *et al*., 2001). Potato late blight (PLB) disease is both seed and soil borne. Seed and soil are important factors in primary inoculum of PLB disease. Infection of shoots via infested tubers can be caused by mycelium growing from the tuber into the developing stem tissue or via sporangia and zoospores formed on the tuber surface under moist conditions (Johnson, 2010).

In Pakistan, late blight of potato causing 50–70% potato yield loss under favourable environmental conditions (Haq *et al*., 2008; Rahman *et al*., 2008) which can reach upto 100% (Ghorbani *et al*., 2004). Forecasting models that predict the likelihood of late blight outbreaks may provide important information for potato producers in Pakistan, enabling farmers to implement a timely disease management plan. Practical benefits include an advanced warning system for Faisalabad potato growers in Pakistan. When the disease prevails suddenly farmers have no option except to spray the crop with some effective chemicals (Kirk *et al*., 2005). Current management of late blight is done through repeated fungicides application but consumer concerns more chemical use of spray applications at the time of maximum disease risk (Henshall and Beresford, 2004). Although use of systemic and protectant fungicides for controlling late blight has been the most important aspect of disease management in temperate countries (Olanya *et al*., 2001). Frequent use of fungicides is neither economical nor beneficial for the environment and human health. Environmental factors play significant role in the development of the epiphytotics (Zwankhuizen and Zadoks, 1998). For the most efficient and sustainable disease management strategies, epidemiological and biological data were used to develop a model for the management of late blight dynamics (Khan and Khan, 2000).

Models allow studying the inoculum in a particular area and the suitable environmental conditions for the pathogen, which lead to forecast the emergence of late blight (Morales *et al.*, 2004; Naerstad *et al.*, 2007). Forecasting model gives an early prediction that may help to control late blight without or with minimum number of fungicidal sprays (Shtienberg, 2010). Jhorar *et al*. (1997) developed a disease predictive model based on 15 years data and found that environmental factors (temperature and relative humidity) played significant role in disease development. Disease forecasting models demand a permanent need of validation due to continuous modifications in the model (Andrade-Piedra *et al.,* 2005). The method of validation is to test the model fitness within its region of application and consistent with its future aspects (Grünwald *et al.*, 2002). A disease predictive model may reduce uncertainty about the management decisions by providing a quantitative description of disease potential. Thus the hypothesis of the current study was that the predictive model based upon environmental variables would be helpful for the economic and timely management of disease using fungicides.

In view of the heavy losses caused by PLB disease, it is necessary to record the actual occurrence of the disease and to study its relationship with environmental conditions in major potato growing areas of the Punjab, Pakistan. This information will provide a base for the development of a disease predictive model and to establish a forecasting system in future. This system will facilitate the farmers to take preventive decision against the pathogen. Several available chemicals applied against the pathogen to control the disease. The non-judicious use of pesticides causes environmental pollution and hazards (Xiliu, 2000) and increasing the cost of crop production. Usually in Pakistan 6-7 sprays are applied for the management of PLB disease (Ghazanfar *et al*., 2010). Disease predictive model helps to reduce number of sprays, which leads to economical and environment friendly management of the pathogen population.

This study was therefore, conducted undertaken to develop and validate a PLB disease predictive model, and to evaluate the effectiveness of different fungicides for economical and environmentally safe management of the disease under field conditions by using disease predictive model.

