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Prediction of Potato Late Blight Disease Based upon Environmental Factors in Faisalabad, Pakistan

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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 can induce 100% yield losses under epidemic condition. Due to lack of resistance in indigenous potato germplasm, disease is managed through fungicides by the growers of Pakistan. Excessive use of fungicides causes resistance in the pathogen and creates fatalistic effect on the environment. Disease predictive model under such situation may be effective tool to predict early onset of disease. A disease predictive model was developed on two years data of PLB disease severity and epidemiological factors using stepwise regression analysis. Model explained upto 80% disease variability. Maximum and Minimum temperature, relative humidity, rainfall and wind speed appeared to be most significant factors in the PLB disease development. The environmental conditions conducive for the development of PLB disease were characterized. Maximum and minimum temperatures in the range of 16-20°C and 1-6°C were found favourable for potato blight disease. Similarly, relative humidity, rainfall and wind speed in the range of 63-71%, 1.5-3.75 mm and 1-5.5 Km/h, respectively, were conducive for PLB disease which are helpful in disease development.

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

Introduction

P. infestans is a water mold lower fungus that infects potato crops during cool and wet weather, causing potato late blight. Late blight disease on potato crops is a major concern to potato growers worldwide, and considered to be the most economically important disease to potato crops in North America [1]. Potato late blight disease is 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 [2,3].

U.S. growers can experience annual losses of revenue of $210.7 million, $77.1 million being the cost of late blight fungicides alone [4]. In Pakistan, late blight of potato causing 50-70% potato yield loss under favourable environmental conditions [5,6] which can reach upto 100% [7]. 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. Environmental factors play significant role in the development of the epiphytotics [8]. 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 [9].

Models allow to study the inoculum in a particular area and the suitable environmental conditions for the pathogen which lead to forecast the emergence of late blight [10.11]. Forecasting model gives an early prediction that may help to control late blight without or with minimum number of fungicidal sprays [12]. Jhorar et al. [13] developed a disease predictive model based on 15 years data and found that environmental factors (temperature and relative humidity) played significant role in disease severity. Thus, the hypothesis of current study was that “on the basis of knowledge about the environmental conditions expected severity of late blight on potato crop could be predicted for timely management of disease through fungicides”.

Current study would help to forecast disease at specific area in Pakistan and will reveal scope for fungicides application. Farmers can effectively control blight disease, if level of disease severity is early known which can easily be determined by currently developed model. Objective of study include, developing a disease predictive model on two years data collected from experimental area of Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan.

Materials and Methods

Present study was under taken for two consecutive seasons during the period from November 2011 to February 2013. In each season, tubers were sown in autumn planting (middle of October). Five susceptible varieties of potato against late blight disease were bought from Potato Research Center Sahiwal. The planted potato cultivars were Desiree, Diamant, SH-5, SH-339 and FD35-36. These five varieties were grown under RCBD design (Randomized Complete Block Design) in the research area of Plant Pathology Department, University of Agriculture Faisalabad (U.A.F), each variety had three replications. The distance between plant to plant was 20 cm and row to row was 75 cm. Two year disease severity data were recorded on weekly basis during the growing seasons of 2011-12 and 2012-13, starting from last week of December to 2nd week of February.

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To measure the percent severity of disease following formula was used.

No. of infected leaves/ plant

$$\% \text{ Severity of PLB} = \frac{\text{No. of infected leaves / plant}}{\text{Total No. of leaves / plant}} \times 100$$

Data recording

The data on disease severity were recorded on weekly basis after disease prevailing using 1-9 Henfling scale till the end of the season [14]. 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. University of Agriculture, Faisalabad.

Analysis of data

The data were analyzed using statistical software SAS 9.3 (Statistical Analysis Software) [15]. Effects of environmental parameters (maximum temperature, minimum temperatures, relative humidity, rainfall and wind speed) on disease severity were determined by correlation analysis [16]. Disease predictive model for PLB disease based on two years (2011-2013) environmental variables was developed using stepwise regression analysis [17]. Environmental factors exhibited significant relationship with disease severity was graphically plotted and critical ranges of environmental variables conducive for PLB disease development were determined.

Results

Five weather variables examined from the research area of Plant Pathology Department, University of Agriculture Faisalabad (U.A.F), Pakistan, three were significant in predicting disease occurrence in the multiple linear regression model. Maximum temperature, relative humidity and wind speed were significant among environmental conditions with all five varieties i.e., Desiree, Diamont, SH-5, SH-339 and FD35-36 during two years. A significant correlation of PLB disease severity with minimum temperature was also found except Desiree (r=0.81) during the two years. Rainfall was only found significant in case of Desiree and Diamont during two years (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). 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:

$$Y=-6.03+0.29x_1+0.29x_2+0.08x_3+0.49x_4; R^2=0.80$$

Where Y=PLB disease severity, x_1=maximum temperature x_2=minimum temperature, x_3=rainfall and x_4=wind speed. It is evident from the model that major factors responsible for the occurrence of PLB disease were maximum temperature, minimum temperature, rainfall and wind speed prevalent at that time. It indicated that with one unit change in maximum temperature, minimum temperature, rainfall and wind speed there would be probable change of 0.29, 0.29, 0.08 and 0.49 units in PLB disease severity, respectively. The participation of relative humidity would be negligible in disease prediction. The change would be 0.03 units in case of relative humidity (Table 2).

The environmental variables maximum and minimum temperature, relative humidity, rainfall and wind speed were biologically important in the development of PLB disease on five potato varieties. The models with significantly important variables were developed by stepwise regression on five potato varieties/lines separately to predict PLB disease severity during two years. Out of five variables entered, two of them i.e. maximum temperature and wind speed exerted significant influence in the development of disease actively while minimum temperature and wind speed appeared as the main contributing environmental variables in the stepwise regression analysis in case of FD35-36 variety. In stepwise regression analysis minimum temperature was assessed as its influence was very poor in Desiree, Diamont, SH-5 and SH-339. When these two environmental variable models were used to predict PLB disease severity, there was a fairly good R^2 value, low C (p) value and low RMSE value obtained (Table 3).

During two years all the five varieties performed similarly with the very little variation in the environmental conditions. As the maximum and minimum temperature increased from 16°C to 20°C and 1°C to 6°C, the disease severity also increased (Figures 1 and 2). A good linear relationship was observed on the five varieties in case of among maximum, minimum temperature and genotypes i.e, Desiree, Diamont, SH-5, SH-339 and FD35-36 respectively. Initially significant correlation was observed between relative humidity and disease development. Maximum disease severity was observed at 75% relative humidity on Diamont variety (Figure 3). A significant correlation was observed between rainfall, wind speed and PLB disease severity. The maximum variability observed was 64% in case of Diamont and

Varieties	Environmental Factors				
	Maximum temp. (°C)	Minimum emp.(°C)	Relative humidity (%)	Rainfall (mm)	Wind speed (km/h)
Desiree	0.6661* 0.0180	0.8111 NS 0.0581	0.6210* 0.0493	0.6211* 0.0047	0.8122* 0.0011
Diamont	0.7291* 0.0074	0.8012* 0.0250	0.7513* 0.0058	0.6452* 0.0052	0.8088* 0.0012
SH-5	0.7215* 0.0091	0.8305* 0.0231	0.6412* 0.0048	-0.7914NS 0.8062	0.8219* 0.0015
SH-339	0.6713* 0.0160	0.8471* 0.0231	0.5614* 0.0021	-0.5211 NS 0.6381	0.7851* 0.0026
FD35-36	0.6875* 0.0161	0.6941* 0.0123	0.5412* 0.0104	-0.5412 NS 0.9901	0.6468* 0.0231

*=Significant P=0.05 NS: Non Significant

Table 1: Correlation of environmental conditions with PLB disease severity during two years (2011-2013).