Materials and Methods

Collection of Disease Severity and Environmental Variables Data

For the development of a model, previous ten years (2001-2010) potato late blight disease severity unpublished data of five susceptible varieties (Desiree, Diamont, SH-5, SH-339 and FD35-36) were collected from Plant Pathology Section, Ayub Agricultural Research Institute (AARI), Faisalabad, continuously cultivated for ten years. In the Plant Pathology Section, (AARI), Faisalabad, these varieties were sown in randomized complete block design (RCBD), each variety had three replications. Each entry was planted in a 15 m length row. The tubers were planted through dibbler at a distance of 25 cm. The row to row distance between two entries was 75 cm. In each season, tubers were sown in autumn planting (middle of October) and harvested at the end of February. Plots were inoculated with spore suspension of *P. infestans* (5000 spores/mL). Disease severity data were recorded on weekly basis from the month of December to February on five varieties during all ten years (2001-2010) using 1-9 Henfling disease rating scale (Henfling, 1979). Environmental variables data consisting of rain fall, maximum and minimum air temperature, wind speed and relative humidity were also collected from Ayub Agriculture Research Institute (AARI), Faisalabad. The influence of each variable (rainfall, maximum and minimum air temperature, wind speed and relative humidity) on disease development was determined by correlation and regression analysis. The data were analyzed using two statistical software's packages i.e. IBM SPSS statistics 22 and SAS 9.3 (SAS institute, 1990). Effects of environmental variables on disease severity were determined by correlation analysis (Steel Torrie, 1997). Disease predictive model for PLB disease based on ten years (2001-2010) environmental variables was developed using stepwise regression analysis (Myers, 1990).

Establishment of Experiment for Validation of Model

The present study was conducted at the Experimental Area, Department of Plant Pathology, University of Agriculture Faisalabad during the autumn season of 2011-2012 and 2012-2013. Experiment was conducted under natural conditions for two consecutive seasons. In each season, tubers were sown in autumn planting (October 18, 2011 and October 23, 2012) and harvested at the end of February in sandy loam soil. Five varieties of potato against late blight disease were bought from Potato Research Center Sahiwal. The planted potato varieties were Desiree, Diamant, SH-5, SH-339 and FD35-36. Experiment was laid out in a randomized complete block design in a factorial arrangement with three replicates per treatment and net plot size was 6 m × 3 m. The distance between plant to plant (P×P) was 20 cm and row to row (R × R) was 75 cm. Fifteen plants were planted in a single row. Two year disease severity data were recorded on weekly basis during the growing seasons of 2011-2012 and 2012-2013, starting from 2nd week of January to last week of February.

Observations

The data on disease severity were recorded on weekly basis after disease prevailing using 1-9 Henfling scale till the end of the season (Henfling, 1979). Where 1 indicated that there was no disease (immune) and 9 indicated that all the leaves and stems were drying and dead due to disease (highly susceptible). The host status was assessed by HS: Highly susceptible (8-9 grade on rating scale), S: Susceptible (7 grade on rating scale), MS: Moderately susceptible, (5-6 grade on rating scale), MR: Moderately resistant (3-4 grade on rating scale), R: Resistant (2 grade on rating scale) and HR: Highly resistant (1 grade on rating scale). Data of environmental factors maximum temperature, minimum temperature, relative humidity, rainfall and wind speed was collected from the website www.uaf.edu.pk. Weather station was installed at the experimental station of University of Agriculture, Faisalabad and environmental variables data was used with the permission institute.

Validation of Model by Two Years Data (2011-2013)

The model developed from ten years (2001-2010) data collected from AARI, Faisalabad were validated on two years (2011-2013) data recorded from the experiment established in research area of the Department of Plant Pathology, UAF. The environmental data consisting of maximum and minimum temperature, rainfall, wind speed and relative humidity and disease severity on five varieties sown at UAF from November 2011 to February 2013 were used for the model validation. The data were analyzed using statistical software SAS 9.3 (Statistical Analysis Software) (SAS Institute, 1990). Effects of environmental variables (maximum temperature, minimum temperatures, relative humidity, rainfall and wind speed) on disease severity were determined by correlation analysis (Steel and Torrie, 1997). Severity of potato late blight recorded from plots and the weekly environmental data were subjected to stepwise regression analysis to determine the significance of environmental conditions conducive for disease development; Multiple regression models were developed employing late blight severity for all five varieties for two years as the dependent variable, with environmental variables (maximum, minimum air temperature, rainfall, relative humidity and wind speed) as independent variables. All possible regressions were calculated using SAS with intercept model (SAS Institute, 1990). Coefficient of determination (R^2) (maximum value), mean square error (MSE) (minimum value) and Mallows C (p) (p = number of regressor variables in the model) were used to select the best model to predict late blight severity (Myers, 1990).