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	0.079**
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 2: Coefficients of variables, standard error, t stat, p-value and level of their significance.

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Regression equations of PLB Disease Severity (%)	Observed	Predicted	R^2
$Y=b_o+b_1X_1+b_2X_2+b_3X_3\ldots$			
Desiree: $-4.488+0.36X_{1+}0.49X_2$			0.80
(X_1=maximum temperature, X_2=wind speed)	1.25 5.50 5.75 2.20	1.02 5.16 5.24 2.54	
Diamont: $-5.26+0.36X_1+0.32X_2+0.51X_3$			0.89
(X_1=maximum temperature, X_2=min. temperature,$X_{3=}$wind speed)	5.25 1.10 5.67 6.42	5.21 1.09 5.43 6.27	
SH-5: $-4.33+0.32X_1+0.34X_2+0.53X_3$			0.91
(X_1=maximum temperature, X_2=min. temperature, $X_{3=}$wind speed)	4.33 3.75 6.00 1.15	4.30 3.82 5.91 1.25	
SH-339: $-3.85+0.26X_{1+}0.38X_2+0.51X_3$			0.86
(X_1=maximum temperature, X_2=min. temperature, $X_{3=}$wind speed)	5.08 1.10 6.00 1.00	5.07 0.99 5.97 1.10	
FD35-36: $-12.54+0.29X_{1+}0.14X_{2+}0.43X_3$			
(X_1=max. temperature, X_2=min. temperature, X_3=wind speed)	4.90 1.08 4.42 4.17	4.92 1.05 4.33 3.87	0.80

Table 3: Multiple regression equations based on environmental conditions and predicted PLB disease severity values during two years.

82% in case of SH-5 among rainfall, wind speed and disease severity, respectively (Figures 4 and 5). Environmental conditions favourable for disease development were characterized during two years (2011-2013). Maximum and minimum temperatures in the range of 16-24°C and 1-12°C were found favourable for blight disease (Figures 1 and 2). Similarly, relative humidity, rainfall and wind speed in the range of 60-73%, >3 mm and 2.5 Km/h, respectively (Figures 3-5), were conducive for late blight disease.

Discussion

During two years (2011-2013), maximum temperature, relative humidity and wind speed were significantly correlated. When relative humidity increased the PLB disease severity increased in 2011-13 and when relative humidity decreased the PLB disease severity decreased during 2011-13. It is concluded from significant correlation of environmental conditions with potato blight that these factors influence disease development, so can be used to predict its onset. Thus to quantify potato late blight disease severity in relation to environmental variables, regression analysis was used. A regressions model containing maximum and minimum temperature, relative humidity, rainfall and wind speed explained 80% of the variability in PLB disease severity. It was also investigated in earlier studies that all the environmental parameters exerted a significant influence on disease development [18]. The timing and duration of each event is very important. The relationship between the development of disease and environmental factors are the main components of disease forecasting system. For predicting epidemic development, weather forecasting can be used in these systems. Environmental variables present in these models are important as reported by other researchers. First model anticipated, based upon night temperature, dew at night, rainfall and mean cloudiness [19]. Forecasts are typically highly specific to certain regions. They are developed in response to specific cultural procedure adopted, prevailing environment of that region and to grower's responses in the region. It is well known by Singh et al., [20] that forecast that work well in some locations, may not work in other locations. Some models were tested with Dutch rules, Beaumont rules, Cook's and Hyre's method and Wallins [21]. Relative humidity and temperature predicted late blight in North West Uttar Pradesh. But none of them were applicable to this region, thus supporting the idea of developing region specific models [22].

Current multiple regression model i.e. two years model is the first time study in Pakistan according to best information to predict potato blight disease. Model contains fairly large data set and satisfactory results have been achieved regarding potato blight predictions.