Management of Potato Late Blight under Field Conditions

Five potato varieties N-22, FD-48-4, FD-69-1, FSD- White and Cardinal tolerant to potato late blight bought from Potato Research Center Sahiwal, were sown under randomized complete block design with three replications at the research area of Department of Plant Pathology, University of Agriculture, Faisalabad. The distance between plant to plant (P × P) was 20 cm and row to row (R × R) was 75 cm. Treatments were randomized within the replication in a block. In each replication there were seven treatments and a control. Fungicides are often applied to control PLB when favorable conditions of disease are prevailed. Two types of fungicides are used for the chemical control of late blight: contact fungicides (more properly defined as non-systemic, also called residual fungicides) and systemic fungicides. Contact fungicides are also known as protective or preventive fungicides, while the systemic ones are also known as curatives. It is the authors' understanding that these terms are not adequately used and may create confusion among farmers. Thus, they use systemic fungicides only when late blight symptoms are evident (because they consider them as "curative"), by which time it is often too late to control the disease well. Consequently, in this document, the terms used will be contact and systemic. The fungicides including three contact (Hexamethylenetetramine 3.5 g L^{-1}, Propineb 2.5 mL L^{-1} and Acitamide 2.4 g L^{-1}) and four systemic (Fluopicolide 3.5 mL L^{-1}, Iprovalicarb 3 g L^{-1}, Phenylamide 2 g L^{-1} and Ethyl hydrogen phosphonate 2.5 g L^{-1}) were selected to evaluate their effectiveness for controlling PLB disease. The fungicides were applied at their commended doses. Untreated rows of each variety served as check. First spray of the fungicides was applied after sixty five days when thirty to forty percent symptoms of disease appeared. Second and third spray was applied after 7 days interval. All data of potato late blight disease as influenced by the treatments were statistically analyzed through statistix 8.1 software, all possible interactions and comparisons of fungicides were determined through analysis of variance. Least Significant Difference test was used for mean separation at 5% level of probability (Steel and Torrie, 1997).

Results

PLB Disease Predictive Model Based on Ten Years Data (2001-2010)

Weather variables *viz.* maximum and minimum temperature, relative humidity, rainfall and wind speed examined in order to develop a disease predictive model. Disease severity data of five susceptible to highly susceptible varieties (Desiree, Diamant, SH-5, SH-339 and FD35-36) consecutively sown for ten years (2001-2010) were taken from AARI, Faisalabad, Pakistan. Three environmental variables i.e., maximum temperature, relative humidity and wind speed were positively significant among five environmental conditions with all five varieties/lines i.e., Desiree, Diamont, SH-5, SH-339 and FD35-36 during ten years in predicting disease occurrence in the multiple linear regression model. A negatively significant correlation was observed between relative humidity and rain fall with PLB disease severity in case of all five varieties i.e., Desiree, Diamont, SH-5, SH-339 and FD35-36 except

FD35-36 which showed non-significant correlation in relative humidity (Table 1).

In the present study a multiple regression model was selected on the basis of coefficient of determination R^2 (maximum value), mean square error MSE (minimum value) and Mallows Cp (p = number of regressor variables in the model) minimum value. The model statistically justified, $R^2 = 0.74$ at $P<0.05$, C (p) = 6.0 and MSE = 0.97 was used to predict the probable attack of PLB disease under a set of given environmental variables given as under:

$$Y = 28.89 - 0.63x_1 + 0.10x_2 - 0.18x_3 - 0.80x_4 + 0.19x_5 \quad R^2 = 0.74$$

Where Y = PLB disease severity, X_1 = Maximum temperature, X_2 = Minimum temperature, X_3 = Relative humidity, X_4 = Rainfall and X_5 = Wind speed.

The detailed disease predictive regression model was developed through stepwise regression method. It is evident from the model that all major factors responsible for the occurrence of PLB disease were maximum and minimum temperature, relative humidity, rainfall and the wind speed at that time. It indicated that with one unit change in minimum temperature and wind speed there would be probable positive change of 0.10 and 0.19 units in PLB disease. The negative change would be 0.63, 0.18 and 0.80 units in case of maximum temperature, relative humidity and rainfall, respectively.

One of the most important parameter to check the model reliability is the value of coefficient of determination, i.e., R^2. In the present study it was 74%, which is considered fairly good particularly under field conditions when one has no control on any of the studied variables (Table 2). Similarly standard error of estimate was not so high (6.71). The F-distribution of regression model was significant at P<0.05 (Table 3). The relative contribution of maximum and minimum temperature, relative humidity, rain fall and wind speed towards the development of model was significant at <0.05 (Table 4). Each independent variable in the model showed quite low standard error ~5 (Table 2). These criteria indicated that the model was statistically good, and may effectively predict potato late blight disease severity. Analysis of variance of model data was highly significant. All the environmental variables and disease severity showed significance towards model development.

The model with significant variables was developed by stepwise regression and evaluated to predict PLB disease severity during ten years. Out of five variables entered, four of them i.e. minimum temperature, relative humidity, maximum temperature and wind speed exerted significant influence in the development of disease. In stepwise regression analysis rainfall was assessed as its influence was very poor. The model containing these variables explained 19 to 74 percent variability in disease development (Table 4). When this five environmental variable model was used to predict PLB disease severity, there was a fairly good R^2 value 74%, low C (p) 6.00 and low standard error value 6.71 obtained (Table 2 and 4).

PLB Disease Predictive Model Based on Two Years Data (2012-2013)

During 2012, potato late blight symptoms appeared on lower leaves of SH-5 and Diamont during 2nd week and on the upper leaves in the 3rd week of January. The disease symptoms got intensified in the subsequent three weeks and no symptoms could be recorded during 2nd week of February due to severe necrosis of leaves. Symptoms of late blight of low and mild severity were recorded on Desiree, SH-339 and FD35-36, respectively. Based on late blight severity scale, SH-5 and Diamont were graded moderately susceptible, Desiree, SH-339 and. FD35-36 as moderately resistant. During 2013, late blight symptoms expression was late. On SH-5 and Diamont appearance of blight pustules on upper leaves were evident in the 4th week of January and necrosis of leaves due to disease took place during 3rd week of February. Based on late blight severity scale SH-5 and Diamont were graded as moderately Susceptible, Desiree, SH-339 and FD35-36 as moderately resistant varieties, respectively. Late blight severity was significantly higher on SH-5 and Diamont compared to Desiree, SH-339 and FD35-36 during both the seasons (Table 5). The disease severity was higher on all varieties during 2012-2013 compared to 2011-2012 but the difference in mean disease severity was not statistically significant in all varieties. Except weekly rainfall, environmental conditions were not significantly different during the two years (Table 5). Weekly rainfall was significantly higher in 2012-2013 compared to 2011-2012. Remaining four environmental variables i.e. weekly maximum and minimum temperatures, relative humidity and wind speed expressed statistically same during both seasons (Table 5).

In two year study a multiple regression model was selected on the basis of above mentioned parameters as in ten years model. The model statistically justified, $R^2 = 0.80$ at $P<0.05$, C(p) = 6.0 and MSE = 0.55 was used to predict the probable attack of PLB disease under a set of given environmental variables given as under:

$$Y = -6.03 + 0.29x_1 + 0.29x_2 + 0.03x_3 + 0.08x_4 + 0.49x_5 \quad R^2 = 0.80$$

Where Y= PLB disease severity, x_1= Maximum temperature, x_2= Minimum temperature, x_3 = Relative humidity, x_4 = Rainfall and x_5 = Wind speed (Table 6).

The models with significantly important environmental variables were developed by stepwise regression on five potato varieties separately to predict PLB disease development during two years (2011-2013). Out of five variables entered, two of them i.e., maximum temperature and wind speed exerted significant influence in the development of disease actively in case of three varieties i.e., Desiree, Diamont and SH-5, while minimum temperature and wind speed appeared as the main contributing environmental variables in the stepwise regression analysis in case of SH-339 and FD35-36 varieties. In stepwise regression analysis minimum

Table 1: Correlation of environmental conditions with PLB disease severity during 10 years (2001-2010)