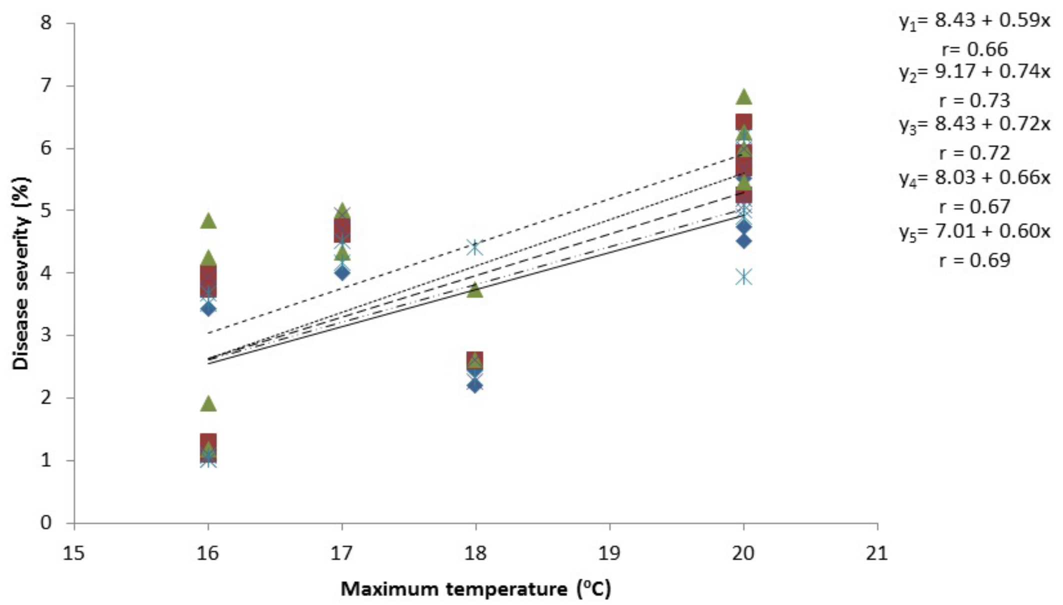

Figure 1: Relationship of maximum temperature with PLB disease severity on five potato varieties i.e. y_1=Desiree, y_2=Diamont, y_3=SH-5, y_4=SH-339 and y_5=FD35-36 during two years (2011-2013).