Varieties	Environmental Factors									
	Maximum temp. (°C)		Minimum temp. (°C)		Relative Humidity (%)		Rainfall (mm)		Wind speed (km/h)	
Desiree	0.5410*	0.0188	0.9106*	0.0018	-0.5390*	0.0001	-0.3891*	0.0021	0.8271*	0.0152
Diamont	0.5830*	0.0150	0.8714*	0.0151	-0.4712*	0.0382	-0.4552*	0.0010	0.7309*	0.0408
SH-5	0.6020*	0.0150	0.7811*	0.0200	-0.4413*	0.0011	-0.5251*	0.0020	0.8634*	0.0076
SH-339	0.6511*	0.0357	0.8402*	0.0045	-0.3935*	0.0002	-0.3322*	0.0121	0.8275*	0.0134
FD35-36	0.6310*	0.0001	0.8911*	0.0170	-0.4115^{NS}	0.2231	-0.5322*	0.004l	0.8112*	0.0394

* Significant at P = 0.05; NS = Non significant

temperature was assessed as its influence was very poor in Desiree, Diamont and SH-5, while maximum temperature was very poor in SH-339 and FD35-36 varieties. Environmental conditions and late blight severity recorded on potato varieties slightly differed in two seasons. SH-5 variety model was observed most suitable to predict disease development as compared two other four variety wise models. The model statistically justified, coefficient of determination R^2 = 0.91 at P<0.05, Mallows Cp = 2.15 and MSE = 1.35 values (Table 7). Selected model was used to predict the probable attack of PLB disease under a set of given environmental variables given as under: $Y = –4.33+ 0.32x_1 + 0.34x_2 + 0.53x_3$ (where Y= potato late blight severity, x_1=maximum temperature, x_2= minimum temperature and x_3 = wind speed). During two years 2011-2013, two multiple regression models containing weekly maximum and minimum temperatures and wind speed explained more than 88% of the variability in PLB disease development on SH-5 = $–4.33+ 0.32x_1 + 0.34x_2 + 0.53x_3$ and Diamont = $–5.26 + 0.36x_1 + 0.32x_2 + 0.51x_3$ (where x_1=maximum temperature, x_2= minimum temperature and x_3 = wind speed) varieties respectively, were most reliable models to predict disease development as compared two other three variety wise models (Table 7).

PLB Disease Predictive Model Validation with Two Year Model

Using the same set of data for model selection and inference, without model validation, may lead to unreliable models. The most reliable option in validating the model is making prediction by collecting data from some other source/location., i.e., any other data not used in the model development. Therefore, model developed from ten years (2001-2010) data collected from AARI, Faisalabad was validated on two years data (2011-2013) collected from the experiment established in the research area of the Department of Plant Pathology, University of Agriculture Faisalabad. The regression lines of the two models showed good fit in to the data. The multiple regression model based on ten years data indicated by R^2 0.74 which can be compared with multiple regression model based on two years data indicated by R^2 0.80. The two regression lines were in close proximity. The comparison of the two models is given in the Table 9. The P-value for model comparison was 3.92, which was not significant indicating that two models can be super imposed with each other (Table 8).

Table 2: Regression statistics of the predictive model for PLB based on ten years (2001-2010)

Regression Statistics	
R-Square	74%
Adj-R Square	73%
MSE	0.97
Standard Error of Y	6.71
Total observations	900

Table 3: Analysis of variance of the predictive model for PLB based on ten years (2001-2010)

Source	DF	Sum of Squares	Mean Square	F Value	P Value
Regression	5	1390.61	278.12	283.79	0.001**
Error	894	878.06	0.98		
Total	899	1668.67			

** = Significant at P<0.05

Table 4: Summary of stepwise regression model to predict PLB disease during 2001-2010

Variable Entered	No. in model	Model R^2	C(p) Value	F Value	P Value
Rainfall (mm)	1	0.19	618.49	70.20	0.001**
Wind speed (km/h)	2	0.41	370.52	111.72	0.001**
Maximum temperature (°C)	3	0.55	221.87	86.78	0.001**
Relative humidity (%)	4	0.73	12.01	206.96	0.001**
Minimum temperature (°C)	5	0.74	6.00	8.00	0.005**

** = Significant at P<0.05

Table 5: Comparison of weekly environmental variables and PLB disease severity recorded on potato varieties during two years (2011-2013)

Environmental factors	2011-2012	2012-2013
Maximum temperature (°C)	17.83 a*	18.66 a
Minimum temperature (°C)	03.42 b	03.44 b
Relative humidity (%)	67.00 c	68.25 c
Rainfall (mm)	00.13 d	03.17 b
Wind speed (km/h)	03.28 b	03.29 b
LSD	2.47	
Potato Varieties		
	Potato late blight severity	
SH-5	5.07 a*	5.61 a
Diamont	5.13 ab	5.86 b
SH-339	3.82 b	3.86 c
Desiree	3.56 c	3.71 c
FD35-36	3.35 c	4.08 b
LSD	0.25	0.21

*Mean values within rows sharing similar letters are not differ significantly as determined by the LSD test (P = 0.05)

Table 6: Partial regression coefficients of variables, standard error, t stat, p-value and level of their significance

Variable	Parameter Estimate	Standard Error	Type II SS	T stat	P Value
Intercept	-6.03	1.09	16.76	30.56	0.001**
Maximum temperature (°C)	0.29	0.04	26.73	48.73	0.001**
Minimum temperature (°C)	0.29	0.06	12.53	22.85	0.001**
Relative humidity (%)	0.03	0.02	1.71	3.12	0.019**
Rainfall (mm)	0.08	0.04	2.77	5.05	0.026**
Wind speed (km/h)	0.49	0.03	124.67	227.30	0.001**

** = Significant at P<0.05

Table 7: Multiple regression equations based on weekly environmental variables and predicted PLB disease severity values during two years (2011-2013)

Regression equations of PLB Disease Severity (%)			R^2
$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3$			
	Observed	Predicted	
Desiree $= -4.488 + 0.36X_1 + 0.49X_2$	1.25	1.02	0.80
(X_1=maximum temperature, X_2= wind speed)	5.50	5.16	
	5.75	5.24	
	2.20	2.54	
Diamont $= -5.26 + 0.36X_1 + 0.32X_2 + 0.51X_3$	5.25	5.21	0.89
(X_1=maximum temperature, X_2= min. temperature, X_3 = wind speed)	1.10	1.09	
	5.67	5.43	
	6.42	6.27	
SH-5 $= -4.33 + 0.32X_1 + 0.34X_2 + 0.53X_3$	4.33	4.30	0.91
(X_1=maximum temperature, X_2= min. temperature, X_3 = wind speed)	3.75	3.82	
	6.00	5.91	
	1.15	1.25	
SH-339 $= -3.85 + 0.26X_1 + 0.38X_2 + 0.51X_3$	5.08	5.07	0.86
(X_1=maximum temperature, X_2= min. temperature, X_3 = wind speed)	1.10	0.99	
	6.00	5.97	
	1.00	1.10	
FD35-36 $= -12.54 + 0.29X_1 + 0.14X_2 + 0.43X_3$	4.90	4.92	0.80
(X_1= max. temperature, X_2= min. temperature, X_3= wind speed)	1.08	1.05	
	4.42	4.33	
	4.17	3.87	

Management of Potato Late Blight through Different Fungicides during 2011-2013

Late blight symptoms appeared on January 12, 2011 and January 15, 2012 in the form of blighted areas consisting of faded green patches turning to brownish black. These lesions were not delimited in size and enlarged rapidly and leaf tissue became necrotic. At the time of first spray there was uniform spread of the disease on most of the varieties. All the fungicides were significantly effective in reducing PLB disease severity compared to untreated control. All the chemicals were significantly different from each other in both years except Ethyl hydrogen phosphonate and Fluopicolide. Phenylamide and Propineb were more effective during 2011-2013. Fluopicolide and Hexamethylenetetramine were less effective during two years (Table 9).

The mean PLB severity was significantly reduced in all varieties i.e., N-22, FD48-4, FD69-1, FSD White and Cardinal in first, second and third sprays during 2012-2013 year while mean PLB disease severity significantly reduced in three varieties i.e., N-22, FD48-4 and FSD White in first, second and third sprays during 2011-2012 year. Three varieties i.e., N-22, FD69-1 and FSD White had significant difference in mean disease severity in third spray with respect to first and second sprays during 2011-2012 and 2012-2013, while variety FD48-4 had no significant difference in its mean disease severity among all three sprays during both years except third spray in 2012-2013 year (Table 10). In first and second sprays three varieties i.e., FD69-1, FSD White and Cardinal showed significant difference in mean disease severity during 2011-2012 year while two varieties N-22 andFD48-4 showed no significant difference in mean disease severity. In third spray three varieties i.e. N-22, FD69-1 and Cardinal showed significant difference in their mean disease severities while two varieties FSD White and FD48-4showed no significant difference during 2011-2012 (Table 10).