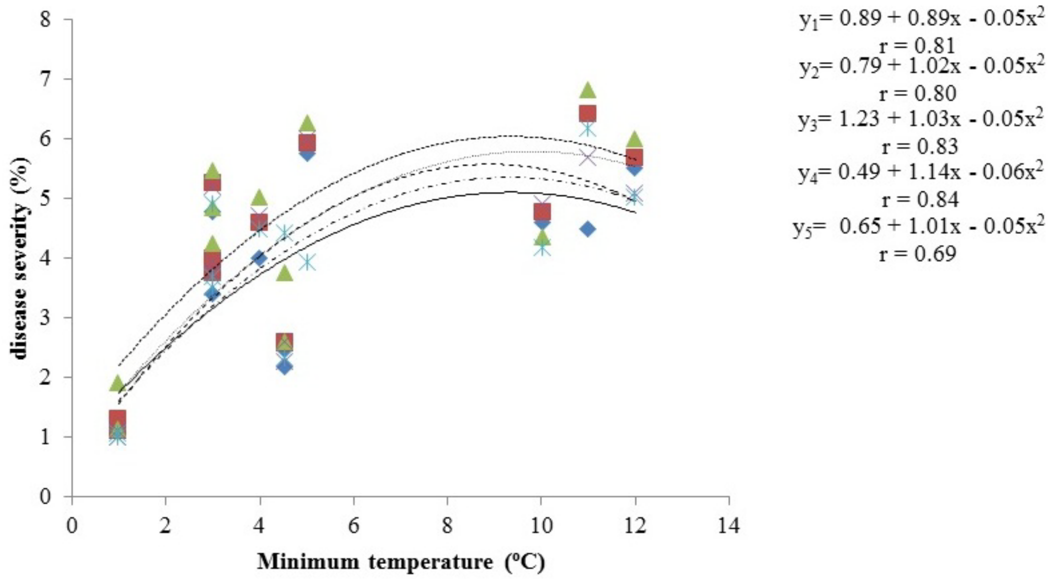

Figure 2: Relationship of minimum temperature with PLB disease severity on five potato varieties i.e. y_1=Desiree, y_2=Diamont, y_3=SH-5, y_4=SH-339 and y_5=FD35-36 during two years (2011-2013).

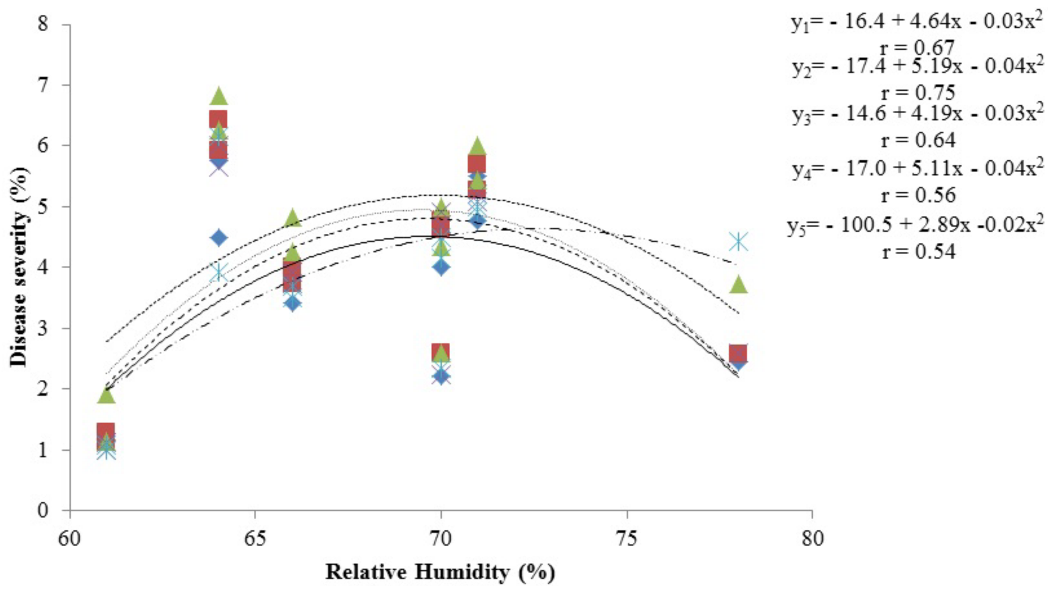

Figure 3: Relationship of relative humidity with PLB disease severity on five potato varieties i.e. y_1=Desiree, y_2=Diamont, y_3=SH-5, y_4=SH-339 and y_5=FD35-36 during two years (2011-2013).

Secondly, model has good forecasting power. Thus, model would surely help in taking accurate predictions of blight disease. This is in accordance with the results of many research workers who concluded that variation in environmental variables affected the potato blight disease [23,24]. In this study, higher level of disease severity was recorded at low temperature and high rainfall ranges, explaining that, rainfall by keeping temperature low, favours potato blight disease. There is also possibility that low temperature and high rainfall influence disease severity by maintaining the leaf wetness period, which is critical for the development and intensity of blight disease. Reason behind this is that low temperature declines down evaporation rate which helps in maintaining the leaf wetness. The heavy weather-dependence of the disease cycle also required that environment-pathogen interactions were included in the model. In order to maintain transparency of model results, a highly idealized set of environment-pathogen relations were developed using the experimental results of Zwankhuizen and Zadoks [25] and Rotem et al., [26]. For successful prediction at different locations necessitates the characterization of suitable environmental variables for potato blight disease development, therefore environmental conditions favourable for this disease were characterized during two years (2011-2013). Maximum and minimum temperatures in the range of 16-20°C and 1-6°C were found favourable for potato blight disease. Similarly, relative humidity, rainfall and wind speed in the range of 63-71%, 1.5-3.75 mm and 1-5.5 Km/h, respectively