Discussion

Present study depicts that disease forecasting models are a useful component in plant disease management. They enable predictions of disease outbreaks, and therefore lead to improved use of control measures. A large amount of research has been directed at forecasting potato late blight

Table 8: Comparison of two models for validation

Model	Regression equations	R^2 Value	F value	P value
Model(I)	$Y= 28.89 - 0.635x_1 + 0.101x_2 - 0.181x_3 - 0.806x_4 + 0.193x_5$	0.74		
Vs	Vs			
Model(II)	$Y= - 6.035 + 0.294x_1 + 0.297x_2 - 0.028x_3 + 0.078x_4 + 0.496x_5$	0.80	393.64	3.92^{NS}

Model (I) = Model based on ten years data
Model (II) = Model based on two years data

Table 9: Year wise comparison of treatments with PLB disease severity during 2011-2013

Treatment	Chemical name	2011-2012	2012-2013
		Mean disease severity%	Mean disease severity%
T0	Control	40.69 a*	40.48 a
T1	Iprovalicarb	30.32 cde	30.22 bc
T2	Propineb	23.02 e	25.04 bc
T3	Phenylamide	19.09 de	18.78 c
T4	Hexamethylenetetramine	30.74 ab	30.17 bc
T5	Ethyl hydrogen phosphonate	30.53 bc	30.09 bc
T6	Acitamide	30.42 bcd	30.20 bc
T7	Fluopicolide	30.93 b	30.90 b
LSD		05.05	07.03

*Means with similar letters in a column are not significantly different at $p = 0.05$

Table 10: Comparisons of potato late blight severity with varieties, sprays and years

Varieties	2011-2012			2012-2013		
	1st Spray	2nd Spray	3rd Spray	1st Spray	2nd Spray	3rd Spray
N-22	40.63 bc*	37.54 bc	17.46 d	39.08 bc	38.25 bc	2.46 hi
FD48-4	36.46 c	34.38 c	25.88 c	35.42 c	34.37 c	6.50 efg
FD69-1	37.33 ef	9.92 def	4.21 g	9.96 de	9.91 def	2.50 hi
FSD White	90.96 a	86.25 a	38.54 bc	88.81 a	86.15 a	8.46 efg
Cardinal	2.25 ij	2.58 hi	2.54 hi	2.04 gh	2.58 hi	1.67 j
LSD	0.61					

*Means with similar letters in a row and column are not significantly different at $p = 0.05$

throughout the world. Three main attributes of late blight that justify the use of forecasting (Bourke, 1970) are its potential for severe damage (Hooker, 1981) through tuber infections or defoliation; its strong dependence on weather conditions (Shtienberg and Fry, 1990), which make late blight occurrence irregular, and sometimes explosive; and availability of management practices for disease suppression (Halscth *et al*., 1987). The basis for the development of late blight prediction in Pakistan looked for historical weather data relative to epidemic records. Disease predictions determine the environmental conditions needed for the initial appearance of late blight and, therefore, indicate when fungicide applications should be initiated. This study clearly showed that the environmental conditions were actively participated in pathogen emergence during ten years (2001-2010) and two years (2011-2013). When relative humidity increased the PLB disease increased and when relative humidity decreased the PLB disease severity decreased in ten and two year studies. It is concluded from significant participation of environmental conditions with PLB that these variables influence disease development and could be used to predict its onset. Thus to quantify PLB disease severity in relation to environmental variables, regression analysis was developed. This model was validated by comparing it with another regression model based on two years data. All the environmental variables exerted a significant influence on disease development. The two models were compared for validation and reliability; the two models had close association with each other. Current multiple regression is the first time study in Pakistan according to significant information to predict potato blight disease. Model contains fairly large data set, have been validated with two years data set and satisfactory results have been achieved regarding potato blight predictions. Secondly, model has good forecasting potential. Thus, model would help in taking accurate predictions of blight disease (Ullrich and Schrödter, 1966; Fry *et al*., 1983).