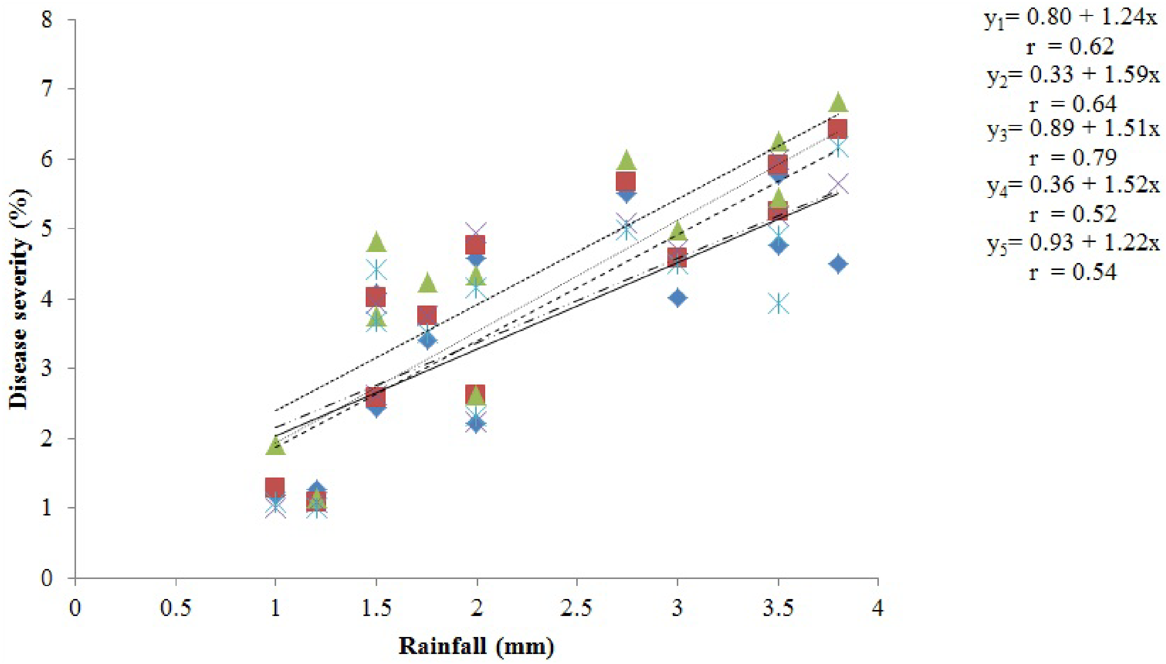

Figure 4: Relationship of rainfall with PLB Disease severity on five potato varieties i.e. y_1=Desiree, y_2=Diamont, y_3=SH-5, y_4=SH-339 and y_5=FD35-36 during two years (2011-2013).

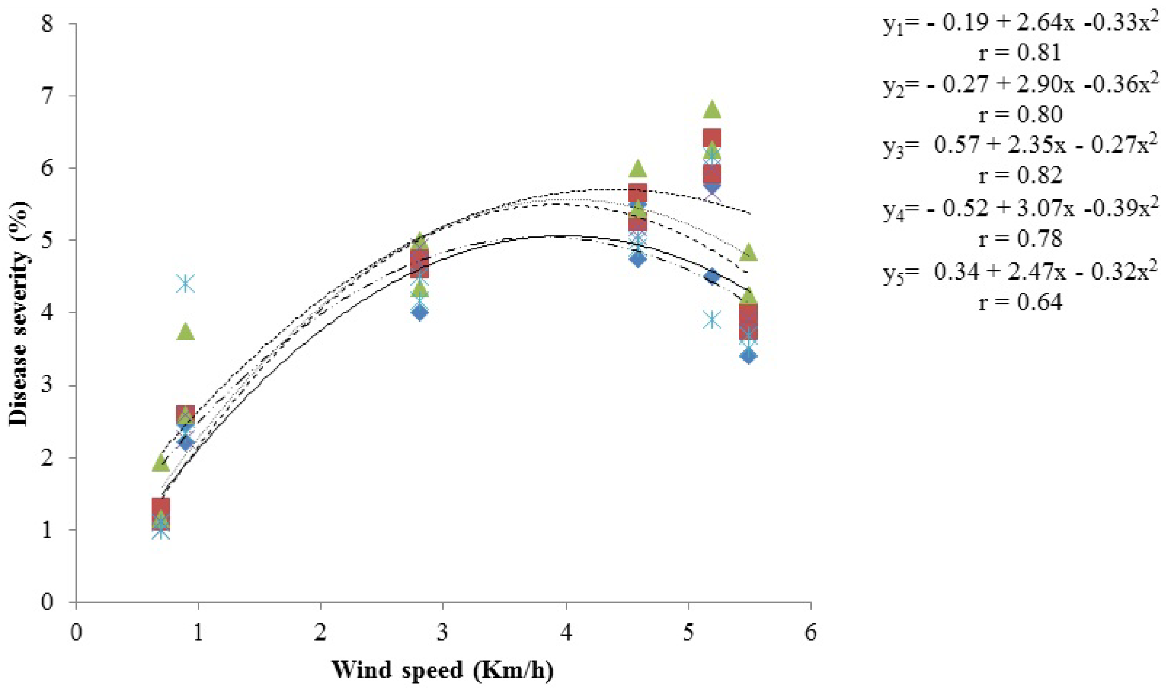

Figure 5: Relationship of wind speed with PLB disease severity on five potato varieties i.e. y_1=Desiree, y_2=Diamont, y_3=SH-5, y_4=SH-339 and y_5=FD35-36 during two years (2011-2013).

were conducive for potato blight disease. In this study, higher level of disease severity was recorded at low temperature and high rainfall ranges, explaining that, rainfall by keeping temperature low, favours disease. There is also possibility that low temperature and high rainfall influence disease severity by maintaining the leaf wetness period, which is critical for the development and intensity of blight disease. Reason behind this is that low temperature declines down evaporation rate which helps in maintaining the leaf wetness. Currently, disease severity also increased with the increase of wind speed. This is due to the role of wind in spreading inoculum from one plant to other plants in the field.

Environmental parameters	R^2	Adj. R^2	C (p)	RMSE	Pr > F
Desiree	0.80	0.76	2.17	1.58	
Maximum temperature					0.0309*
Wind speed					0.0029*
Diamont	0.89	0.86	2.25	1.45	
Wind speed					0.0015*
Maximum temperature					0.0065*
Minimum temperature					0.1146^{NS}
SH-5	0.91	0.88	3.55	2.35	
Wind speed					0.0008*
Maximum temperature					0.0067*
Minimum temperature					0.0677^{NS}
SH-339	0.86	0.80	2.16	2.58	
Wind speed					0.0016*
Minimum temperature					0.0191*
Maximum temperature					0.1476^{NS}
FD35-36	0.80	0.73	2.93	1.65	
Minimum temperature					0.0123*
Wind speed					0.0421*
Maximum temperature					0.1114^{NS}
*Significant at 0.05 NS: Non-Significant.					

Table 4: Summary of stepwise regression model developed to predict PLB disease with respect to environmental factors on five potato varieties during two years (2011-13).

Wind also affects disease by its speed and direction (Table 4).

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