Disease predictive model mainly contributed to the elimination of unnecessary fungicide applications at the beginning of the season and provide benefit for timing the frequency of fungicide applications (Doster *et al*., 1989). Therefore, eight treatments, one control and seven fungicides (Fluopicolide, Iprovalicarb, Phenylamide, Ethyl hydrogen phosphonate, Hexamethylenetetramine, Propineb and Acitamide) were applied under field conditions to control PLB disease. Phenylamide and Propineb provided excellent control against late blight on potato, due to their mode of action. Propineb and Phenylamide are effective to prevent several stages of the fungal development cycle such as the release and the motility of zoospores, the germination of cysts as well as the growth of mycelium and sporulation (Fernández-Northcote *et al.*, 2000; Lazzari *et al.*, 2008). Contact fungicides affect the pathogen structures in the plant surface area by acting during the germination and penetration phases. Once the pathogen is inside the plant, the fungicides are useless (Fernández-Northcote *et al.*, 2000). Since the new shoots and the parts of plants which grow after an application should be protected, and the application should be repeated in case of rainfall, a good control of late blight with this type of fungicides is effective only with frequent applications at short intervals (Fernandez-Northcote *et al.*, 1999). Using contact fungicides, it is very importa'8nt to maintain an appropriate fungicide layer in the foliage, both on the upper surface and the aba'xial side of the leaf (lower surface). All the aerial part of the plant must be covered (Jende *et al.*, 1999). Given the above-mentioned conditions for the effectiveness of contact fungicides, combined with the fact that the farmer often applies inadequately and does not cover the plant well, either because he is unaware that this is necessary or because of time restrictions (Samoucha y Cohen, 1990), the effectiveness of these fungicides is significantly reduced. The development of the systemic fungicides during the 70's offered a new alternative in the solution of these problems and achieving better control of late blight. Systemic fungicides penetrate the plant (Seitz *et al.*, 1999). They move translaminarly from the upper surface to the abaxial side of the leaf, and from there to the upper part of the plant. In the case of systemic fungicides, a constant and uniform application is not as important as it is with contact fungicides (Davidse *et al.*, 1981). After its application, the systemic fungicide penetrates into the plant and migrates acropetally even into the parts of the plant not reached by the application (Stubler *et al.*, 1999). The interval between applications can be extended and shortly after its application the fungicide is not washed off by rain (Samoucha y Cohen, 1990). These are the significant advantages of systemic fungicides in comparison with contact fungicides, mainly in areas very favorable for late blight. The disadvantages of systemic fungicides are its higher cost, as well as the selection and increase of fungicide resistant strains in the pathogen populations when used inadequately (Williams and Gisi, 1992). In order to manage the problem of resistance to systemic fungicides, there is need to mix the systemic fungicides with contact fungicides (Evenhuis *et al.*, 1996). Other five chemicals Fluopicolide, Iprovalicarb, Ethyl hydrogen phosphonate, Hexamethylenetetramine, and Acitamide provided poor protection to the crop against PLB. These chemicals only minimizing the population of pathogen but not inhibit the germination of spore and not strengthening the health of plants (Ransom and McMullen 2008). It may be concluded that among the seven fungicides, Propineb and Phenylamide are highly effective to minimize late blight and to improve health of crop. So, these may be recommended to control late blight disease of potato in the country.

Conclusion

Ten years PLB disease predictive model based on five environmental variables i.e. maximum and minimum temperatures, relative humidity, rainfall and wind speed explained 74 percent significance while two years model explained 80 percent significance with disease severity. Maximum and minimum temperature, relative humidity and wind speed during ten years (2001-2010), while maximum and minimum temperature, relative humidity and rainfall played most significant role in the development of PLB disease during two years (2011-2013). Both regression models based upon ten and two years disease severity data were compared and found non-significant, indicating that there was a close conformity between models. The model was found fit for PLB disease forecasting. Models on five potato varieties Desiree, Diamont, SH-5, SH-339 and FD35-36 respectively, were in close conformity with observed values of PLB severity during 2011-2013. Phenylamide and Propineb were found most effective chemicals to control PLB disease.

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